GASWORKS RECORDERS

LEONARD LEVY

Section X

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THEIR CONSTRUCTION AND USES

BY

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PREFACE

Progress in any branch of knowledge is intimately connected with improvements in the accuracy with which measurements appertaining to the branch of knowledge in question can be made.

The advances in electrical engineering were largely influenced by the development of measuring instruments, whereby the determination of the various quantities involved could be made with great accuracy.

The same correlation holds true in the gas industry, and progress therein is largely determined by advances made in the science of measuring the various factors and quantities involved.

Furthermore, it may be regarded as axiomatic that in every case in which an instrument is employed, additional advantages accrue if an automatic instrument, preferably a recorder of equal accuracy, can be employed.

The invention and usage of automatic recording apparatus is a comparatively modern development of engineering and chemical engineering practice. Very few indeed of such instruments were in use twenty-five years ago, yet at the present day they are regarded as essential adjuncts.

The advantages of a continuous record of the variation of a physical condition or of the amount of a particular substance formed in any large scale reaction is obvious. The commercial efficiency of any reaction or process depends upon the maintenance of the conditions of reaction and the quantities of reacting materials as nearly as possible to the optimum value for each.

The operation of a plant can thus be controlled by means of continuously recording instruments, with a resultant efficiency which would be impossible by any other means.

These remarks apply with as great force to the gas industry as to any other. The scope and variety of the recording instruments designed specially for use in gas works have been increased in recent years, and much ingenuity has been displayed by their inventors.

There is not at present any work dealing exclusively with this subject, and this fact is the author's excuse for venturing upon this volume.

The book is intended to give a description of the *modus operandi*, application and care of all recording instruments of utility in gas engineering.

It is the author's desire to deal with the subject matter from the point of view of both the gas engineering student and of the gas engineer. For this reason certain elementary matter has been introduced which will not be of interest to the latter, but which may be helpful to the former.

The introductory chapter comprises a general survey of the operations carried out in a gasworks, in so far as these operations are susceptible of control by various types of automatic recording appliances.

The various instruments required to control the operation in question are referred to in this chapter, in which references are made to the complete description of the apparatus given in subsequent chapters.

Although the subject-matter as a whole refers merely to continuously recording instruments, the author has considered it desirable to include descriptions of one or two non-automatic indicating instruments, either in cases in which such appliances cannot be made as continuous recorders, or when there would not be any advantage in a recorder rather than an indicator.

A few practical notes on the precautions necessary to maintain the various appliances in working order are included with the descriptive matter. Attention to these details will usually ensure the continued accuracy of the recorder within its original limits, and will greatly reduce repair and maintenance charges.

The author desires to express his indebtedness to Mr J. F. Simmance for much information regarding his various instruments, and for many valuable suggestions.

The frequent references to Mr Simmance are an indication of the extent to which, as it seems to the author, the gas industry is indebted to him for inventive activities extending over many years.

Thanks are also due to Mr Alwyne Meade, the author of *Modern Gasworks Practice*, on whose suggestion the work was originally undertaken.

The author further desires to express his thanks to the various firms whose instruments are described, for information supplied, and for the loan of blocks illustrating their appliances ; and also to Mr W. E. Rolph for the preparation of a large number of the drawings illustrating the contents.

L. A. L.

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CHAPTER I

THE CONTROL OF GASWORKS OPERATIONS BY AUTOMATIC RECORDING APPLIANCES

A MODERN gasworks may be described as a plant for producing and distributing a special fuel in a convenient form suitable for general use. Concurrently with this main sphere of operation certain by-products of gas manufacture are produced, collected, and worked up into various preparations, the scope and variety of these operations depending upon the importance and size of the undertaking.

Very many of the various operations carried out in a gasworks are most efficiently performed by being constantly controlled by means of automatic recorders.

It should be borne in mind that the engineer in charge cannot always be on the works, and in any event cannot be in more than one place at a time. The only method, therefore, whereby he can maintain efficient control over all the various operations performed is by the use of recording instruments which will show him how the various operations have been performed at every period. He can in this way maintain an efficient control which would be quite impossible if indicating instruments were employed instead of recorders.

The former are only of utility to the operative who is in charge of a particular operation, and for this reason it is obvious that recording instruments are to be preferred to indicators in almost every case.

Gasworks operations may be, from the point of view of their automatic control, conveniently divided into four main subdivisions :—

I. Manufacture.
II. Production and purification of by-products.
III. Testing and control of finished products.
IV. Distribution.

I. MANUFACTURE

(*a*) *Control of Waste Gases from Retort Settings.*—The production of coal gas involves the heating of coal in one of the various types of retorts now in common usage.

The necessary heat is obtained by the combustion of fuel, sometimes solid but usually gaseous. This operation is one requiring for its effective performance a nicety of control, which can be most suitably obtained by automatic selective gas analysers.

In the case of a small works equipped with direct-fired settings heated by solid fuel, much of the latter is wasted owing to the difficulty of controlling the air supply. The combustion of the fuel in such a furnace is on a par with that in a furnace employed for steam raising, and the following argument applies equally to both.

When heat is obtained by the combustion of solid fuel—coal or coke—the most economical results are obtained if the amount of air supplied to the furnace is sufficient for the complete combustion of the fuel, and is not in excess of this amount. If insufficient air be supplied, incomplete combustion occurs, resulting in the production of smoke and the formation of carbon monoxide which escape in the flue gases. The presence of either or both of these products represents loss of heat due to incomplete combustion of all the combustible matter originally present in the fuel.

If excess of air be supplied, a portion of the heat of the fuel is employed in heating up this surplus air, thus resulting in a loss of heat, more of which is carried away by the waste products.

If the exact amount of air required for the combustion is supplied, the carbon dioxide produced will occupy the same volume as the oxygen originally in the air, 20·8 per cent. Such a result could theoretically be attainable if the fuel consumed were composed of pure carbon.

When anthracite or coke are employed the percentage of carbon dioxide in the waste gases should be about 19; but in the case of bituminous coal, some of the oxygen is consumed by the hydrogen which it contains, and a percentage of carbon dioxide of 12 to 16·5 per cent. represents efficient stoking.

The relationship between the percentage of carbon dioxide in the flue gases and the loss of fuel in the case of bituminous coal is shown in Table I.

TABLE I

(The figures show the percentage loss in coal as a result of the flue gas having a percentage of carbon dioxide and a temperature as per the intersecting columns. The air temperature is assumed to be 60° F.)

Percentage of CO_2.	300° Fahr.	420° Fahr.	540° Fahr. (Temperature of Waste Gases).
4	39·40	59·00	78·8
5	32·00	48·00	64·0
6	26·30	39·50	52 6
7	22·50	33·75	45·0
8	19·70	29·50	39·4
9	17·52	26·28	35·0
10	15·77	23·65	31·5
11	14·33	21·50	28·6
12	13·14	19·70	26·3
13	12·10	18·15	24·0
14	11·25	16·90	22·5
15	10·50	15·75	21·0

The unavoidable 10·5 per cent. loss which occurs even when the percentage of carbon dioxide is 15 is due to the fact that it is impossible to reduce the temperature of the flue gases to that of the atmosphere.

Hence the amount of heat required to raise the products of combustion from atmospheric temperature to that at which they leave the setting must always be lost. (*N.B.*—A certain percentage recovery of this heat is effected by waste heat boilers, but this fact does not affect the accuracy of the above argument.)

The relationship between the percentage of carbon dioxide in the flue gases and the loss of fuel is well shown in the accompanying diagram, which expresses this relationship when the temperature of the flue gases is 300° F.

The composition of the flue gases is most readily controlled by some suitable type of carbon dioxide recorder. The stoking of the furnace and the regulation of the dampers are effected by constant reference to the record obtained, which in addition gives the manager a permanent record of the efficiency of the stoking operations.

Control of the composition of waste products of combustion is equally important when (as is nearly always the case) the retorts are fired by gaseous fuel. The arguments adduced above with regard to solid fuel hold good when gaseous fuel is employed.

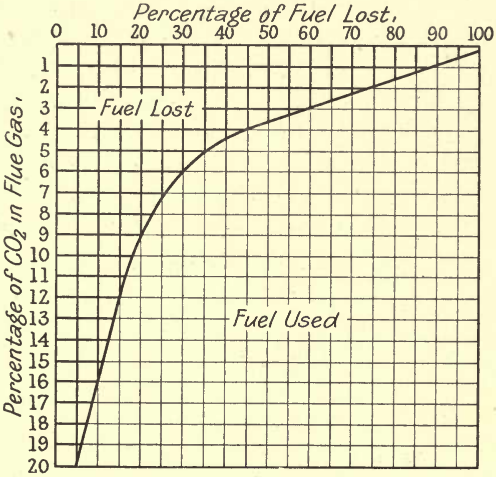

FIG. 1.—VARIATION OF ECONOMY OF COMBUSTION WITH PERCENTAGE OF CARBON DIOXIDE IN FLUE GAS.

The following table[1] (Russell, *Operation of Gasworks*, p. 30) shows how the efficiency of a setting fired by producer gas varies with the composition of the waste products.

Waste Gases per cent.				Efficiency per cent.	Conditions Prevailing.
CO_2	N_2	CO	O_2		
20	80	..	..	61·7	Complete combustion.
17·4	78·2	4·4	..	49·3	Air 10 per cent. deficient.
18·2	80·0	..	1·8	58·2	Air 10 per cent. excess.
18·0	80·0	..	2·0	57·8	Excess air 18 per cent. CO_2.
18·0	78·7	3·3	..	55·4	Deficient air 18 per cent. CO_2.

The temperature at which the waste gases are allowed to leave the setting is not, *per se*, any guide to the efficiency of the firing. A low temperature may be due to bad

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[1] See also *Modern Gasworks Practice*, p. 127.

stoking or to admission of excess air to the flues. For example, if the temperature of the flue gases is as low as 300° F., and there is only 5 per cent. of carbon dioxide, a preventable loss of 21·5 per cent. (32·0 – the unavoidable 10·5) is occurring. If, however, the composition of the waste gases is controlled so that the percentage of carbon dioxide is as high as possible, then it is obviously most economical for the waste gases to be discharged at a low temperature. This temperature control must only be considered in conjunction with the record of carbon dioxide.

It is, therefore, desirable to have a continuous record of the temperature of the gases in the main waste gas flue. A sudden temperature disturbance shown on the record indicates that some fault is occurring in the combustion. Recording pyrometers, for this purpose, should have a range from 200° to 800° F.

A knowledge of the draught in the main waste gas flue is, as in the case of the temperature, not by itself any guide at all to economical working. A record of its value is, however, of utility in assisting to keep the conditions as constant as possible.

For this reason it is usually convenient to have a simultaneous record of the draught in the main waste gas flue, and draught recorders are frequently combined with carbon dioxide recorders in one instrument designed for the control of furnace operations. Such draught recorders are usually calibrated in hundredths of an inch, and read from 0–1 inch in hundredths. In the ordinary way the draught in the flue will vary from $\frac{3}{10}$th to $\frac{6}{10}$th inches of water, the reading on the record being 30 to 60 divisions.

(*b*) *Control of Producer Gas Manufacture.*—The production of the producer gas used for firing the retorts should be carefully controlled so as to maintain the composition of the gas uniformly at its optimum value. If considerable variation be permitted it will be accompanied by concomitant losses of heat.

Ideal producer gas made from pure carbon would be composed of 34·8 per cent. of carbon monoxide and 65·2 per cent of nitrogen by volume. In practice, however, the ideal composition is impossible for many reasons. A certain amount of carbon dioxide is always present, and also a little hydrogen formed from steam. In general it may be stated that the carbon monoxide should be as high as possible and the carbon dioxide as low as possible.

The production of the gas may be controlled by a special type of carbon dioxide recorder fitted with a chart reading from 0–10 per cent.

It is, however, now possible to obtain a continuous record of the percentage of carbon monoxide in addition to the amount of carbon dioxide. A combined carbon monoxide and carbon dioxide recorder suitable for this purpose has recently been devised. Such a dual record is to be preferred to a record of the carbon dioxide only.

It is desirable to note that the temperatures of the combustion chambers and of the interiors of the retorts should occasionally be checked by means of some type of optical radiation pyrometer. Advantage would not be gained by employing a recording pyrometer for either of these observations; and, therefore, the type of instrument required does not, strictly speaking, come within the scope of this volume.

The use of such instruments is, however, very desirable in order to ensure optimum working conditions and to obtain constancy of results. For this reason a brief description of indicating pyrometers suitable for this purpose is given in a subsequent chapter.

(c) *Control of Conditions of Manufacture of Coal Gas.*—The necessity of controlling the combustion processes employed in firing the retorts and of checking the production of the producer gas used as fuel has been considered in the preceding paragraphs. The use of automatic recording appliances of various descriptions is equally important in controlling the production and flow of the coal gas from the time it is evolved in the heated retorts to its final transference to the holder.

The vacuum on the foul main between the retorts and the retort house governor is continuously regulated by reference to a recording vacuum gauge. This control is most essential for the proper regulation of the quality of the gas. If the vacuum maintained be inadequate, the gas is likely to escape into the furnace through any small leaks which may have developed in the retorts instead of flowing through the ascension pipe.

Insufficient vacuum also results in the decomposition of the hydrocarbon vapours with excessive production of retort carbon. At the same time, too great a vacuum is also detrimental and must be avoided, as in this case furnace gases, air, and products of combustion are drawn through leaks and are mixed with the coal gas, thereby raising the proportion of inerts to an undesirable amount. It is of equal importance in working vertical retorts to maintain and therefore to control the factors already referred to when " steaming "—a record of steam pressure and, if possible, steam volume is desirable.

The range which the vacuum recorder is required to show is, therefore, comparatively limited. A sensitive vacuum recorder of the diaphragm type with a very open scale reading from 0 to 2 inches should be employed.

Sometimes a combined pressure and vacuum gauge ranging one inch on either side of zero is employed. A record on the " pressure " side will occasionally be obtained in special circumstances, particularly when dry hydraulic working is in use.

The vacuum at the inlet of the exhauster is controlled by another similar recording gauge. In this case a somewhat greater range, 0 to 4 inches or 5 inches, is required on the recorder. These two vacuum recorders are also essential to the proper regulation of the " draw " of the exhauster and of the concomitant adjustment of the retort house governor when gas making is intermittent, and when the actual amount of gas produced during the non-charging period is only a small portion of the total production.

It is most essential that the foreman in charge of the retort house be provided with means for ascertaining the quality of the gas at the earliest possible moment after it has been generated. The Jet Photometer had for many years been employed for this purpose, for which it was invaluable. The altered conditions of modern practice and the conversion from illuminating to calorific power standards have relegated the Jet Photometer to the background, and it cannot now be usefully employed for gas manufacture. It has been replaced by a recording calorimeter which gives a continuous record of the variation of the calorific value of the gas.

The instrument should be arranged to record the calorific value of the gas at the outlet of the exhauster, and should itself be situated in the retort house.

A recording calorimeter for this purpose should be of fairly robust type, and need not be designed with all the refinements required to make it record with accuracy over long periods without any attention. The instrument will be of the utmost utility if its record can be relied upon for say twenty-four hours without any readjustment or attention.

A pressure recorder is also required at the outlet of the exhauster in addition to the recording calorimeter. As already explained, the function of the latter is to enable the gasmaker accurately to control the quality of his product by regulation of the " draw " in the exhauster according to the quality recorded on the calorimeter.

The pressure recorder is required for a totally different purpose. Its function is to indicate any variation in the pressure thrown by the plant following the exhauster. Any undue back pressure in the purifiers, for example, will be shown by the change in pressure shown on the recorder. The range of the recorder required varies greatly according to the resistance offered by the purification plant and the quantity of gas passing. The range of pressure on the outlet of the exhauster varies from about 8 to 10 inches on a small works, to as much as 50 inches in the case of a very large undertaking.

(*d*) *Control of Water Gas Manufacture.*—The production of water gas by the intermittent system (the only method which it is necessary to consider) consists of forcing air and steam alternately through a bed of hot fuel, usually coke. If (as is nearly always the case) the gas is to be carburetted, oil is sprayed into a subsidiary vessel during the period when the steam is introduced. Occasional brief stoppages occur when fresh fuel is added and when it is necessary to remove the clinker formed.

The precise periods of time occupied by the " blow " with air and the " run " with steam vary with individual plants, and are obtained as a result of experience. Any deviation from the optimum cycle of operations will result in waste of oil for carburation, reduced production of gas, and increased cost of purification, due to excessive carbon dioxide. It is, therefore, highly necessary that the cycle of operations prescribed by the engineer in charge should be rigidly adhered to by the operatives working the plant.

The cycle of operations in a water gas plant can be very closely followed by a special type of recording pressure gauge, usually termed a water gas cycle recorder.

The periods occupied by the " blow " and " run " are both comparatively short—three or four minutes for the former, and six or eight minutes for the latter. It is therefore obvious that the time scale on the recorder chart must be very greatly enlarged so that pressure readings can be clearly differentiated even at intervals of a few seconds. For the same reason the clock must drive the chart much more rapidly than is usual in recording instruments.

The use of a water gas cycle recorder enables the working of the plant to be followed very clearly indeed. Coking, the period of " blow," the period of run with steam and oil, the period of run with steam alone, and clinkering operations are all clearly indicated by abrupt pressure changes on the record. Any stoppage in the connections is also recorded as an unusually great pressure.

Control of the quantity of steam employed during a " run " is absolutely necessary for efficient working. The amount of steam required towards the end of a " run " is less, as the fuel is not so hot. No attempt is made to control the flow of steam in many plants, and the surplus steam admitted towards the end of the " run " results in increase of carbon dioxide and depreciation of the quality of the gas produced.

The amount of steam supplied should be controlled by some form of steam meter as described in Chapter VIII., while an automatic reducing valve[1] should always be introduced into the pipe line.

The carburettor, in which the oil is introduced into the blue water gas, and the superheater, in which the oil is " fixed " and converted into permanent gases, must be operated at the correct temperatures. If these temperatures are incorrect, the gas will experience a loss of quality during its passage through the purification plant and possibly the district mains.

Temperature control of the carburettor is the more important, and is effected by an electrical recording pyrometer. A similar instrument should also be fitted to the superheater, but it is not necessary to have a continuous record. Occasional momentary observations of the temperature of the superheater can be observed on the chart of the pyrometer controlling the carburettor by the use of a switch which momentarily cuts out the latter instrument and connects the superheater pyrometer to the recording mechanism.

The pressures of the air-blow and of the steam must be maintained as constant as possible. These are observed and recorded on gauges connected to the air-blow and steam respectively.

As in the use of coal gas manufacture, a recording pressure gauge is required on the outlet of the exhauster to indicate pressures thrown by the purifiers.

The composition of the water gas should be recorded by a combined carbon monoxide and carbon dioxide recorder, as mentioned in the case of the producer gas for retort firing. This instrument is of greater importance in the case of water gas.

The chief function of such a recorder is to indicate whether the steam flow is in excess or not, particularly during the later period of the " run." The most important factor in the manufacture of water gas is to ensure that as the " run " progresses towards its finish, the percentage of carbon monoxide does not drop unduly with a concomitant increase of the percentage of carbon dioxide. The carbon dioxide should not exceed about 2 per cent. at the start of the run, and 10 per cent. at its completion. Similarly, the carbon monoxide should start at about 46 per cent. and should not drop below 30 per cent. at the finish of the run.

A special carbon dioxide recorder with an open scale range 0–10 per cent. can be employed instead of the combined recorder, but, *cateris paribus*, the latter is obviously preferable.

The carbon monoxide and carbon dioxide recorder gives a summation of the

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[1] For description see *Modern Gasworks Practice*, p. 717.

results of the various operations contributing to the manufacture of the gas, each of these operations being itself controlled by a suitable instrument as indicated.

The foregoing observations apply with equal force to the control of so-called complete gasification plants, in which, as a rule, the separate processes of making coal gas, water gas, and producer gas are more or less combined. This type of plant has not yet become standardized, so that no useful purpose can be served by stating here the figures equivalent to optimum values for the various processes. The high-water mark of working having been ascertained, however, it is only by the use of suitable recording instruments that this can be controlled and maintained.

(*e*) *Control of Steam Plant.*—The most economical production of steam is ensured by exactly the same method of control as described for furnace settings. The flue gases are continuously analysed by a carbon dioxide recorder, their temperature observed by a recording pyrometer, and the chimney draught is recorded on a draught gauge. The reasons for the use of these appliances have already been explained (*q.v.*). The steam pressure is recorded by a Bourdon gauge.

II. PURIFICATION AND PRODUCTION OF BY-PRODUCTS

The operations involved in the purification of gas and the production of by-products, are, generally speaking, not so susceptible to automatic regulation as those involved in the production of crude gases. The supervision which can be applied consists mainly of the proper maintenance of optimum temperatures and of the regulation of the amounts of the reacting substances.

(*a*) *Purification Plant.*—Differential pressure gauges are extremely useful for recording the drop in pressure experienced by the gas in its passage through any particular part of the purification plant. The gauge is connected on one side to the inlet, and on the other side to the outlet of the apparatus. Any stoppage or partial choking up will be recorded as an increase of the pressure thrown.

These remarks apply with equal force to other parts of the purification plant. Condensers, scrubbers, and washers become clogged, moving parts become deranged, and defects may occur in any part of a gasworks. The use of pressure recorders, either positive or differential, is essential to the detection and prevention of any such defects.

Recording thermometers may be employed with advantage for controlling the working of the condensers.

The temperature of the material in oxide purifiers is very important, and consistent results are only to be obtained if fluctuations in temperature are avoided as far as possible. If the temperature is too low the purifiers are sluggish in their action, and if too high the material tends to become caked owing to moisture being carried forward to succeeding boxes ; thus considerably increasing the back pressure. The range of working temperature is quite small, 21–27° C. A recording thermometer will assist in the maintenance of the correct working temperature.

The working of the oxide purifiers may be checked by the use of a sulphuretted hydrogen recorder. This instrument is arranged so that several streams of gas can be caused to record their content of sulphuretted hydrogen upon a single chart. These streams are derived respectively from the main inlet and the several outlets of a set of purifying boxes, thus affording a check upon the working of each one; particularly when the backward rotation system is employed.

(*b*) *Benzol Stripping Plant.*—If a benzol stripping plant be employed, the temperature of the benzol still should be recorded. A very suitable instrument for this purpose is the mercury-in-steel thermometer connected to a recording Bourdon gauge by steel capillary tubing.

The amounts of liquids in the wash-oil and crude-spirit tanks can be with advantage registered by recording depth gauges.

(*c*) *Sulphate of Ammonia Plant.*—The automatic control of the operations of the sulphate of ammonia plant consists in ensuring the passage of correct amounts of reacting liquids. Special types of liquid flow meters may be employed for this purpose.

The rate of flow in these instruments is measured continuously, and by means of special integrating devices the total amount of the liquid passing during any period is recorded.

These liquid flow meters may be used for recording the flow of ammoniacal liquor and of sulphuric acid respectively. The instruments must be calibrated with special scales according to the liquid flow which they are required to measure. The materials of which they are constructed must be selected so as to withstand the corrosive action to which they will be subjected.

A recording densimeter, and preferably one in which an automatic temperature correction is applied, is of utility in checking the quantity of sulphuric acid supplied to the saturator, especially in the case of large undertakings manufacturing their own acid.

Recording thermometers are of general utility in various other parts of the purification and by-products plant, as, for example, in the tar distillation stills, and should be installed in every instance where temperatures have to be maintained within certain limits.

III. TESTING THE FINISHED GAS

(*a*) *Calorific Value.*—In view of the recent legislation in connection with the sale of gas, whereby the consumer pays according to the gross amount of heat supplied, and *not* according to the volume of gas used, the calorific value of gas has become of the utmost importance.

The calorimeter has, in fact, supplanted the photometer as the chief instrument in the calculation of the commercial value of gas. In order to meet this changed situation recording calorimeters have been devised, and the use of a standard recording calorimeter of approved type to furnish a continuous record of the calorific value of the finished gas is essential in the vast majority of works.

(*b*) *Specific Gravity.*—The specific gravity of the finished gas is recorded by means of a gravitometer, an instrument which shows the value of this function with very great accuracy. The record of the specific gravity will indicate any undue proportion of inerts by an increase in value.

(c) *Content of Carbon Monoxide.*—The carbon monoxide content of the finished gas may be recorded by a carbon monoxide recorder. The amount of carbon monoxide will depend upon the proportion of water gas admixed with the coal gas, and a knowledge of the percentage is a close guide to the proportion of water gas employed.

There is a remote possibility that legislation restricting the amount of carbon monoxide in gas supplied for domestic use may be introduced, in which event a carbon monoxide recorder would become quite as necessary as a recording calorimeter.

(d) *Sulphuretted Hydrogen.*—Freedom from sulphuretted hydrogen after the gas leaves the holder (in which this impurity is occasionally produced) is ensured by testing the gas with the sulphuretted hydrogen recorder referred to above.

IV. DISTRIBUTION

Until very recently, effective control of gas distribution systems has not been accomplished to any extent. Automatic surveillance, which can now be applied with very great advantage, is achieved by the use of instruments and appliances, not any of which were devised (or if devised were certainly not perfected) ten years ago.

The automatic control of gas distribution systems is effected by constant knowledge of the values of the following factors :—

(a) Specific gravity.
(b) Pressure at various places in the system.
(c) Volume passing at various points.
(d) Calorific value of the gas delivered at distant points.

(a) *Specific Gravity.*—The automatic recording of specific gravity has already been referred to. The variation of the value of this function is of considerable importance in distribution, as the power required to deliver the gas through the mains is directly proportional to the specific gravity. Further, a change in specific gravity furnishes certain proof of " stripping " or " picking up " in the mains.

(b) *Pressure at Various Places in the System.*—The legal prescription of pressure minima which are now demanded in all parts of a distribution area postulates effective control of gas pressures in all parts of the system. The attainment of this end is not at all easy, as pressures are subject to considerable variations, the causes of which are totally outside the control of the engineer. Demands vary greatly, and are subject to considerable fluctuations, depending upon the period of the day and the prevailing weather conditions. It is, therefore, of great importance for information regarding the pressures prevailing in various places to be conveyed to the engineer with rapidity.

Considerable use is made of automatic pressure recorders placed locally in various parts of the system, the information being conveyed to headquarters as soon as possible. The use of these instruments, placed, say, a mile or two from the works, will frequently assist in locating stoppages due to the deposition of naphthalene.

This system has advantages, but is also subject to obvious limitations owing to the time which must inevitably elapse before the information arrives at the works.

Apparatus has recently been devised whereby the continuous automatic transmission of gas pressures to the works from each district has been successfully achieved.

Several advantages are obtained from the use of these appliances, amongst which may be mentioned :—

1. A heavy drop in pressure can be avoided, as it is indicated immediately it occurs and remedial measures can be taken at once.

2. Considerable saving will result in wages of district pressure testers.

3. Disputes and disagreements between the works and the distribution staff on the subject of district pressures are no longer possible.

4. In the case of works using power-driven pressure-raising plant, considerable savings will be effected in fuel and attendance charges, due to the fact that the works' staff being kept continuously acquainted with the district pressures, the pressure-raising plant will only be run when actually required, and will not be run-up early and shut-down late in order to be " on the safe side."

5. In addition to the saving in the actual hours of running as indicated in the preceding paragraph, the pressure-raising plant will run under a smaller load, as, the district pressures being known, the plant will be run at whatever speed is necessary in order to maintain the desired pressure, and will not be overrun (so throwing useless work upon both the plant and the district governors) simply in order to be " on the safe side." This will again lead to economy in fuel.

(*c*) *Volume passing at Various Points.*—The volume of gas passing at various points in the system can also be recorded at the engineer's office. The Thomas and other meters—whereby this end may be achieved—effect the volume measurement at the desired point and automatically transmit the result to the works, where its value is recorded at any convenient place. The volume of gas leaving the works is always registered on a station meter, modern types of which come within the scope of this volume and are described in a subsequent chapter.

Barographs and recording thermometers are desirable for the purpose of correcting station meter readings in cases where the type of meter installed does not automatically correct for temperature and pressure variations. The use of these instruments will assist in checking the amount of " unaccounted for " gas.

(*d*) *Calorific Value of Gas delivered at Distant Points.*—A recording calorimeter, placed at an official testing station, or at other convenient distant points, will enable a comparison of the thermal value of the gas delivered with that of the gas as it leaves the works to be made. In this way the change in value during the passage of the gas through various portions of the distributing system is arrived at. A drop in calorific value (which has, therefore, to be allowed for by the gasmaker) is usually experienced ; but sometimes an increase is observed due to the gas taking up a little naphthalene, or other volatile deposit, during its passage through the mains.

If the recording calorimeter is fitted with electrical thermometers, as in the

Thomas calorimeter, the calorific record of the gas delivered at a distant point may be graphically inscribed upon a chart situated in the engineer's office.

An attempt has been made in the preceding paragraphs to discuss briefly the various operations in gas making and distribution in so far as these are susceptible of automatic control by suitable appliances. The value of the use of the various instruments has also been indicated. The points elaborated therein are briefly summarized in the following table, in which reference is also made to the ensuing chapters, in which full descriptions are given of the construction, use, and care of the various apparatus.

TABLE SHOWING METHOD AND UTILITY OF AUTOMATIC CONTROL OF GASWORKS OPERATIONS

Operation.	Instrument Employed.	Utility of Automatic Control.
Combustion in (*a*) retort settings and (*b*) steam plant.	CO_2 recorder (*see* Chapter VII.).	Results in great saving in consumption of fuel.
	Recording pyrometer (see Chapter IV.).	Affords immediate indication of faults occurring in combustion process, and in conjunction with CO_2 recorder, effects economy of fuel.
	Draught gauge (see Chapter III.).	Assists in maintenance of constant conditions.
Manufacture of producer gas for firing retorts.	Combined CO and CO_2 recorder or special CO_2 recorder (see Chapter VII.).	Maintains a constant check upon the composition of the gas, thus enabling the carbon dioxide to be kept as low as possible and the carbon monoxide as high as possible.
Manufacture of coal gas.	Vacuum recorder on foul main (see Chapter III.).	Enables a constant vacuum to be maintained and thus prevents :— (1) Escape of coal gas into the furnace setting. (2) Excessive formation of retort carbon. (3) Dilution by air and furnace gases.

TABLE SHOWING METHOD AND UTILITY OF AUTOMATIC CONTROL OF GASWORKS OPERATIONS—*continued*

Operation.	Instrument Employed.	Utility of Automatic Control.
Manufacture of coal gas —*continued.*	Vacuum recorder on exhauster inlet (see Chapter III.).	Regulates " draw " of exhauster so that quality of gas is kept as constant as possible during periods of variable production.
	Recording calorimeter on exhauster inlet (see Chapter VI.).	Affords a very rapid indication of the quality of the gas, of extreme value to the retort-house foreman in regulating the exhauster.
	Pressure recorder on exhauster outlet (see Chapter III.).	Indicates pressure troubles in purification plant.
Manufacture of water gas.	Water gas cycle recorder (see Chapter III.).	Affords a check upon the periods of " blow " and " run," and also time taken in clinkering and coking. Assists in maintenance of the period of the cycle of operations at its optimum value. Also indicates any stoppage in the connections.
	Steam meter (see Chapter VIII.).	Prevents the production of poor gas, especially towards end of a " run," by excessive steam.
	Recording pyrometers in carburettor and superheater (see Chapter IV.).	Prevents loss of quality of gas in its passage through the mains.
	Pressure recorders on " blow " and steam (see Chapter III.).	Maintains conditions of manufacture constant.
	Combined CO and CO_2 recorder or special CO_2 recorder (see Chapter VII.).	Prevents production of gas with excessive carbon dioxide and insufficient carbon monoxide.

TABLE SHOWING METHOD AND UTILITY OF AUTOMATIC CONTROL OF GASWORKS OPERATIONS—*continued*

Operation.	Instrument Employed.	Utility of Automatic Control.
Purification. — Condensers, purifiers, washers.	Differential pressure gauge (see Chapter III.).	Indicates any stoppage in the plant.
	Recording thermometer (see Chapter IV.).	Ensures maintenance of best working temperature.
	Sulphuretted hydrogen recorder (see Chapter VII.).	Affords a check upon the efficiency of each of the purifier boxes.
Benzol stripping.	Recording thermometer (see Chapter IV.).	For regulating temperature of benzol still.
	Recording depth gauges (see Chapter IX.).	Shows amounts of liquid in wash-oil and crude-spirit tanks.
Ammonium sulphate manufacture.	Liquid flow meters (see Chapter VIII.).	Ensure the use of correct quantities of reacting liquids—sulphuric acid and ammoniacal liquor.
	Recording densimeter (see Chapter IX.).	Regulates the strength of sulphuric acid used.
Tar distillation.	Recording pyrometer (see Chapter IV.).	For regulating temperature of tar still.
Testing finished gas.	Standard recording calorimeter (see Chapter VI.).	To ensure calorific value of gas is always above the penalty point.
	Barograph (see Chapter III.).	Useful in check tests on calorific value and for all gas measurements.
	Gravitometer (see Chapter V.).	Indicates undue proportion of inerts.
	Carbon monoxide recorder (see Chapter VII.).	Shows amount of carburetted water gas in the finished product.
	Sulphuretted hydrogen recorder (see Chapter VII.).	Records freedom of the finished gas from sulphuretted hydrogen.

TABLE SHOWING METHOD AND UTILITY OF AUTOMATIC CONTROL OF GASWORKS OPERATIONS—*continued*

Operation.	Instrument Employed.	Utility of Automatic Control.
Distribution.	Gravitometer (see Chapter V.).	Gives a measure of the power required to deliver the gas through the mains.
	Recording pressure gauges on district (see Chapter III.).	Show pressure variations at various points in the system, and indicates stoppage due to naphthalene.
	Distance pressure gauges (see Chapter III.).	Show at engineer's office pressure changes at distant points of system, enabling remedial measures to be applied at once.
	Distance volume recorders (see Chapter VIII.).	Record volumes passing in distant parts of system at headquarters.
	Barograph. Recording thermometer.	For reducing station meter readings to N.T.P. and checking "unaccounted for" gas.
	Recording calorimeters (see Chapter VI.).	Record changes in quality of gas during its passage through the mains. The value of the gas in distant parts can be directly recorded at the works.

CHAPTER II

GENERAL REMARKS UPON RECORDING MECHANISM

THE various types of recording instruments described in the subsequent chapters—for whatever purpose they are designed—have one factor in common. They produce a mechanically inscribed record (correlated with the time factor) of the variation of some property or function. This record is inscribed upon some form of chart upon which the time factor is printed, and which is marked with a series of lines to enable a close reading of the value of the variable to be made readily at any period.

The recording mechanism accordingly consists of some appliance for marking the paper or chart, such as suitable pen and ink, a chart upon which the record is inscribed, a drum or plate carrying the chart and driven by a special appliance, usually a clock.

So far as recorders for use in gasworks are concerned, the different functions, the variations of which it is desired to follow, can all be registered in a variety of ways which are common to all. For this reason this chapter contains a general discussion on the recording mechanism, which applies with equal force to all the instruments described subsequently.

I. CHARTS

The quality of the paper employed in the manufacture of charts for recorders is of importance. It must be sufficiently absorbent for the ink to dry thereon, but, at the same time, the ink must not run. It should have a fairly glazed surface to reduce the friction of the pen point to a minimum.

In the vast majority of cases the paper of the chart is merely required to receive an ink or pencil mark. There are, however, one or two exceptions to this.

Charts are sometimes printed on sensitized paper, the record being produced by the action of a pencil of light which moves over the surface of the paper, producing a photographic action which constitutes the visible record. This device has been employed to avoid frictional errors when the moving part is very delicately suspended (see Thread Recorder below).

The paper of which the chart is composed may be chemically impregnated and the record obtained by reaction between the impregnated chart and a fine stream of gas. An example of this is afforded by the sulphuretted hydrogen recorder described in a subsequent chapter.

The ruling of the chart must be done with the greatest possible care, as the accuracy of the record is dependent upon the printing. Whenever possible, recorders are arranged so that the ruling is composed of equidistant lines giving a regularly divided chart. For certain instruments, however, such a regular subdivision is impossible and charts are unequally divided. In such cases the chart is arranged so that the most open portion of the scale corresponds to the most generally useful range of the apparatus in question.

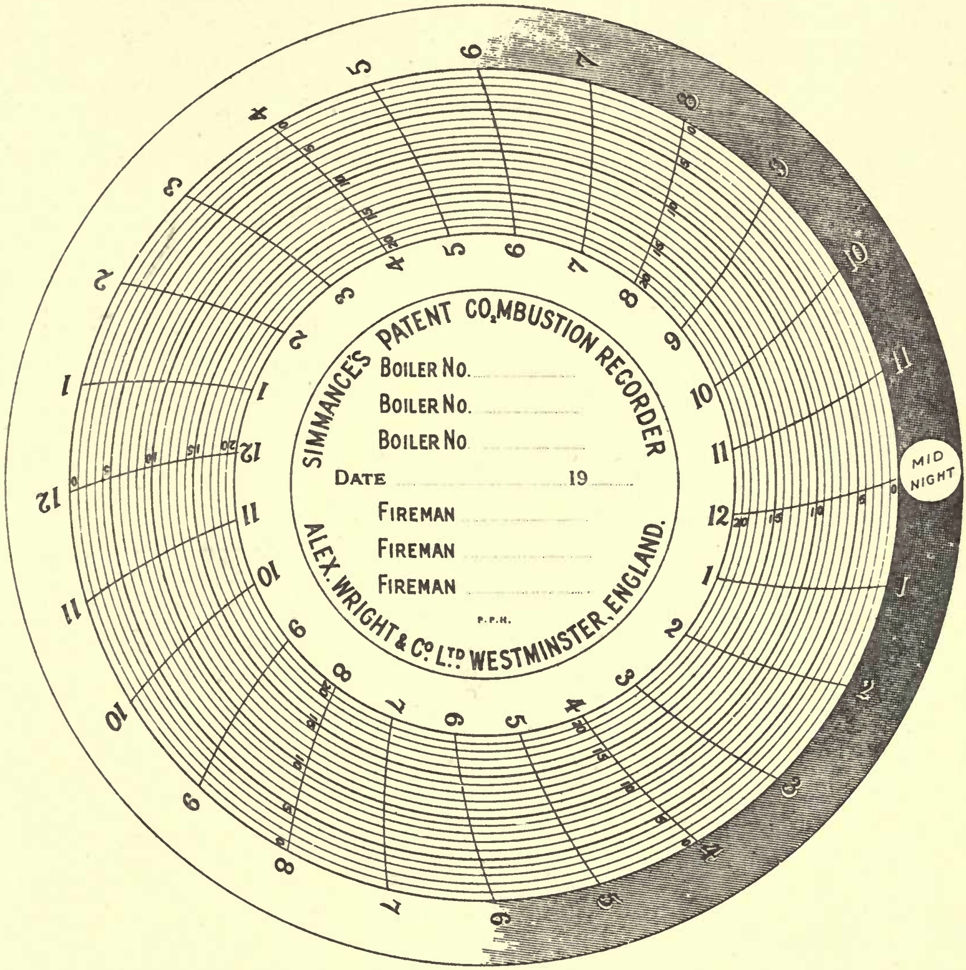


FIG. 2.—DISC CHART.

An example of such a ruling is afforded by the " square-root " charts employed in connection with certain types of volume recorders. The quantity to be recorded is proportional to the square root of a certain pressure, and hence the linear motion of a float, which is actuated by the pressure in question, is recorded upon a square-root chart.

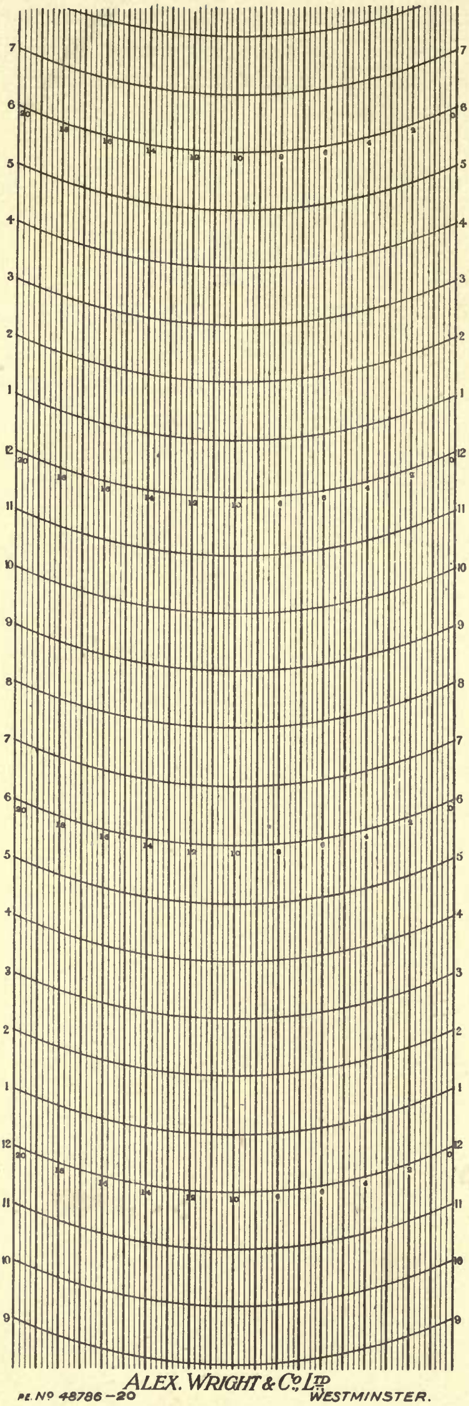


FIG. 3.—DRUM CHART.

The records obtained can be presented in a variety of ways according to the type and ruling of the chart employed. There are three main types of charts in general use.

(*a*) *Disc Charts.*—These are circular, flat discs, upon which the record when constant is inscribed in a line roughly parallel to the circumference. They are usually made to take one record in twenty-four hours or in seven days, after which period the chart is changed. The time is printed on the periphery, and night is commonly distinguished from day by printing a black ring on the circumference, extending from 6 p.m. to 6 a.m., the remaining half of the ring, representing the daytime, being left clear.

The centre of the chart is usually left free for the insertion of various particulars such as date, description of plant under control—*e.g.* boiler number, name of operative, etc., etc.

Disc charts have the advantage that the record is always in view and the chart is changed very easily and quickly. The disadvantages attached to their use is that the ruling is in radial lines instead of rectilinear. Hence the hour space and the record decreases in sensitiveness towards the centre. For the same reason, should it be desired to integrate the record, a special planimeter is required.

(*b*) *Drum Charts.*—These charts consist of a roll of paper fixed once round the circumference of a moving drum. They require fixing either by a gummed edge or by some other fastening device to keep them firmly attached to the moving drum. They are frequently arranged to run for twenty-four hours, but can of course be made for other periods if required.

(*c*) *Tape Charts.*—These charts form a continuous roll which slowly unwinds as the record is inscribed thereon. They are employed in cases where a continuous record is required for considerable periods, and their use avoids the trouble of frequent changing of charts. It follows that they record without attention during week-ends. The portion of the tape chart corresponding to any required period can always be cut off when required.

Tape charts are commonly made to run for sixty days, the drum making one revolution in twenty-four hours. In some cases, however, as in a water gas cycle recorder, the drum is made to revolve much more rapidly. For example, it may be made to revolve once every four hours, thus opening out the time spacing on the chart which would then last ten days instead of sixty.

It is sometimes convenient to provide for the simultaneous inscription of two separate records upon a single chart. The synchronization of the two records is thus assured, and a certain amount of mechanism can be dispensed with.

The percentage of carbon dioxide and the draught in wasteflue gases are frequently recorded upon a single chart in this manner (fig. 5). Another example is afforded by the record obtained with a combined carbon monoxide and carbon dioxide recorder, in which the quantities of each of these constituents is simultaneously recorded upon a single chart.

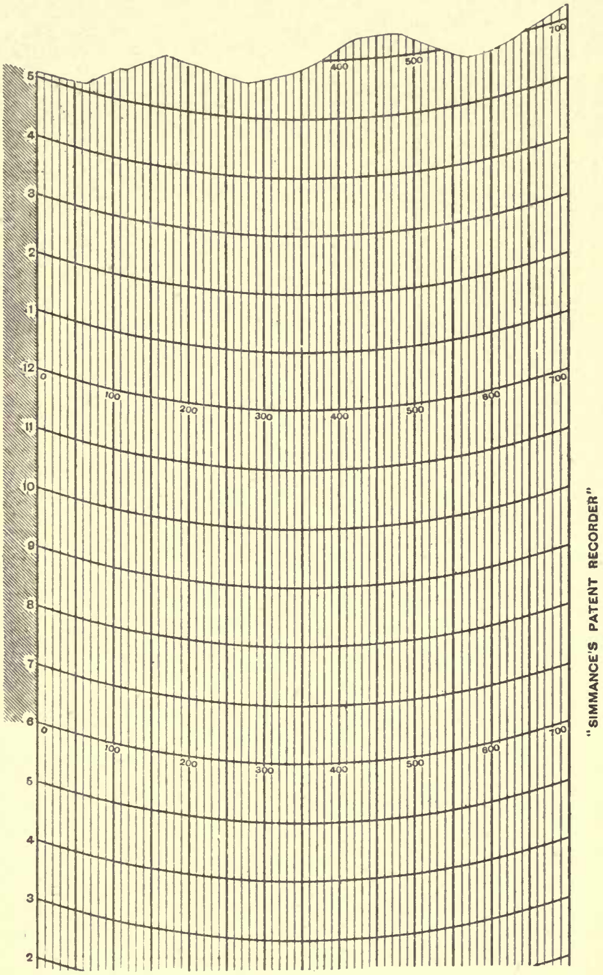


Fig. 4.—Tape Chart.

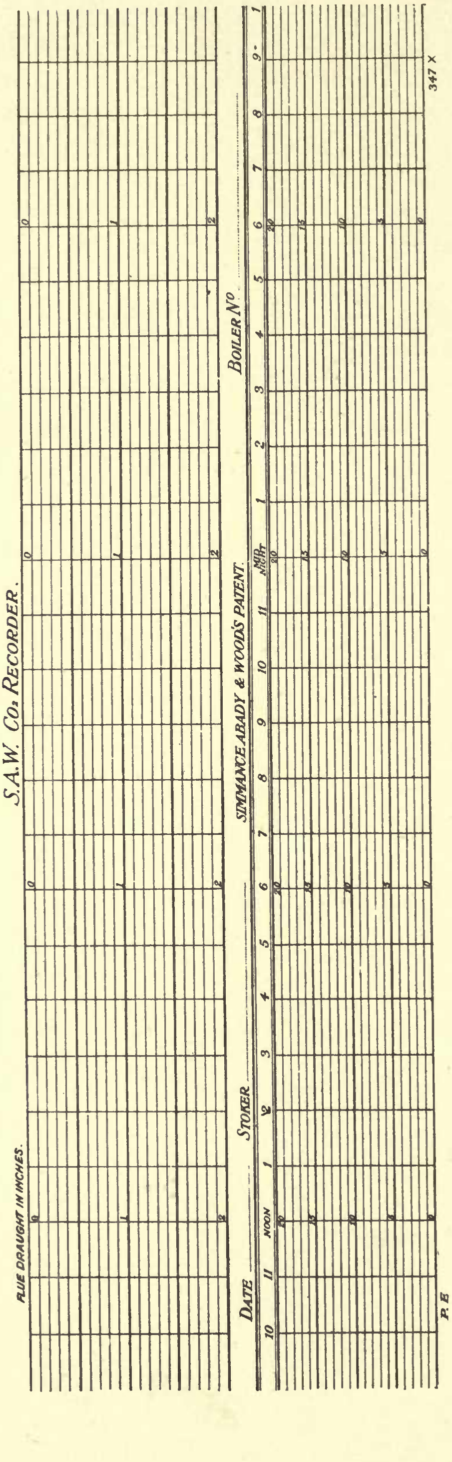


Fig. 5.—Chart showing Percentage of Carbon Dioxide and Draught.

II. RECORDING INK

The ink employed in recording instruments is of a special nature. It must not dry in the pen, but should dry with fair rapidity when on the chart. It must not corrode or stop up the pen. The use of various colours is convenient if more than one record is required on the same chart. The ink bottle may with advantage be fitted with a rubber bladder pipette for convenience of filling the pen.

A special ink is required for use in very dry and hot climates, in which ink suitable for use in temperate countries would dry up in the pen.

Recording inks are usually composed of aqueous solutions of aniline dyes to which certain quantities of glycerine and alcohol have been added.

In certain instruments (some types of recording pyrometers) a smoked chart is employed, and the pointer of the galvanometer is depressed intermittently thereon. A portion of the soot is thus removed at each depression, and the series of clear dots thus produced forms the record. When complete, the record can be preserved if desired by spraying with a suitable varnish.

Pencils are very occasionally employed in recorders. They may be employed in instruments in which the power exerted by the moving part is relatively large—as for example in a Wright's Register—and which are not required to give fine readings. The pencil is maintained in contact with the chart by means of an elastic band. There is not any particular advantage in the use of pencils. Trouble is caused by the point wearing away, and a very soft chart is required.

III. RECORDING PENS

Recording pens must give a fine line so that the width of the latter is inappreciable in comparison with the subdivisions of the chart. The ink should flow freely and regularly, and the filling should be quite simple. The following are the types most frequently employed.

(*a*) *Boat Pen.*—The commonest and most satisfactory type of pen is the boat pen (fig. 6), so called from its shape, like the half of a boat. The ink is fed to the chart between the two sides forming the point, by capillarity. The point of a boat pen should not be opened, or too much ink will flow. Boat pens are easy to fill and are readily cleaned by inserting a thin piece of card (such as a visiting card) between the two portions of the point.

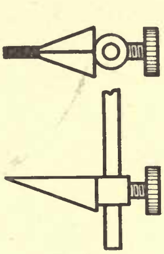


Fig. 6.—Boat Pen.

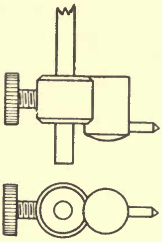


Fig. 7.—Pot Pen.

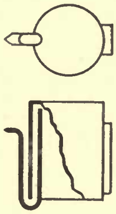


Fig. 8.—Dittmar Pen.

(*b*) *Pot Pen.*—This consists of a small pot fitted with a very fine orifice at the base (fig. 7). It does not possess any particular advantage over the boat pen, and is not so easy to clean.

(*c*) *Dittmar Pen.*—This pen consists of a small syphon pipe leading to the point. In this manner the same head of liquid is always maintained. Experience has shown that this precaution is not necessary in the case of boat pens (fig. 8).

(*d*) *Glass Pens.*—Recording instruments were formerly fitted with glass pens, as shown (fig. 9). They are easy to fill but have no other advantage, and are now being gradually superseded by boat pens.

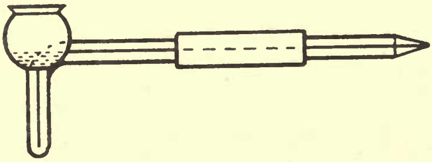


Fig. 9.—Glass Pen.

(*e*) *Self-inking Pens.*—These are useful in cases where an instrument remains unattended to for considerable periods—as, for example, during the run of a sixty-day chart. A small capillary tube is maintained continuously in a long, narrow trough of ink, so placed that the capillary tube is always immersed, whatever the position of the recording pen may be. The ink is fed by capillarity to the recording pen, which is thus kept full and does not require attention (fig. 10).

(*f*) *Thread Recorder.*—In certain types of recording instruments the moving pointer is very delicately suspended, and the actuating force which displaces it is so small that a recording pen could not be attached to it owing to the friction of the chart. This is notably the case in certain types of moving coil galvanometers employed for recording pyrometers (*q.v.*).

This difficulty has been surmounted by the Thread Recorder, devised by Sir Horace Darwin, in the following manner.

A thread, saturated with recording ink, is stretched between the moving pointer B (fig. 11) and the chart J, in a direction parallel to the axis of the drum carrying the chart.

A metal bar K is situated above the moving pointer, and is normally kept free from the latter by means of a cam L and the strip of metal M connected to it. At regular intervals the cam L is caused to make a half revolution; this first allows the bar K to fall upon the pointer B and immediately afterwards raises the bar to its normal position. When the bar falls it depresses the pointer on to the chart, thus nipping the inked thread between the latter and the pointer. This produces a dot upon the paper at the point of intersection of the pointer and the thread, thus making a visible record of the position of the pointer at the moment of contact. The moving pointer is hinged so that the bending does not injure its suspension. In the interval between the formation of the dots the pointer is free to move without any frictional errors.

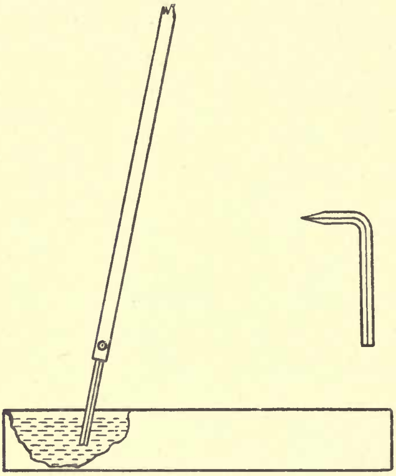


Fig. 10.—Self-inking Pen.

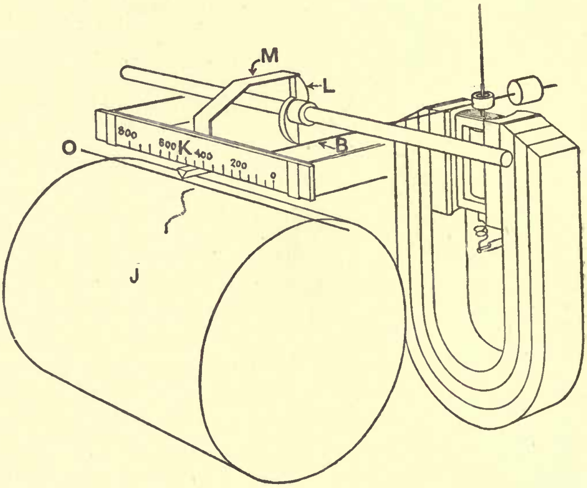


Fig. 11.—Thread Recorder.

The cam shaft and cam L are driven by an auxiliary clock, thus operating the bar K. If the chart drum is driven so as to make one revolution in twenty-four hours, the thread recorder is usually arranged so as to make one dot per minute, but if a more rapid rotation of the chart drum is employed, the recorder can be set to give a dot every half-minute.

The clock driving the chart drum is fitted with a removable cam which engages with a wire arm driven by the auxiliary clock, and only allows it to rotate at the minute or half-minute interval, according to the cam employed.

The thread is continuously fed in one direction and is therefore not worn in one particular place. The record obtained consists of a series of small dots very close together. This, of course, is just as effective as a continuous line.

Foster's Recorder is another type of mechanism designed for production of a practically continuous record by the formation of intermittent dots upon the chart, in cases where the frictional effects of continuous contact would be undesirable.

The pen is normally out of contact with the chart, but is pressed thereon once every minute by means of a presser bar actuated by clockwork. When the dot has been made (the position of the pen being determined only by the magnitude of the quantity which is being recorded), the same clockwork mechanism deflects the pen to the side of the recorder case and presses it upon an ink drum, thus receiving a fresh supply of ink for the next dot.

The clockwork which actuates the pen in the manner described is also employed to drive the chart.

IV. PEN MECHANISM

The mechanism actuating the recording pen may be required to cause a motion of the pen commensurate with that of the moving portion of the recorder, or it may be required to cause a highly magnified motion, corresponding to an exceedingly small movement of the moving part of the recorder.

As an example of the former type of mechanism, the arrangement adopted in the Simmance CO_2 Recorder may be considered. The record is obtained from the height to which the receiving bell rises when the charge of gas, freed from carbon dioxide, is blown therein (fig. 12).

The pen mechanism consists of a balanced pen A pivoted upon two points, one engaging in a groove and the other in a conical depression so as to move without friction and normally maintained in a fixed position, usually corresponding to zero on the chart. At certain intervals of time the pen is released and then swings upon its pivots until its movement is arrested by the contact of the drop arm B with the top of the receiving bell C.

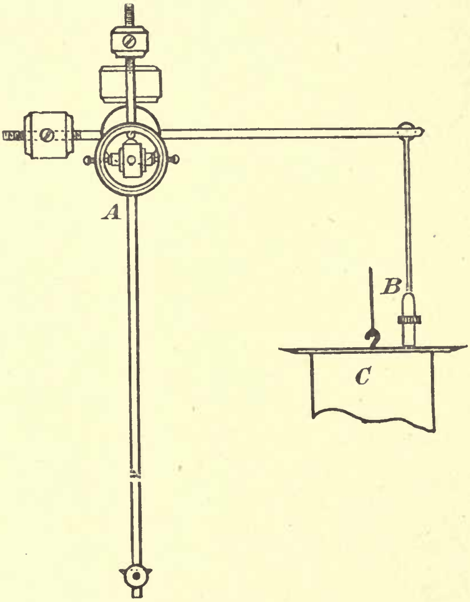


Fig. 12.—Pen Gear used in Simmance Carbon Dioxide Recorder.

The adjustment of the movement of the pen is effected by alteration of the length of the drop arm B, until the record given by the pen corresponds with the reading on the fixed scale attached to the side of the receiving bell.

The chief requisites of this type of mechanism are accuracy of balancing and freedom from frictional effects at the point of support.

In the majority of types of pen mechanism, the pen arm is carried by two pivots at right angles to its length, and is balanced about the point of support in which the pivots engage, by a weight threaded on to a bent arm (fig. 13, A).

The pressure of the pen upon the paper can be adjusted very closely by movement of the threaded weight A.

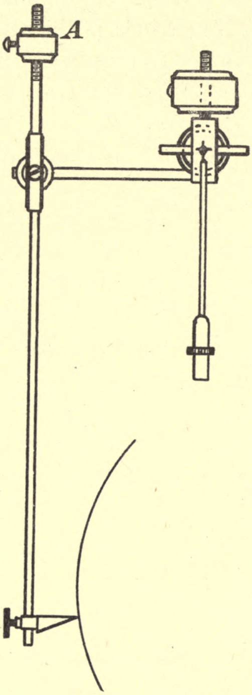


Fig. 13.—Simmance Balanced Pen.

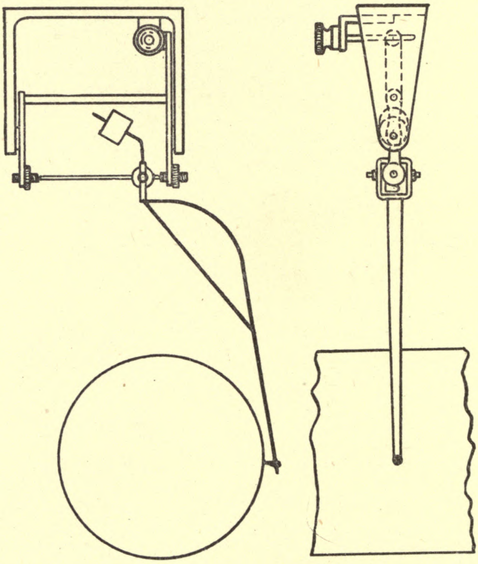


Fig. 14.—Pen Gear used in Simmance Recording Calorimeter.

In some cases the pen itself is hinged on the end of the pen arm and weighted so that the pen swings forward and is maintained in contact with the chart.

The mechanism employed in most recording pressure gauges, recording calorimeters, and many other instruments, is required to magnify a very small original movement in order to give an adequate sensitiveness of reading on the record. This magnification is effected by a system of levers. It is most important that there be complete absence of back lash and that the pen is rigidly constrained in its position, so that there is no tendency to vibration about a mean position.

The pen mechanism employed in Simmance's Recording Calorimeter offers an example of a magnification system in which these desiderata are completely fulfilled (see fig. 14).

V. ANTI-FRICTION WHEELS

In many instruments the moving parts are balanced over a wheel which rotates when the equilibrium is disturbed, until it assumes a new position of equilibrium. The pen arm is attached to the spindle of the wheel, and thus the rotation of the latter causes an angular deflection of the pen arm. It is very important indeed that such mechanism should be as free from friction as possible, and this is effected by carrying the moving spindle upon anti-friction wheels and not upon a fixed bearing.

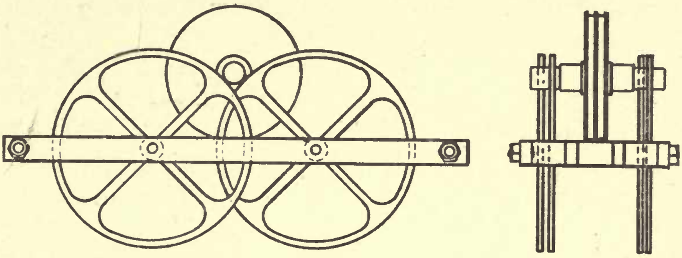


FIG. 15.—ANTI-FRICTION WHEELS.

The arrangement is shown in fig. 15.

VI. CHART CARRIER

The charts on recording instruments are borne by some form of carrier which moves regularly in one direction, carrying the chart forward and so introducing the time factor.

When a chart is changed, or when a long tape chart moves forward, its position with respect to the carrier should always be constant. This is readily effected in the case of disc charts by printing a dot at its centre through which a needle at the centre of the carrier is passed. The matter is not quite so simple in the case of drum and tape charts. The lateral position of these is determined by means of flanges on the carrier. A slight clearance must be provided to allow for slight differences in the width of charts, but the uncertainty due to this cause should not in any event exceed about ½ per cent. of the total ruling.

Disc charts and roll charts are firmly attached to the carrier and move forward with it. Tape charts have to be driven forward, and only a portion thereof is in contact with the moving carrier. It is therefore evident that there must not be any slip between the chart and the moving drum. The driving of the chart in Simmance's instruments is effected by a series of discs mounted on a framework, which maintain the necessary contact of the chart on the drum by friction.

Another commonly employed method of driving is by means of a perforated edging on the chart which engages a spur-wheel device, driven by the clock.

VII. CLOCK MOVEMENT

The chart carrier is driven regularly forward by a clock movement. The arrangement consists of a centre wheel attached to a fixed spindle; the movement itself rotates about this fixed wheel and causes the chart carrier, which forms a portion of its outer casing, to rotate. The spindle carrying the centre wheel, upon which the movement rotates, can be released by loosening a nut so that the clock can be moved as a whole relatively to the pen, thus enabling the latter to be set to the correct time as shown on the record.

As a general rule the clock mechanism is driven by an ordinary clockwork spring, but occasionally the clock is driven electrically. This may be effected by causing the pendulum to operate a mercury switch in such a manner that when the pendulum approaches a suitably placed solenoid, the current is caused to flow through the latter, and an impulse is communicated to the pendulum whereby it is kept swinging at its full amplitude. The same switch may also be used to cause the current to flow through another solenoid, which causes a ratchet to engage in a toothed wheel, and thus drives the chart forward a very small distance each time the contact is made.

The timing of the clock is controlled by the length of the pendulum only, and is quite independent of any fluctuation in the actuating current.

VIII. INTEGRATING MECHANISM

It is often necessary, as in the case of recorders for measuring rates of flow, to obtain an integration of the total quantity which has been measured by the recorder in a given time. When the instrument is such that the rate of flow is recorded or indicated by the rotation of a moving part, a simple train of counting wheels giving the total number of revolutions is employed. The dial or dials of the counting train are calibrated in terms of the function to be measured.

In other cases the rate of flow may be determined by the position assumed by a portion of the mechanism—*e.g.* the level of a float. In such cases the counting mechanism is driven separately by a suitable clock or other device. If the relationship between the position of the moving part and the quantity recorded is linear, the counting mechanism can be driven by friction on a rotating disc. The position of the moving part is arranged so as to determine the distance of the driving wheel from the centre of the disc, and thus to regulate the number of revolutions of the counter per revolution of the disc (see p. 225).

If the relationship is not linear, the train of counting wheels may be brought into action at intervals, the amount added on being determined by the position of a specially shaped cam, the disposition of which is regulated by the rate of flow at any instant.

CHAPTER III

RECORDING PRESSURE AND VACUUM GAUGES

Observations of pressure and of vacuum are perhaps the most essential measurements required for carrying out the operations employed in gasmaking. Such measurements have been made from the beginning of the industry, and apparatus in which the pressure or vacuum variations are continuously *recorded* have been in use for at least seventy years.

The varieties of pressure which it is necessary to record in a modern gasworks cover a very wide range. This varies from a few tenths of an inch water gauge to about 250 lbs. to the square inch. It is quite obvious that the type of instrument employed for low pressure reading will be quite unsuitable for high pressure measurements.

The terms in which the pressure or vacuum measurements are expressed upon the chart vary considerably. It is frequently convenient to scale the chart in units of various terms and magnitudes. The values thus presented are chosen to convey an accurate idea of the operation of the plant and to avoid the necessity of any calculations. The following list includes the most common methods in which pressure or vacuum readings are presented :—

- Inches of water.
- Feet head of water.
- Inches of mercury.
- Pounds per square inch.
- Atmospheres.
- Ounces per square inch.
- Millimetres of water.
- Centimetres of water.
- Millimetres of mercury.
- Centimetres of mercury.
- Kilogrammes per square centimetre.

The earliest types of recording pressure and vacuum gauges comprise the different varieties of so-called registers—*e.g.* Wright's registers, Crosley registers, portable registers, etc. These instruments are suitable only for comparatively low ranges. Although large numbers are in use, they are now mostly superseded by the Dead-beat aneroid gauges described below.

WRIGHT'S REGISTER

Wright's register (so called after its inventor, Alexander Wright, who died seventy years ago) may be described as a U gauge, in one limb of which a float is placed, its movement being recorded on a chart.

The U tube consists of two concentric tanks A and B (fig. 16), joined together at their upper edges as shown in the sketch. It is usual to make the respective areas of the float tank A and the outer tank B equal to each other. In this case the float will rise $\frac{1}{2}$ inch for each 1 inch water gauge pressure, and the chart is ruled so that 1 inch pressure = $\frac{1}{2}$ inch space on the chart.

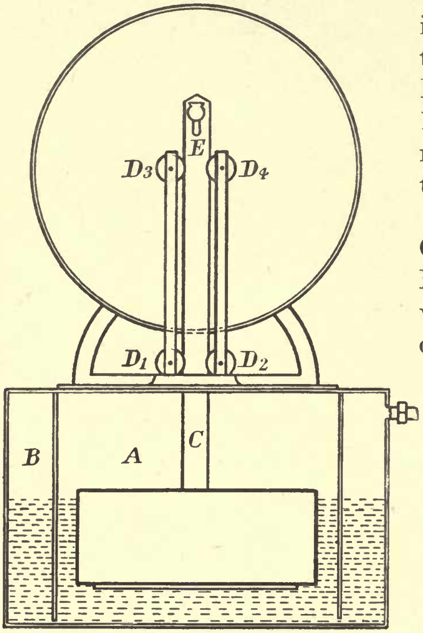


Fig. 16.—Diagram of Wright's Register.

The float itself carries a vertical brass rod C, running in guides fitted with the rollers D_1, D_2, D_3, D_4. The pen E is carried by the vertical rod C and records the pressure upon a disc chart. It is obvious that the motion of the float corresponding to any particular pressure will depend upon the relative areas of the float and annular chambers. If the area of the annular chamber be very large compared to that of the float chamber, the vertical movement of the float will be very nearly equal to the water pressure applied. Such a construction would, however, tend to become very cumbersome, and it is usual to obtain a more open scale, if required, by other means as described below.

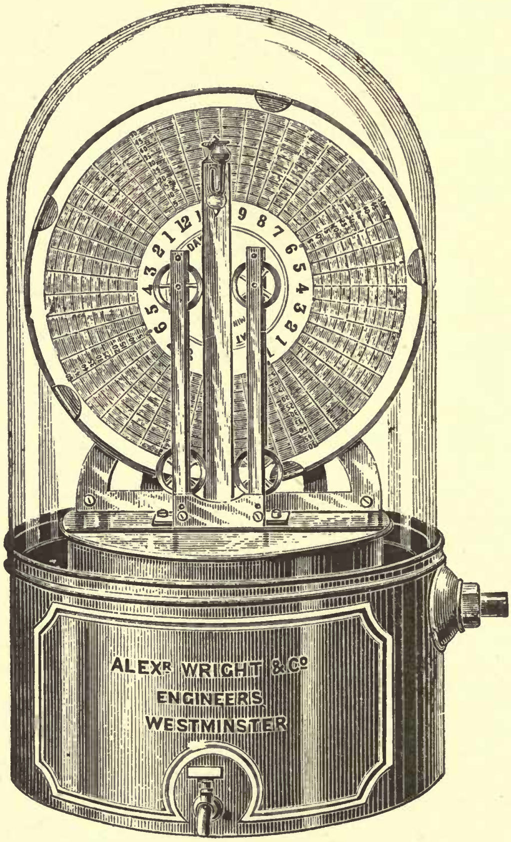


Fig. 17.—Wright's Register.

Wright's registers (see fig. 17) are constructed to record various ranges of pressure and vacuum; the extreme ranges covered by the various instruments are 4 inches pressure to 4 inches vacuum.

Portable Registers.—These are very similar to Wright's registers, and differ from the latter only in detail and not in principle. As the name implies, the instrument is of a light construction and is a portable form of gauge. The construction of the register is shown in fig. 18, from which it will be noted that the instrument differs from Wright's register in the following respects :—

(*a*) The pen is carried by a rod attached to the side of the float.

(*b*) The record is on an eight-day drum chart.

(*c*) The ranges covered by the instrument are greater—6 inch vacuum to 12 inch pressure.

The float and annular chamber are of equal area, and thus the movement of the pen is ½ inch for each 1 inch pressure.

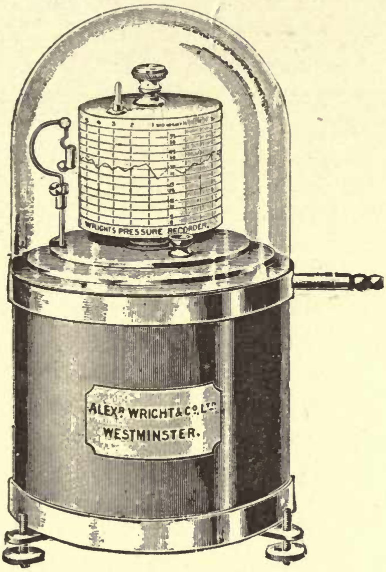


Fig. 18.—Portable Register.

OPEN SCALE REGISTERS

It is sometimes a disadvantage that the scale on the registers described is always compressed—*i.e.* the vertical movement of the pen, which is carried by the float itself, is always less than the pressure applied measured in terms of water column. This difficulty has been surmounted in Simmance's Open Scale Recorder in the following manner :—

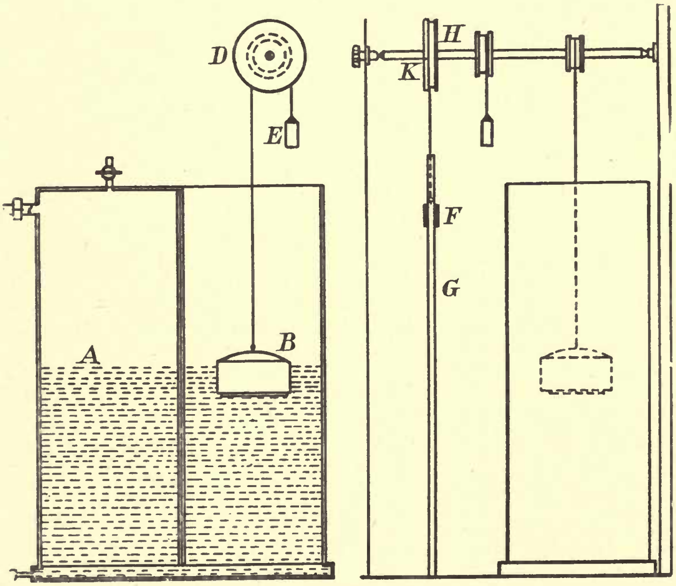


Fig. 19.—Diagram of Open Scale Recorder.

The pressure and float chambers A and B (fig. 19) are both of exactly equal area and have absolutely parallel sides. The float is suspended over a wheel D and balanced by a counterweight E. The pen F moves in a vertical guide G, and is carried over a wheel H mounted on the spindle K, which is common to the two wheels. The diameter of the wheel H is exactly twice that of the wheel D. The vertical movement of the float C causes the wheels D and H to rotate, and as the diameter of the pen wheel is exactly twice that of the float wheel, it is clear that the movement of the pen is also twice that of the float. A pressure of 1 inch therefore causes the pen to move through 1 inch exactly.

The principle employed is obviously capable of extension; so that, if desired, a magnified pressure reading may be obtained by increasing the diameter of the pen wheel relative to that of the float wheel to the necessary extent.

CROSLEY REGISTER

The Crosley Register is a sensitive instrument for the measurement of pressure or vacuum of small amount. The design of the instrument is such that a magnified movement is obtained; if necessary a movement of 12 inches for 1 inch of pressure or vacuum can be secured. The principle upon which the instrument is operated will be gathered by reference to fig. 20.

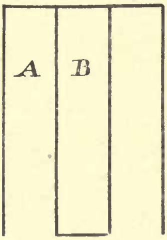


Fig. 20. — Float for Crosley Register.

The moving bell A is of special construction, and consists of a chamber in which a float B is mounted so that its sides are parallel to the walls of the bell. An annular space is thus enclosed between the outside wall of the bell and the wall of the float. The bell is immersed in the tank, and constrained by guide rollers to move in a vertical direction only.

Suppose the bell to be floating in equilibrium when nearly completely immersed and when there is no external pressure applied to the annular space.

Let the area of the cross-section of float and outside walls of the bell be a square centimetres.

Let the area of the cross-section of the annular enclosure between the float and the outside walls be b square centimetres.

Let a pressure p grams per sq. cm. be applied, then the reduction in the effective downwards weight of the bell is pb grams.

This will cause the bell to rise until the change in buoyancy is such as to compensate for the reduction in the effective weight of the bell. If the bell rises through a height h cm.

$$\text{then } ha = pb$$

$$\text{or } h = p\frac{b}{a};$$

hence the sensitiveness depends upon the ratio $\frac{b}{a}$, and can be made large by suitably reducing the area of the cross-section of the float relative to that of the annular portion. The positions of the float and annular portion can be interchanged.

The actual construction of the instrument is shown in fig. 21. A is the bell fitted with the float B. The rod C carries pen D. The pressure is transmitted to the central space through the standpipe E. When assembling the instrument for use the float chamber is filled with water almost up to the water-line, and a little oil is then added to cover the water surface and so prevent evaporation.

There is a practical limit to the magnification of the scale which is attainable on a Crosley register. If too great a magnification be attempted, errors are introduced owing to surface tension effects, and to frictional effects of the guide rollers.

Crosley registers are rather large, and are frequently fitted with ordinary time clocks for use in engine-rooms of gasworks. Crosley registers of suitable design and range are employed as draught recorders for registering the vacuum in chimney flues. For this purpose a restricted range with a very open scale is preferable—a construction for which a gauge of this type is very suitable.

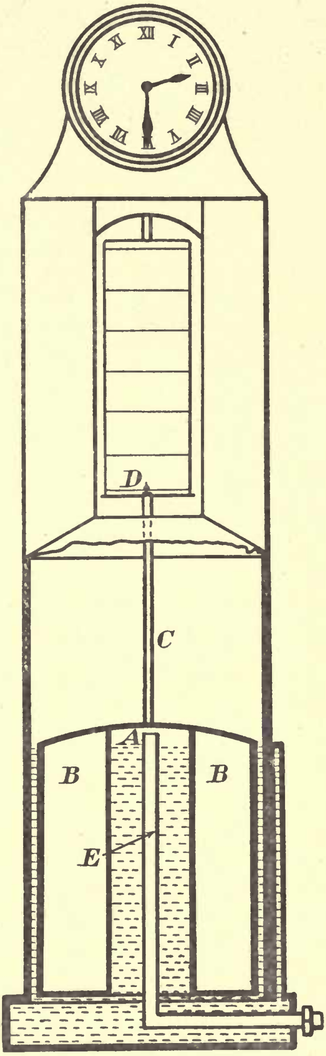


FIG. 21.—DIAGRAM OF CROSLEY REGISTER.

DIAPHRAGM GAUGES

The production of diaphragm gauges has been brought to a very high degree of perfection. They are now widely employed owing to their convenience and simplicity of construction, and to the fact that no liquid is required.

Diaphragm gauges were first devised about the beginning of the nineteenth century, and were employed for the measurement of barometric pressure. They were called aneroid barometers, from the fact that liquid was not employed in their construction (ἀ without ; νηρὸς, moist).

Diaphragm gauges are also constructed with a single flexible partition composed of leather or some similar material (*vide infra*) ; but the term "aneroid diaphragms" is not applied to such a construction, and refers only to the flexible metallic chambers described below.

Diaphragm gauges consist of two main parts :—

(*a*) The aneroid chamber ;
(*b*) The mechanism for magnifying and recording the movement of the chamber.

(*a*) *Aneroid Chamber.*—Aneroid diaphragms are all constructed upon the same principle, and differ in detail according to range and degree of pressure or vacuum for which the gauge is intended. They consist of a sealed metal chamber with flexible sides, which expand or contract with changes of pressure applied to the interior or exterior of the chamber.

The pressures for which aneroid gauges can be usefully employed cover a wide range. The most delicate aneroid barometers are so sensitive that they will give an indication if moved from the table on to the ground ; that is to say, they will indicate a pressure due to the weight of a column of air, say three feet high. In gasworks practice, the lowest ranges for which diaphragm gauges are usually made is 1 inch pressure to 1 inch vacuum. Aneroid chambers are employed for gauges reading up to 150 inch water pressure. It is advisable to employ the Bourdon tube gauge (*vide infra*) for pressures greater than this amount.

In spite of numerous attempts it has been found impossible to develop a formula connecting the movement of an aneroid chamber with the pressure change to which it is subjected. The knowledge which has been gained is entirely empirical, and is the result of trial and experience on the part of the makers of these instruments. It is, however, possible to give certain generalizations which are the result of experience.

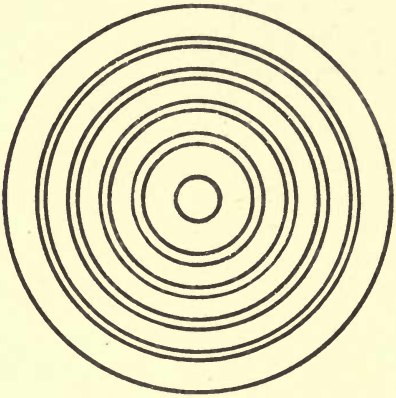


Fig. 22.—Single Aneroid Disc.

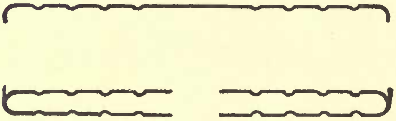


Fig. 23.—Aneroid Chamber.

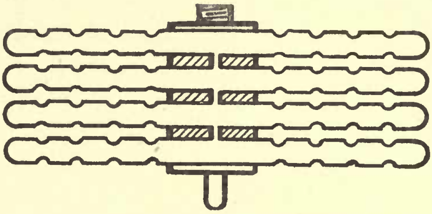


Fig. 24.—Series of Aneroid Chambers.

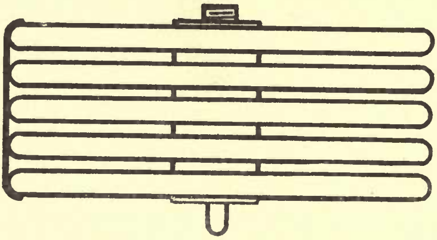


Fig. 25.—Aneroid Chambers with Metal Strip.

Aneroid chambers are constructed of an elastic metal or alloy—usually German silver. This is cut into circular discs and spun on metal formers to produce two or more circular ridges and an edging. Such a spun disc is shown in fig. 22.

Two such discs are soldered together to form an aneroid chamber (see fig. 23).

The thickness of the metal sheets employed depends upon the range of pressure or vacuum for which the aneroid is intended. The thinner the sheet the greater is the sensitiveness of the chamber.

Aneroid chambers vary in diameter. In the case of gauges employed for gasworks' use they are usually about three inches in diameter, but are occasionally four inches.

Aneroid chambers are scarcely ever used singly ; they are usually coupled together in numbers of four or six. The coupling is commonly effected by a short piece of tubing about $\frac{1}{2}$ inch diameter, as shown in fig. 24.

A large number of chambers are employed for certain types of instruments, and these are sometimes anchored together by a strip of metal along one edge, see fig. 25. The other edge of the pile of aneroid chambers is free to move, and hence, when pressure is applied, the pile expands on one side only, thus giving a tilting movement to a pen arm.

The movement obtained is nearly proportional to the number of chambers which are coupled together. The full movement is, however, not quite obtained owing to the junction which must necessarily exist between two adjoining chambers. This should be maintained as small as possible, as the larger this junction is, the more is the movement restricted, and the advantage of multiple chambers is thereby reduced.

The movement of a diaphragm system is most regular for the middle portion of its stroke, and the same proportional expansion is not obtained at the beginning or end of the stroke. For this reason it is desirable to maintain the diaphragms under a slight tension when in their zero position, so that the initial readings are not obtained from a movement at the beginning of the stroke. It therefore follows that the design of a diaphragm gauge should be such that the range of the instrument is kept well within the limits of movement of the aneroid system, and is not extended to the limits within which the expansion or contraction can occur.

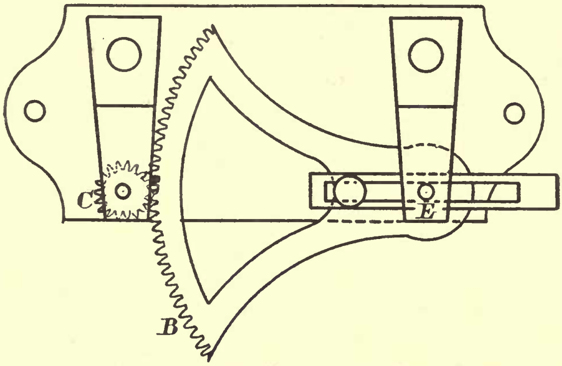


Fig. 26.—Quadrant Magnifying Mechanism.

Diaphragm gauges for use in gasworks are frequently exposed to corrosive gases which have access to the interior of the aneroid chambers. It is therefore desirable to protect the latter as far as possible by a coating of protective metal, such as pure tin or lead.

(*b*) *The Mechanism for Magnifying and Recording the Movement of the Aneroid Chamber.*—The movement of the aneroid chambers, even if composed of several diaphragms coupled together, is quite small and must be amplified by suitable mechanism in order to obtain a motion of adequate magnitude. The amplifying mechanism must conform to certain requirements for the production of a satisfactory instrument.

1. The movement must be as free from friction as possible.

2. There should be a complete absence of back-lash, so that the pen always assumes the same position from whichever side this position is approached.

3. The instrument must be dead-beat; that is to say, the pen must take up its position without any vibration about a mean.

4. A suitable zero adjustment should be provided for setting the apparatus, if necessary, when it is fixed in its position.

Fig. 26 shows diagrammatically a type of amplifying mechanism commonly employed on many instruments.

The movement of the diaphragm is transmitted by the toothed quadrant B, which engages in the pinion wheel C. The back-lash in the gearing is taken up by means of a fine hairspring. The quadrant B is pivoted at E, and the position of the pivot can be varied for the adjustment of the leverage and hence of the magnification.

The movement employed by Simmance is of a different character.

The pen arm A is balanced by a counter-weight B and carried by a hard steel spindle C, the ends of which are points carried in the bearings D_1 D_2. E is an adjustable link firmly fixed to the spindle C and attached to the diaphragm F by a suitable linkage.

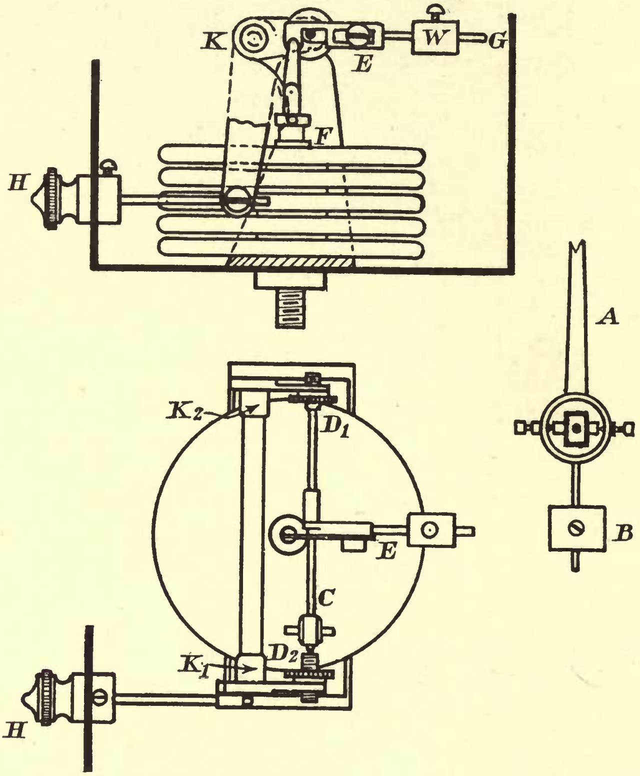


Fig. 27.—Simmance's Dead-beat Magnifying Mechanism.

The magnification of the diaphragm movement is the ratio of the length of the adjustable link E to that of the pen-arm A. The weight W is carried on a bent arm G and exerts a pull tending to expand the diaphragm system. In this way the diaphragms are slightly extended at the zero position, which, as explained above, is advantageous. Owing to the special shape to which the arm G is bent, the moment exerted by the weight W increases as the diaphragms expand. This has the effect of increasing the proportional movement of the diaphragms towards the upper limit of the scale, and so compensating for the diminished movement which would otherwise necessitate the use of a scale which was not uniformly divided.

If a diaphragm gauge recorder is connected to a pulsating pressure, the pen may be caused to move from side to side and so make a thick line. This vibration of the pen can be prevented by the use of a damping valve through which the pressure is transmitted to the gauge. The construction of a suitable valve is shown in fig. 28, and oscillations of the pen, should they occur, are prevented by screwing in the plunger B until they cease.

The pull exerted by the weight W is direct and is always in action. The movement is therefore dead-beat, and no oscillation occurs when the pen moves. The gauges are calibrated directly against a standard U gauge by adjustment of the length of the link E. The whole movement can be moved relatively to the chart for the purpose of zero adjustment, as it is fixed on a moving framework, which is pivoted at K_1 and K_2 and operated by an adjusting screw H.

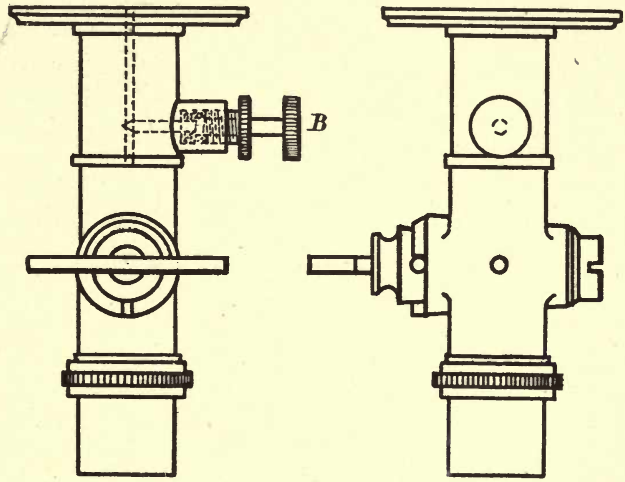


FIG. 28.—VALVE FOR DAMPING OSCILLATIONS.

TYPES OF ANEROID DIAPHRAGM GAUGES

Aneroid diaphragm gauges are constructed in a multitude of types and ranges according to the purpose for which they are required. Low-range pressure or vacuum recorders up to 4-inch water gauge are usually constructed with six-chamber aneroid systems. Such instruments are very suitable for the construction of draught recorders for connecting to chimneys and waste gas flues. Pressure or vacuum recorders intended for a greater range up to about 50 inches water are usually constructed with four aneroid chambers. Instruments intended for greater pressures up to 100 inches may be constructed with four aneroid chambers, the metal employed in this case being somewhat thicker.

It should be understood that the above-mentioned data are not to be taken as invariable, as the practice followed by various makers differs somewhat.

Fig. 29 illustrates the complete mechanism of a diaphragm gauge, the front of the case being removed.

Diaphragm gauge mechanism is employed extensively in recording instruments intended for various purposes, as for example in certain types of recording calorimeters (see Chapter VI.).

As a general rule the pressures or pressure differences for which this gauge mechanism is required, results from temperature changes, and the diaphragm gauge in these instruments functions as a recording thermometer.

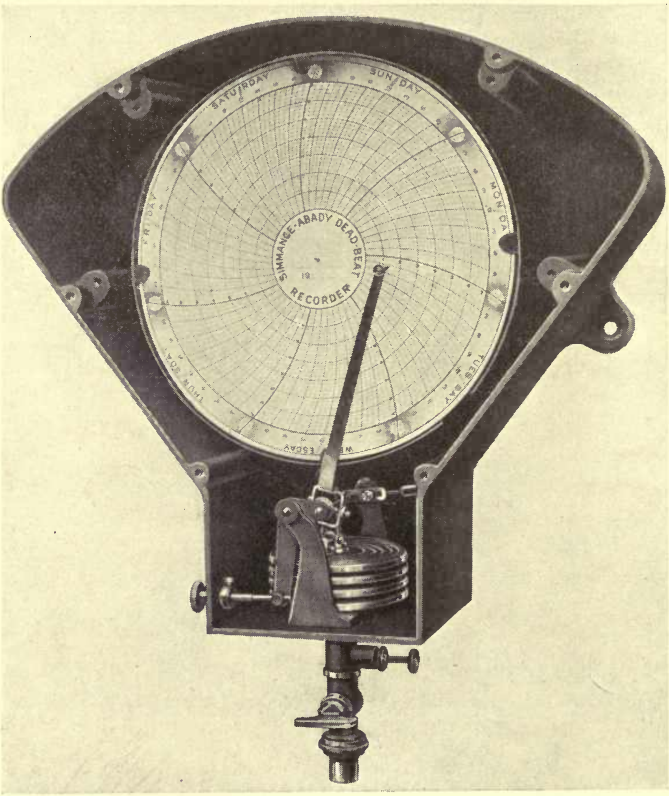


FIG. 29.—RECORDING ANEROID GAUGE

LEATHER DIAPHRAGM GAUGES

A diaphragm gauge of different type to the aneroid diaphragm gauge is sometimes employed for the measurement of low pressures or vacua, as for example for draught gauges. The Cambridge draught gauge is an example of this method of construction. The instrument consists of a diaphragm composed of leather or of a similar flexible material. This diaphragm is stretched across a metal container, and is arranged so that one side is exposed to the atmosphere and the other side is exposed to the small pressure or vacuum to be measured. The pressure variations on the one side of the diaphragm cause it to make small movements inwards or outwards, and these movements are magnified and transmitted to the pointer of the instrument.

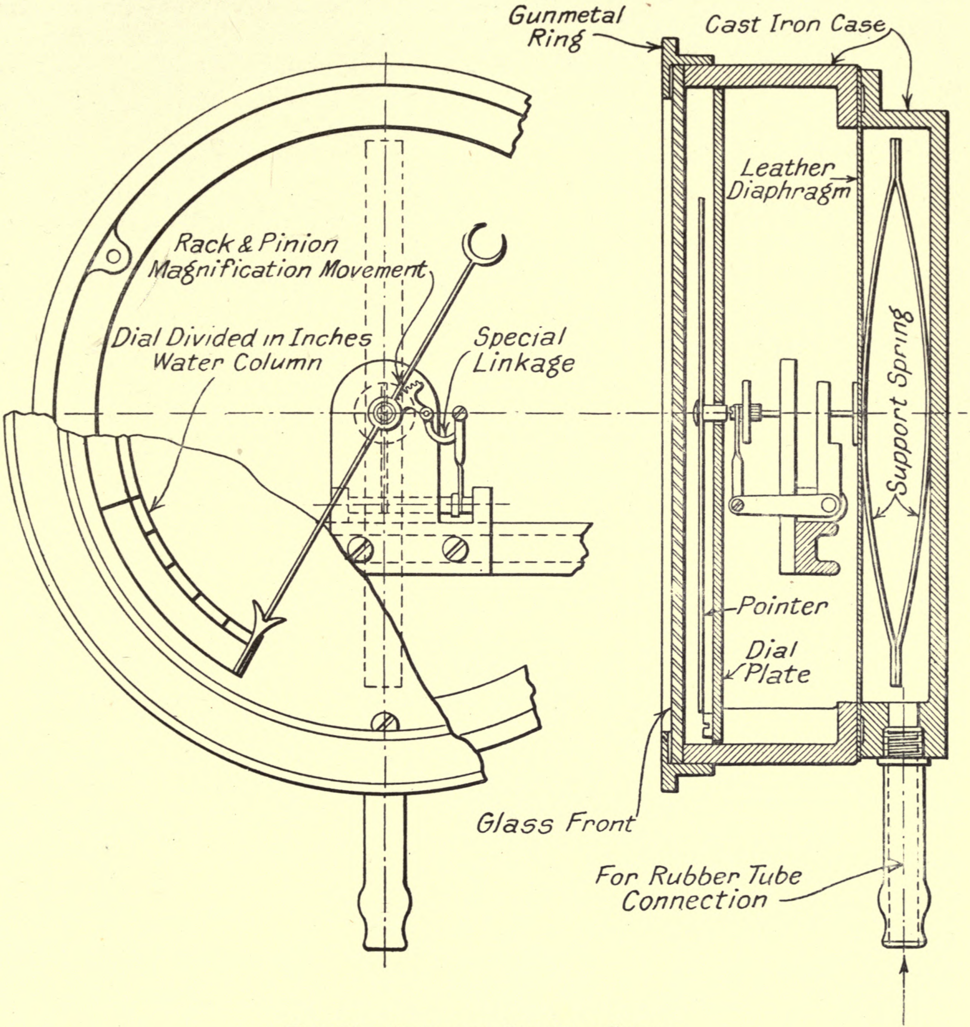


FIG. 30.—CAMBRIDGE DRAUGHT GAUGE.

The construction adopted in the Cambridge draught gauge is shown in fig. 30. The back portion of the metal case of the instrument forms a chamber closed by the flexible diaphragm, which is controlled by a spring. The part of the diaphragm is open to atmospheric pressure. The tube leading from the chamber is connected to the position at which the draught is to be measured. The diaphragm carries a metal plate at its centre, and the motion of the plate is transmitted by the lever system to the rack-and-pinion motion, which in turn actuates the pointer.

The scale of the instrument is very open, as a total length of scale of 12 inches can be calibrated to cover a range of 2 inches of water pressure.

The appliance is constructed for indicating only, and is not made as a recorder.

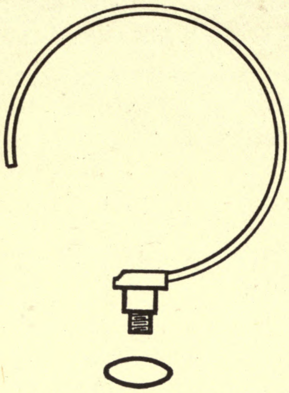


Fig. 31.—Diagram of Bourdon Tube.

BOURDON GAUGES

Bourdon gauges differ from diaphragm gauges insomuch as the expanding diaphragms in the latter are replaced by a Bourdon tube. A Bourdon tube consists of a flattened tube of elastic metal, usually brass, which is bent into the arc of a circle. Two views of a Bourdon tube are shown in fig. 31. When pressure is applied to the interior of a Bourdon tube it tends to straighten out and increase its radius of curvature. The movement thus obtained is small, and is magnified by exactly the same type of mechanism as is employed in diaphragm gauges. Bourdon tube gauges are employed for recording high pressures greater than those which can be suitably measured with a diaphragm. Bourdon gauges are not so suitable for recording comparatively low pressures; they cannot be made so sensitive as diaphragm gauges.

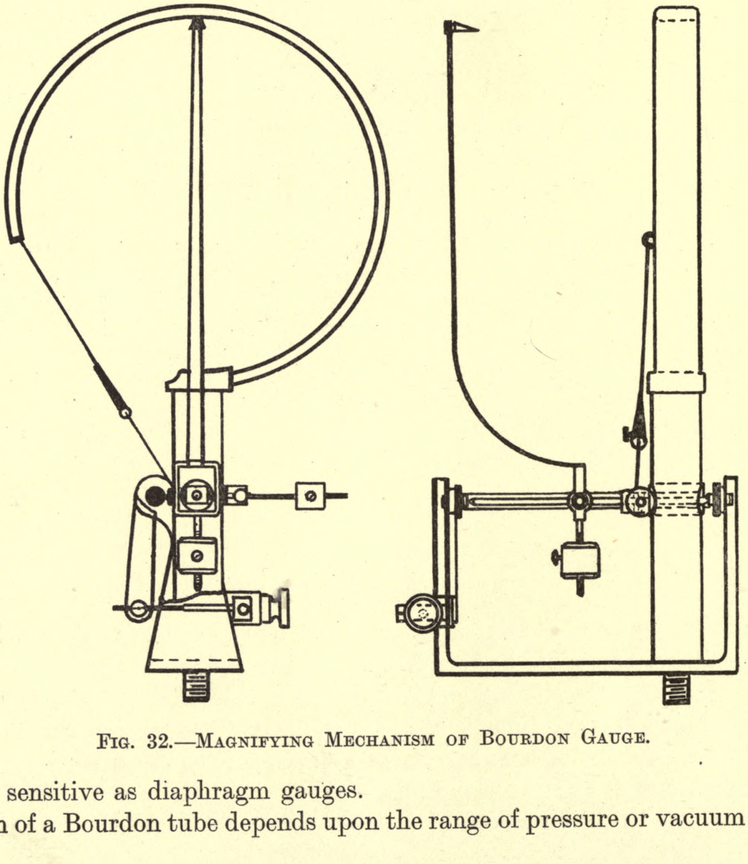


Fig. 32.—Magnifying Mechanism of Bourdon Gauge.

The construction of a Bourdon tube depends upon the range of pressure or vacuum to which it is to be subjected. The thinner the walls of the tube, the greater is the movement obtained with the same pressure. Increased movement is also obtained by a greater flattening of the tube, and *vice versa.*

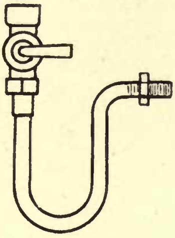


Fig. 33.—Syphon and Cock for Steam Pressure Recorder.

Bourdon tube gauges are employed for pressures ranging from 100 inches water gauge—say, 4 lbs. to the square inch—to 300 lbs. to the square inch. Their chief application is for steam pressure recorders and for recording the pressure in the high-pressure gas systems.

Bourdon tube gauges are also employed for the construction of vacuum gauges in such cases as the degree of vacuum is considerable—as, for example, on a condensing plant. The complete mechanism of a Bourdon tube gauge is shown in fig. 32.

If a Bourdon tube is required to record steam pressures, it is necessary to have a syphon, and the steam must be allowed to condense in the tube, as otherwise it would enter the instrument and so cause damage.

It is convenient to have a two-way cock fitted to the recorders. The arrangement of the syphon and cock is shown in fig. 33.

GAUGES DESIGNED FOR SPECIAL PURPOSES

(*a*) *Twin Gauges.*—It is frequently necessary to make simultaneous records of two different pressures or vacua. Such records are most conveniently made upon a single chart provided with two sets of rulings. As the chart carrying the two records is driven by a single clock, any errors due to lack of synchronization (which might occur if two separate recorders were employed) is avoided.

Instances in which such instruments are of utility are afforded by twin vacuum recorders for controlling the efficiency of a condenser used in connection with a steam plant. This consists of two separate pieces of Bourdon tube mechanism. One of the Bourdon tubes is exhausted and serves to record the prevailing barometric pressure; the other is connected to the condenser. The difference between the two readings is a measure of the efficiency of the condenser, and should, of course, be as small as possible.

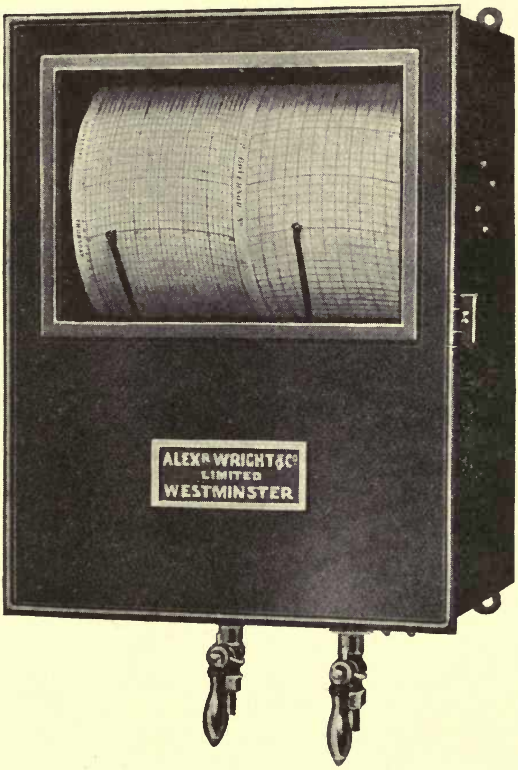


Fig. 34.—Twin Pressure Recorder.

Another use to which twin-pressure recorders have been put is for simultaneous registration of the pressures on the low and high pressure gas systems respectively at various places in the district.

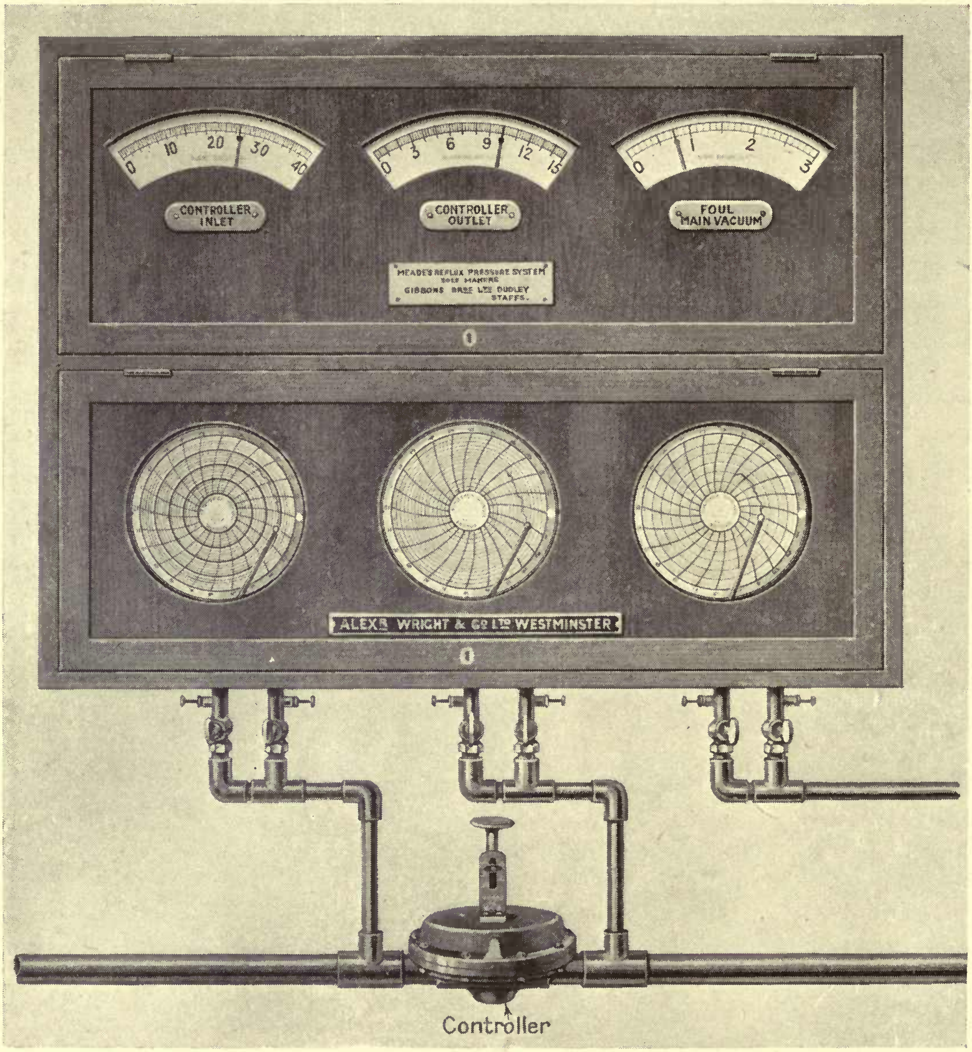


FIG. 35.—BATTERY OF GAUGES FOR MEADE'S REFLUX PRESSURE SYSTEM.

A twin pressure recorder is illustrated in fig. 34.

(*b*) *Batteries of Gauges.*—Batteries of gauges are sometimes required for the effective control of certain plants, and are usually situated in the engineer's office. A good example of such regulation is afforded by the outfit required for the control of Meade's Reflux Pressure System. According to this system a constant draw is always maintained on the foul mains, and the depth of seal is altered when necessary.

The latter is varied by adjusting a special controller which regulates the pressure of the gas taken from the scrubbers and communicated to the " pressure box " of the reflux pressure system.

The gauges required for control of the plant consist of pressure gauges on the inlet and outlet of the controller, and a vacuum gauge on the foul main.

Fig. 35 illustrates a battery of gauges and controller employed for the control of an installation of the reflux pressure system. It will be observed that three indicating gauges are employed in addition to the three recording instruments.

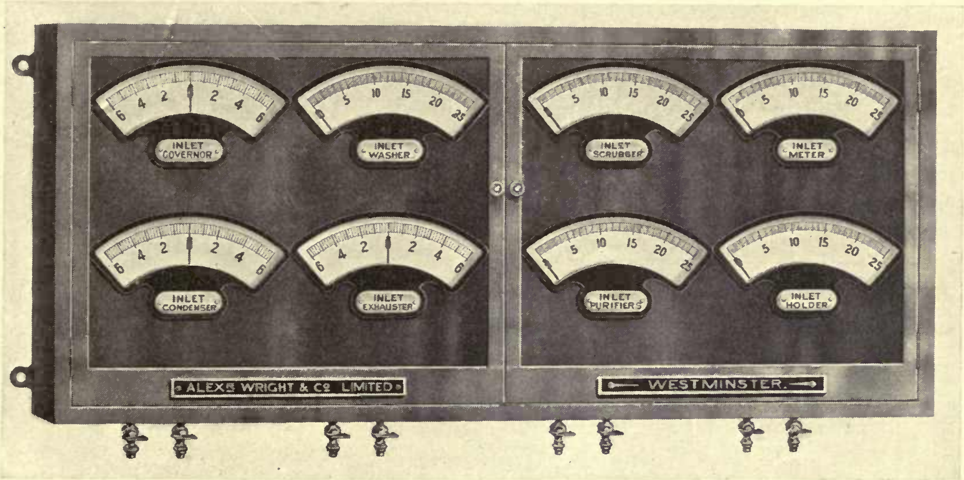


Fig. 36.—Battery of Pressure Gauges.

It may be found convenient to couple the various working points in a gasworks to a battery of gauges placed in the engine-room or other convenient place. The gauges usually employed for this purpose are indicators, but there is no reason why recorders should not be similarly installed in batteries. Such a battery of indicators is shown in fig. 36.

(*c*) *Electric Alarm Gauges.*—Electrical alarms are sometimes fitted to gauges and are provided with an adjustable electrical contact for ringing a bell when the indication reaches any desired point The arrangement employed is illustrated diagrammatically in fig. 37.

(*d*) *Differential Gauges.*—Differential gauges of the portable register type have been constructed in the following manner :—

A A (fig. 38) is the outer tank, and B is the float chamber in which the float C is situated. The two pressures P_1 and P_2 are connected at D and E, which communicate with the outer and inner chambers respectively. The tops of the chambers are closed to air.

The pen F is carried on a vertical rod G which passes right through the float and is carried by a platform H connected to the bottom of the latter. The rod G is surrounded by a narrow tube K, which does not impede its motion and serves to seal the tube from the outside air.

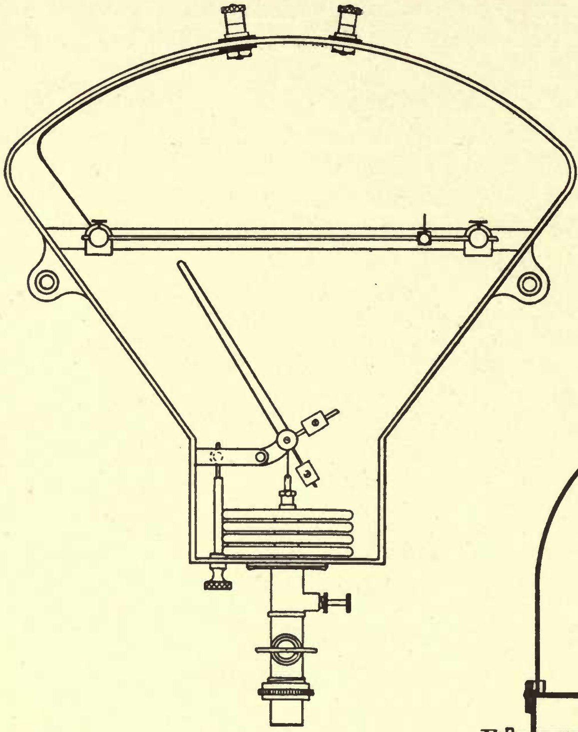


Fig. 37.—Gauge fitted with Electrical Alarm.

The rod must be carried right through the float, as the rod in the tube K must always be sealed in water, otherwise the float chamber would be open to the air.

The indications of the gauge cannot theoretically be perfect owing to the fact that water is forced into the glass tube K, thus altering the water level. If, however, the tank is, say, 6 inches diameter and the glass tube $\frac{1}{4}$ inch, the alteration in level due to this cause will only be $\frac{1}{736}$th of an inch for each inch of water pressure of P_2, so that practically the gauge is correct.

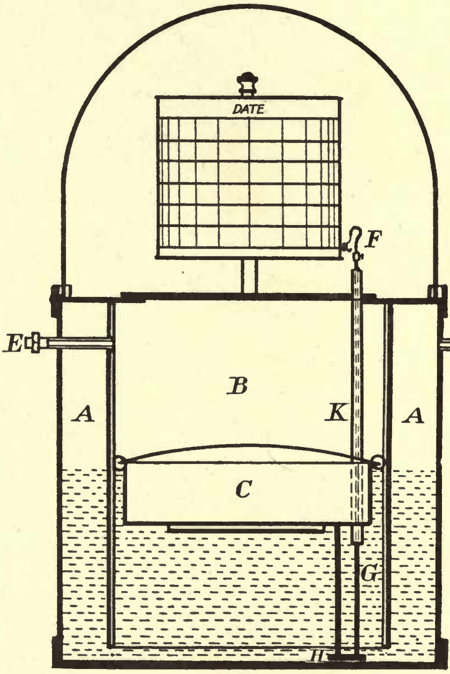


Fig. 38.—Diagram of Differential Pressure Register.

Differential gauges are most conveniently constructed by the employment of aneroid diaphragms. This can be effected by two different methods :—

1. Two exactly similar sets of aneroid chambers, of construction and dimensions suitable for the pressures involved, are arranged so that their expansions are in opposition, and the movement of the pen is due to the difference between the expansions of the two sets of diaphragms respectively. The two pressures are of course applied to the two diaphragms.

A differential gauge of this type is illustrated in fig. 39.

This method of construction suffers from the drawback that the movement obtained is restricted owing to the opposing motions of the two diaphragms. It is also, of course, essential that the two diaphragm systems are identical in their indications throughout the whole range of pressure covered by the instrument.

2. The other method which may be employed involves the use of one diaphragm system only. This is contained in an air-tight case. One pressure is communicated to the interior of the diaphragm, and the other is communicated to the interior of the case. The two pressures are thus applied to the interior and exterior of the diaphragm, and the full movement, corresponding to the pressure difference, is obtained.

This method of construction can only be employed for comparatively small pressures, owing to the difficulty of rendering the case absolutely sound in the case of large pressures. The arrangement is usually employed for indicating instruments only.

(*e*) *The Barograph.* — The barograph is a special type of aneroid diaphragm gauge employed for recording the variation of barometric pressure.

Instruments constructed by various makers naturally differ slightly in detail, but the following description typifies the construction of the most widely used instruments.

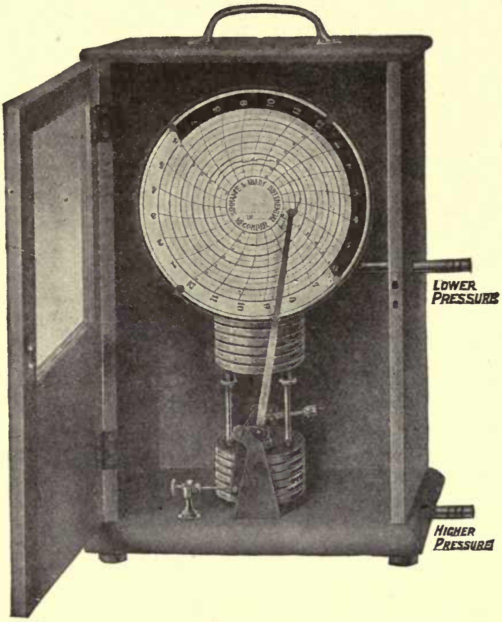


Fig. 39.—Differential Aneroid Gauge.

The aneroid system usually consists of six chambers connected together. The aneroid is exhausted and expanded by a spring, so that any variation of the barometric pressure will cause a movement of the diaphragms. The motion of the aneroid system is transmitted to the pen by means of a system of jointed levers as shown in fig. 40.

The record is made on a drum chart making one revolution in seven days, after which the chart must be changed. The pressure range on the chart is restricted to the limits between which barometric pressures can vary at sea-level (except in the case of instruments scaled for use in high altitudes), usually 27 to 31 inches of mercury.

The instrument is usually enclosed in a case fitted with glass sides and top.

(*f*) *Water Gas Cycle Recorder.*—The pressure variations, which are associated with the different operations performed in the manufacture of water gas, occur at very short intervals. It is for this reason that a pressure recorder designed to register these changes (and so to control the operation of the plant) must have a greatly extended time scale, so that pressure readings at intervals of even half a minute are clearly differentiated. It is not, however, necessary for the pressure readings to be open, these can be recorded with sufficient exactitude upon a compressed scale.

The pressure register known as Thorp & Marsh's Water Gas Cycle Recorder is provided with a chart ruled in spirals (see fig. 41). The chart carrier makes one revolution every four hours, and at the same time it falls through a distance such that, at the completion of the revolution, the pen is in position to record upon the second spiral on the chart. The latter is provided with six spirals, and thus a complete record throughout twenty-four hours' reading is obtained upon one chart, and at the same time the time scale is so extended that pressure differences at intervals of even half a minute are clearly shown.

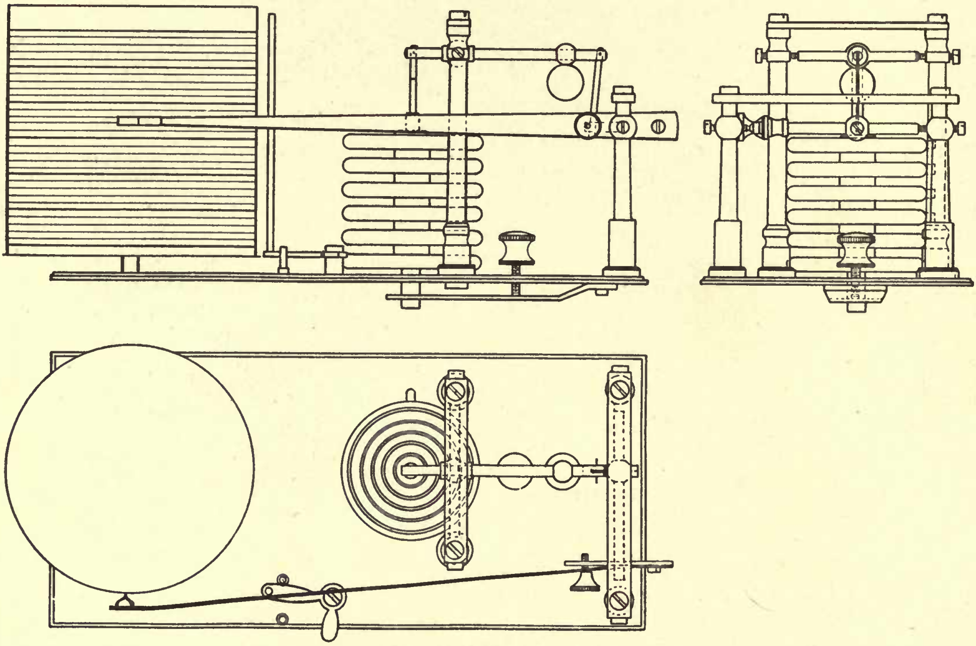


Fig. 40.—Barograph.

The instrument itself is a pressure register similar in type to the appliances previously described, and so designed that the pressure readings are obtained on a very compressed scale, a reading of 5 inches pressure being represented by less than a $\frac{1}{4}$ inch space on the chart.

This compression of the pressure scale is necessary, as otherwise the chart and its carrier would obviously become very large and unwieldy.

The method whereby the chart is read will be facilitated by reference to fig. 41. On consideration of the portion from 4 p.m. to 5 p.m., marked * *, it is seen that coking commences at one and a half minutes past four and occupies *two minutes.*

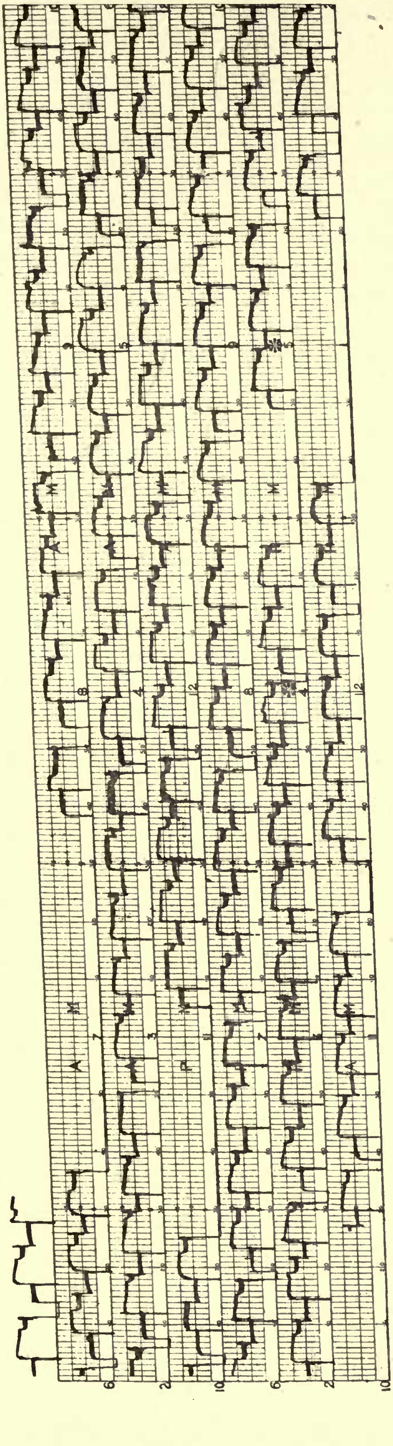


FIG. 41.—RECORD FROM THORP AND MARSH'S WATER GAS CYCLE RECORDER.

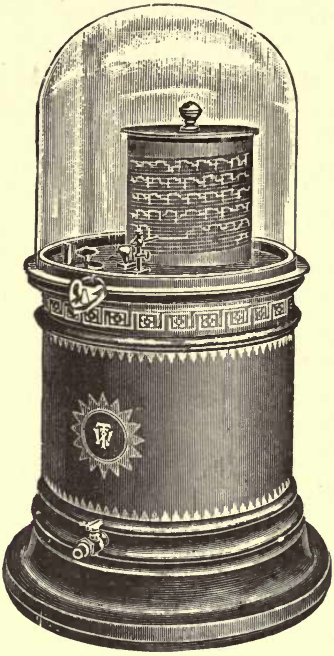


FIG. 42.—THORP AND MARSH'S WATER GAS CYCLE RECORDER.

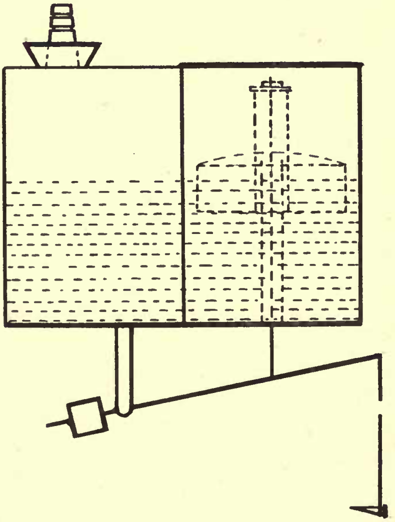


FIG. 43.—DIAGRAM OF DRAUGHT GAUGE ON SIMMANCE'S CARBON DIOXIDE RECORDER.

The blast is then turned on and, as will be seen, occupies *four minutes.* The pressure then falls to zero, denoting that the blast is shut off before the stack valve is closed. Steam and oil together are then turned on, and the pressure rises. The duration of time during which the steam and oil pass together is *six minutes*, the oil is then turned off and the steam is allowed to pass alone for a further *two minutes.* The cycle is then complete.

A slight increase of pressure is shown at four minutes past four. This is probably due to a slight explosion on the introduction of secondary air.

The period 4.26 to 4.49, during which the pressure remains at zero, represents the time occupied in clinkering.

Any stoppage in the connections is shown on the record as an unusually high pressure.

The complete instrument is shown in fig. 42.

The cycle of operations in water gas manufacture can also be recorded upon a diaphragm pressure recorder fitted with a tape chart. The drum which drives the chart is caused to revolve once every four hours, thus giving a time scale of the requisite degree of sensitiveness.

(*g*) *Draught Recorders.*—Any one of the gauges already described, which can be designed to give an extended scale for a vacuum of one or two inches of water, is suitable for use as a draught recorder for registering the draught in chimney flues. Crosley registers and sensitive aneroid gauges are, as already stated, most usually employed for this purpose.

Draught recorders are frequently combined with carbon dioxide recorders in one instrument. The following description refers to the special gauge employed in Simmance's combined CO_2 and draught recorder.

The draught recorder consists of two tanks (fig. 43), connected at the bottom and partly filled with oil, forming a U gauge. One tank is connected to the flue, the other is open to air, and has a float resting on the surface of the oil. This float is provided with a central hole and fits loosely over a central tube in the oil tank. A light chain is attached to the top of the float. It passes down the central tube and is connected to the pen lever.

DISTANCE PRESSURE RECORDERS

Distance pressure indicators and recorders are a very recent development of gas engineering practice. They are intended to provide the gas engineer with facilities for continuously observing and recording at headquarters in the works the gas pressures prevailing in various parts of the district remote from the works. They are also of utility for transmitting the pressure in various portions of the plant to the engineer's office. Two installations for transmitting pressures from a distance have been devised, the principle upon which each is operated is the same, but they vary considerably in the method whereby the operation is effected.

The principle upon which the distance pressure installations are operated depends upon the variation of a current in a closed circuit by the gradual introduction or withdrawal of resistance. This alteration of the resistance is effected by the variation in the gas pressure. The current changes in the circuit will therefore be dependent upon the variations in gas pressure, and the measuring instrument, actuated by the variable current, can be calibrated to read directly in terms of gas pressure.

The essential portions of such distance pressure installations therefore comprise :—

1. A special form of variable resistance or current regulator, which is actuated automatically by the variations in gas pressure, and which is situated at that point in the district of supply regarding which information is required.

2. A battery of primary cells, a current measuring instrument, and suitable switchgear, all of which are situated in the engineer's office, or in some other suitable position in the gasworks.

3. A loop line connecting the current regulator to the battery and measuring instrument. This line is leased from the General Post Office Engineering Department.

ARRANGEMENT OF INSTALLATION

The current regulator, current measuring instrument, and battery are connected in series through the loop line as shown in fig. 44. The current flows from the positive pole of the battery through the current measuring instrument to the automatic current regulator (situated in the district) *via* one side of the loop line. It passes through the current regulator and back to the negative pole of the battery at the works *via* the other side of the loop line.

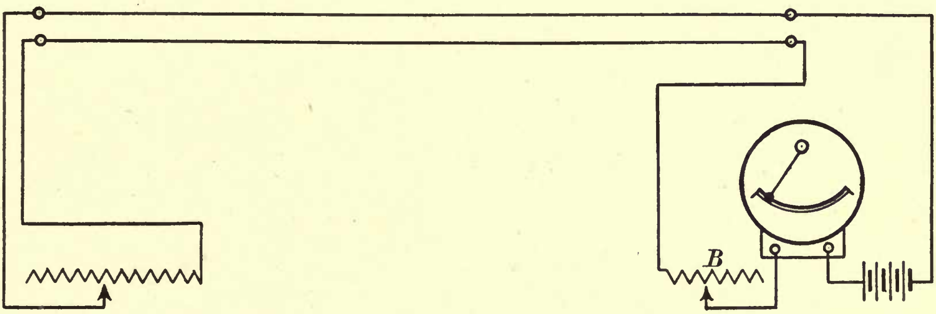


FIG. 44.—CONNECTIONS ON DISTANCE PRESSURE RECORDER.

The presence of earthed currents in districts served by tramway systems precludes the use of the installation on a single wire with an earthed return, and a loop line, as already stated, must be employed.

The current is measured on a milliampere meter, and its amount varies with the installation.

The two instruments developed for the transmission of distance pressure are :—

1. Widlake's long-distance pressure register.
2. Sinclair & Taylor's long-distance pressure recorder.

Both these appliances are operated upon the principle detailed above, but differ in the following respects :—

(*a*) The control of the voltage of the battery and the compensation for resistance variations in the circuit due to temperature.

(*b*) The nature of the current regulator actuated by the variable gas pressure.

(*c*) The Sinclair & Taylor apparatus can be made into a recording instrument for reasons given below.

WIDLAKE'S APPARATUS

1. *Arrangement for the Control of the Voltage of the Battery and for Compensation of Resistance Changes due to Temperature Variations.*—A regulating resistance of about 50–80 ohms is situated at the gasworks, and is connected in series with the remainder of the circuit. This resistance is shown diagrammatically at B (fig. 44).

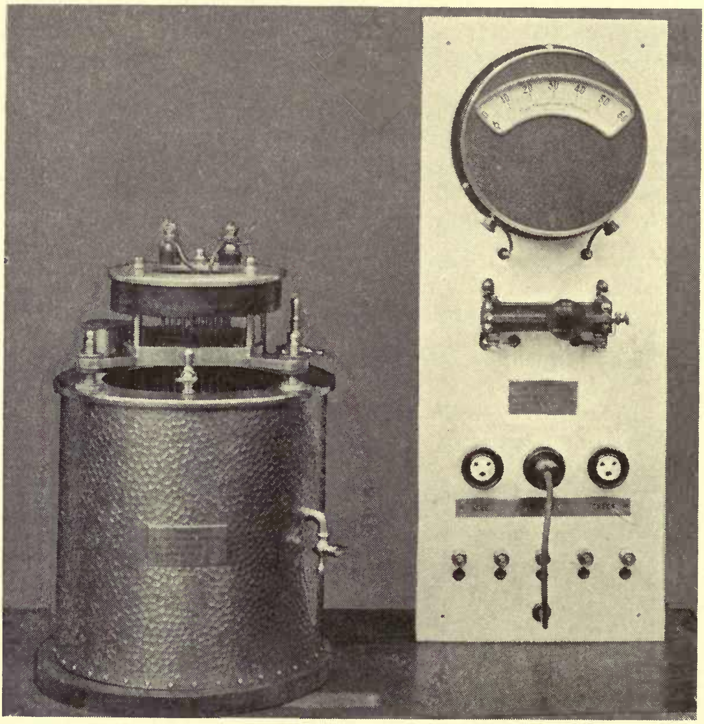


FIG. 45.—WIDLAKE'S REGULATOR.

A three position switch on the switchboard at the works is arranged so as to make the following connections :—

(*a*) A substitutional resistance is thrown into the circuit and causes the pointer to move to a certain check position on the scale of the milliammeter. If the voltage of the battery has altered or the resistance of the loop line has changed owing to temperature variations, the pointer will not move to this check position. The regulating resistance is adjusted until the pointer coincides with the check position, when the instrument will be in a condition to indicate the pressure by moving the switch to position (*b*).

(*b*) The district current regulating gauge is connected in series with the milliammeter, which thus indicates the gas pressure, and graduated to read to one-tenth of an inch water gauge.

(*c*) This connection enables the battery and meter to be employed as a leakage detector, and enables a reading to be made of any leakage current which may arise through a fault on the line. Such a reading, if ever observed, should be at once communicated to the local telephone engineer.

2. *The Current Regulator actuated by Gas Pressure Variations.* — The current regulator comprises a pressure register of the type previously described, consisting of a circular float chamber in connection with an exterior annular chamber to which the pressure is applied (see fig. 45).

The float, the position of which is determined by the water level in the inner chamber and hence by the pressure applied to the gauge, carries a special mercury container made of insulating material. The top of the tank carries a heavy cast brass spider (see fig. 46).

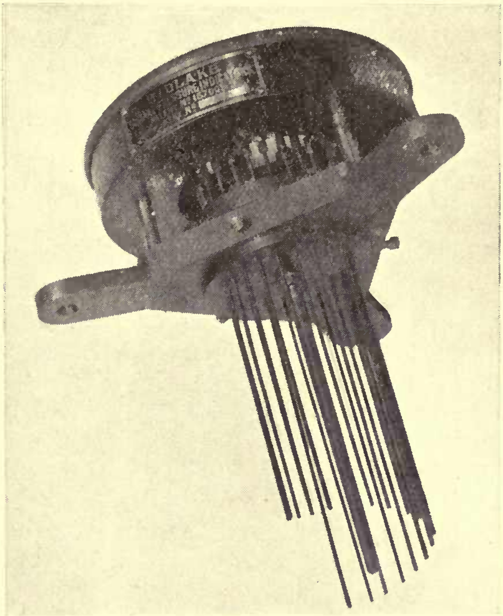


Fig. 46.—Contact Needles in Widlake's Regulator.

The spider is bored out to take a circular insulating base into which a number of contact needles, arranged in a vertical plane, are fitted. A circular ring is fitted to it for the purpose of carrying a number of resistance elements which are connected to the respective needles. The spider with the resistances and needles can be removed bodily from the gauge for inspection or cleaning. It is carried on screwed pillars which permit a very delicate vertical adjustment to be effected.

The operation of the gauge is as follows :—

Suppose the gauge is required to transmit pressures ranging from 1 inch to 6 inch water gauge. It is filled with water to the correct level and connected to the gas supply. The float carrying the mercury container rises, and when the pressure reaches 1 inch contact is effected between the two longest needles, which project downwards, and the mercury surface. The circuit is thus completed, and the current during its passage passes through all the resistances fitted to the spider. The magnitude of the current so passed, which is measured on the milliammeter, depends upon the sum of the following resistances :—

(*a*) The sum of all the resistance coils on the gauge.
(*b*) The resistance of the loop line.
(*c*) The resistance of the compensating rheostat at the works.

The total sum of these resistances is so adjusted that when the pressure is 1 inch the milliammeter, calibrated in terms of pressure, also reads 1 inch.

As the gas pressure applied to gauge is increased a third needle comes into contact with the mercury when the pressure is $\frac{12}{10}$ inch, and cuts out such an amount of resistance from the coils mounted on the gauge that the current on the circuit is increased, and the milliammeter reads $\frac{12}{10}$ inch.

In the same way every increase of gas pressure causes a corresponding increase in the amount of current flowing round the circuit.

It is of course obvious that the loop line must be installed and its resistance accurately determined before an instrument can be constructed. The actual value of the resistances employed in the gauge depends upon the resistance of the loop line.

The current required to operate the installation does not exceed about 20 milliamperes, and the voltage required will be that necessary to pass a current of this magnitude through the loop line and the regulating resistance of 80 ohms situated at the gasworks. The lower the resistance of the loop line, the less will be the voltage required to operate the instrument. The current is conveniently supplied by a battery of ordinary standard Leclanche cells.

Maintenance in Working Order

1. The nest of contact needles requires cleaning about once a fortnight, and the gauge is arranged so that the removal of the spider carrying the needles only requires about half a minute.

2. The battery cells require cleaning and recharging about every three or four months.

Sinclair & Taylor's Apparatus

1. *Arrangement for Voltage Control and for Compensation of Resistance Changes due to Temperature Variations.*—The difficulties introduced by a fluctuating battery voltage are surmounted in this apparatus by the use of a special type of Daniel cell. The construction of the cell which is employed is shown in fig. 47.

A is a glass tube cemented into the top of the bell-shaped porous pot B, containing a saturated solution of copper sulphate and a copper electrode C. DD is a thick layer of paper pulp upon which a stout circular zinc casting E is rested. This casting is immersed in a concentrated solution of zinc sulphate or in a dilute solution of sulphuric acid. The lead from the copper electrode is surrounded by a glass tube as shown in the diagram.

The number of cells required to supply the necessary current of 7–8 milliamperes through the circuit forms the battery required to operate the instrument. This special construction of Daniel cell has been known for some years and has been found to give current at a constant voltage.

The method whereby compensation is effected for variation in the resistance of the circuit due to temperature changes depends upon the special construction of the current regulator controlled by the gas pressure. The details of this compensation are therefore described in connection with the special current regulator.

2. *The Current Regulator actuated by Gas Pressure Variations.*—The current regulator comprises an ordinary portable six-inch pressure register, consisting of a float chamber A and exterior annular chamber B as already described. The float carries a movable contact, which varies the resistance in the circuit according to the position of the float, which in turn is governed by the gas pressure applied to the gauge. The details of the construction of the regulator are shown in fig. 48.

The platform C is attached to the float chamber A of the register and carries a block of insulating material D. Two glass strips EE′ are inserted in the block D. Two carbon filaments FF′ are mounted upon the edges of the glass strips. The total resistance of these filaments is about 700 ohms. The float E carries a rod H, fixed at its centre, which supports the contact levers and the guide wheels LL′ of the indicator M. The contact levers, which are shown in greater detail in fig. 49, are connected by a fine wire spiral. The levers terminate in a tubular holder containing a small graphite rod which constitutes the movable contact on the filaments FF′. A small slide guide is also fitted. This engages with the glass strips EE′ and ensures contact being made in the same place. A small adjustable weight is fitted upon the other arm of the lever. Connection to the carbon filament is made by means of two brass strips carried over the top of the float C to two terminals NN′ situated on the oblique side. The ends of the carbon filament are copper plated and soldered to the brass strips.

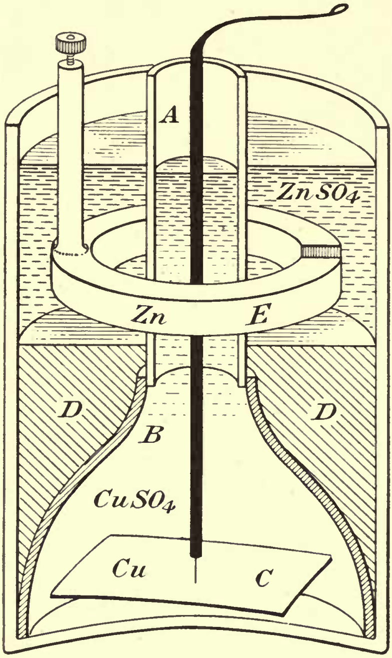


Fig. 47.—Constant Voltage Cell for Sinclair & Taylor Distance Pressure Recorder.

It will be seen that the circuit is completed by the two movable contacts which are connected together, and that the length of carbon filament included in the circuit becomes less and less as the float rises with increase of pressure.

The use of a carbon filament for the variable resistance affords a means of effecting the resistance regulation which is required owing to the effect of temperature variations upon the resistance of the circuit as a whole. The temperature coefficient of the resistance of the carbon filament is negative—*i.e.* its electrical resistance diminishes with increase of temperature. The temperature coefficient of copper, which is

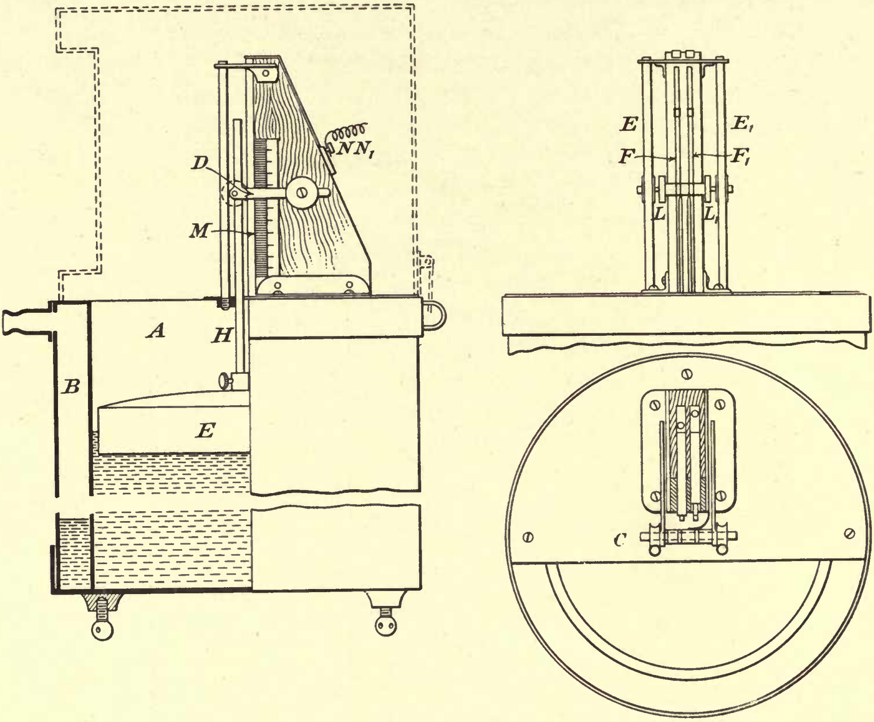
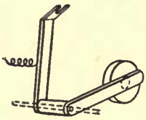


Fig. 48.—Sinclair & Taylor Regulator.

employed for the remainder of the circuit, is positive, and hence the electrical resistance of the remainder of the circuit will increase with increase of temperature. The resistance changes are thus opposed and will tend to cancel one another. The compensation can be made very close by correctly proportioning the line resistance and the average resistance of the current regulator.



Detail at D.

Fig. 49. — Contact Levers for Sinclair & Taylor's Regulator.

The operation of this compensation will perhaps be gathered most clearly by actual example :—

The transmitter is installed in a certain works and the line is composite : three-quarters of a mile is overhead and exposed, and two miles are underground. The current regulator itself is installed in a cellar. The resistance of the line is approximately 220 ohms, and the regulator resistance (carbon filament) at $\frac{40}{10}$ inch water column is approximately 300 ohms. The total variations observed over a considerable period were less than $\frac{1}{10}$ inch water gauge, whereas the temperature varied from 28° to 70° F.

Certain other advantages are derived by the use of a carbon filament as the variable resistance, viz. :—

1. A high resistance is obtained in a small space.
2. A regular gradation of resistance rather than a finite number of steps.
3. There is not any tendency towards oxidation.
4. The resistance is durable and does not wear.

The graphite contacts are not oxidizable, and rapidly wear to shape on the resistance, after which there is very little wear.

As the voltage is constant and resistance variations of the circuit are automatically compensated, the appliance can be made into a recorder by the employment of a suitable recording milliammeter in place of an indicating instrument. In this case the record is obtained by means of special devices such as the Thread Recorder described in Chapter II.

CHAPTER IV

RECORDING PYROMETERS

The accurate control of temperature is a necessity for the most efficient performance of any reaction, and this dictum applies with great force to the operations involved in gas manufacture. The temperatures which have to be controlled are both low and elevated. In the case of the former, control can only be achieved by the use of some instrument for indicating or recording temperature. In the case of elevated temperatures in which the hot body emits visible radiations, it has too frequently been the practice to rely upon eye estimations of the temperatures. It is perfectly true that a trained individual can distinguish between correct and incorrect temperatures with considerable accuracy ; but it will be readily conceded that such observations, dependent as they are upon the personal factor, cannot and should not replace reliable observations or records made by the use of suitable instruments of an adequate degree of precision.

Pyrometers, both recording and indicating, are now largely employed, and are recognised as essential to the proper performance of gasworks processes. The advantages which accrue from accurate temperature control are varied, and comprise :—

1. A general increase in the efficiency of the operation.
2. A reduction of fuel consumption by the maintenance of an adequate rather than an excessively high temperature.
3. A reduction of the time employed in the reaction for the same reason.
4. The assurance of effective control by the person in charge of the operation, due to the elimination of any uncertainty regarding the reacting temperatures.

Pyrometers for use in gasworks must of necessity be robust in construction, simple in use, and not liable to get out of order. These desiderata are preferable to the highest accuracy attainable, as the latter is, generally speaking, not necessary. A moderate degree of accuracy, coupled with a strong and simple construction, is to be preferred.

CLASSIFICATION OF PYROMETERS

Pyrometers may be classified according to the temperatures they are required to measure, but a more logical arrangement is according to their method of operation.

In accordance with the latter scheme, pyrometers, suitable for use in gasworks, may be divided into the following classes :—

(*a*) Instruments in which the increase of temperature gives rise to expansion of a liquid or gas ; this expansion resulting in an increase in the internal pressure of the thermometric system ; which increase is recorded upon a suitable pressure gauge.

(*b*) Electrical pyrometers, either :—

(1) Resistance pyrometers, actuated by the change in electrical resistance of a wire with change in temperature, or
(2) Thermo-electric pyrometers, consisting essentially of a thermo-electric circuit in which the hot junction is exposed to the temperature to be measured, and the resulting E.M.F. is measured by a suitable recording instrument.

(*c*) Pyrometers actuated by radiant energy from a body hot enough to emit visible radiation.

The effect of the radiation received by the instrument is converted into temperature measurements by :—

1. Causing expansion of a suitable device.

2. Warming a thermo-electric junction, thus producing an E.M.F., which is measured.

3. A portion of the total radiation is employed for optical matching with selected standards.

So-called optical pyrometers may at first be considered to constitute a separate classification. These instruments are, however, actuated by a portion of the radiant energy emitted (as they are only suitable for the measurement of temperatures sufficiently elevated to be associated with visible radiant energy), and it therefore appears to be more logical to consider them as a special type of radiation pyrometer.

GENERAL REMARKS UPON RECORDING PYROMETERS

Generally speaking, the essential components of a recording pyrometer comprise the following parts :—

(1) The portion containing the appliance to which heat from the hot body is imparted.
(2) The appliance to which the heat is imparted either directly or indirectly.
(3) A connecting portion which joins (2) to (4).
(4) The recording apparatus.

1. *The Portion containing the Appliance to which Heat is imparted.*—The thermometric appliance, to which heat is imparted, must be surrounded by the hot substance (the temperature of which is to be controlled) in all cases, except radiation pyrometers. The appliance must therefore be contained in a protective sheath which must be mechanically strong, and must at the same time be capable of resisting continuous exposure to high temperatures for long periods. It may also be subjected to the destructive action of molten metal or gases at a high temperature.

It is unfortunately a fact that there is no substance known which is entirely satisfactory for this purpose. Sheaths required for low-temperature instruments can readily be made, but, when the pyrometer is required for very high temperatures, troubles arise in various directions.

Sheaths which are only exposed to a comparatively low temperature, up to, say, 850° C., can be satisfactorily constructed of cast iron or welded steel. They have the advantage of cheapness and mechanical strength.

Sheaths composed of nichrome tubing (nichrome is an alloy of nickel and chromium which is unaltered by heating in air to 1000° C.) can be employed up to 1000° C., and are satisfactory with respect to their mechanical strength. In order to reduce their cost, nichrome sheaths are frequently provided with an upper portion (which is not inserted in the furnace) composed of steel.

Nichrome sheaths are apt to break down if employed in the presence of fuel containing sulphur. The chief drawbacks to their use are their comparatively high cost and the fact that they are not infrequently porous.

In the case of appliances constructed of " rare metals " (*vide infra*), it is essential that the sheath be non-porous and quite impervious to gases. As temperatures increase, all substances tend to become more and more permeable to hot gases, and difficulties are thus introduced for this reason.

Fused silica is suitable for employment for temperatures up to 1100° C., but devitrifies in certain circumstances, and becomes flaky, brittle and pervious to gases. This devitrification does not occur in air, unless the sheath has been heated up to a temperature of 1200°–1350° C., and then cooled below 300° C.

If a silica sheath be heated to a high temperature and cooled either slowly or suddenly to below 300° C., it may devitrify completely, but the devitrification always starts from the outside of the sheath.

On the other hand a silica sheath can be maintained at 1450° C. for months without devitrification. Silica tubes can be employed up to 1450° C. if they are hung vertically. There is not in this case any apparent tendency for them to draw out. Silica is plastic at about 1420° C., and if placed horizontally or approximately so, it slowly bends; but there is no tendency towards elongation in a vertical position. Many substances—especially magnesia—readily attack silica even at a moderate temperature.

Fused silica sheaths have the advantage that they withstand rapid temperature changes very well and can be constructed with very thick walls so that their mechanical strength is moderately satisfactory.

The only fairly satisfactory substance for constructing sheaths intended for very high temperature instruments, up to, say, 1400° C., is a special grade of porcelain, externally glazed. This material is, of course, rather fragile, and it cannot be subjected to rapid changes of temperature.

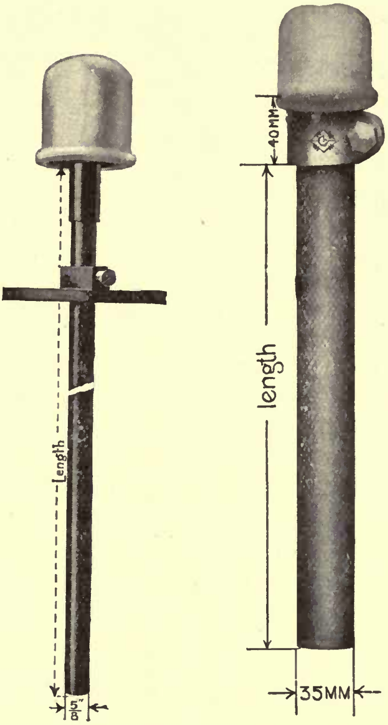
Alundum, which is a special form of fused alumina capable of withstanding very high temperatures, is unsuitable for pyrometer sheaths owing to its great porosity.

In certain cases it is sufficient to obtain measurements of relative temperatures which can thus be reproduced and serve as a temperature control for the whole process. When this can be done satisfactorily, it is possible to prolong the life of the sheath by exposing the pyrometer to some lower temperature which bears a more or less constant relationship to the very high temperature attained in the midst of the main reacting substances.

The upper portion of the sheath is usually fitted with a flange for convenience of attachment to furnace walls, etc.

Typical constructions and sheaths and flanges are shown in figs. 50 and 51.

Reputable makers of pyrometers have taken into consideration the various points in connection with the sheath material which have been discussed, and the instruments which they offer are in that respect quite suitable for the purposes and ranges for which they have been designed.



Figs. 50 and 51.—Pyrometer Sheath and Flange.

2. *The Appliance to which Heat is imparted.*—The portion of the pyrometer to which heat is imparted is (except in radiation pyrometers) contained in the protective sheath. The nature of this body or appliance differs greatly according to the class of pyrometer, and may consist of mercury, nitrogen, various descriptions of thermo-couples, etc.

In radiation pyrometers, the body to which the radiation is imparted is not surrounded by any protective sheath. The radiation is focussed by a suitable mirror upon the element, which responds to the radiation which it thus receives.

In the case of optical pyrometers, heat is not imparted to any appliance or substance, a portion of the radiation is selectively employed to give the temperature measurement.

3. *The Connecting Portion.*—The nature of the connection which unites the thermometric appliance to the recorder will, of course, depend upon the type of pyrometer. In the case of pyrometers which function by increase of internal pressure, the connection consists of metallic capillary tubing of fine bore. Electrical pyrometers are fitted with connecting leads, the nature and resistance of which are of considerable importance and are discussed in some detail below.

In the case of indicating pyrometers of the optical type, there is not of course any connecting portion; nor is this employed in the expansion pyrometer actuated by radiant energy.

4. *The Recording Apparatus.*—In the case of pyrometers which operate by the expansion of a liquid or gas, a pressure gauge is employed. This is of the Bourdon type (see Chapter III. p. 38); but the Bourdon tube is modified to suit the particular requirements, and differs somewhat from the Bourdon tubes fitted to pressure gauges.

The recorder used in thermo-electric pyrometers consists of a delicate millivoltmeter. In the case of resistance pyrometers, a delicate milliammeter is employed. The actuating force moving the suspended portion is very small, and the power would therefore be insufficient to overcome the friction of the pen on the chart.

The instruments are therefore made to record either by the Thread Recorder or the dotting method described in Chapter II.

A. INSTRUMENTS ACTUATED BY INCREASE OF INTERNAL PRESSURE DUE TO INCREASE OF TEMPERATURE

Instruments of this type are characterized by their simplicity and robustness. They will withstand rough usage and are not easily deranged.

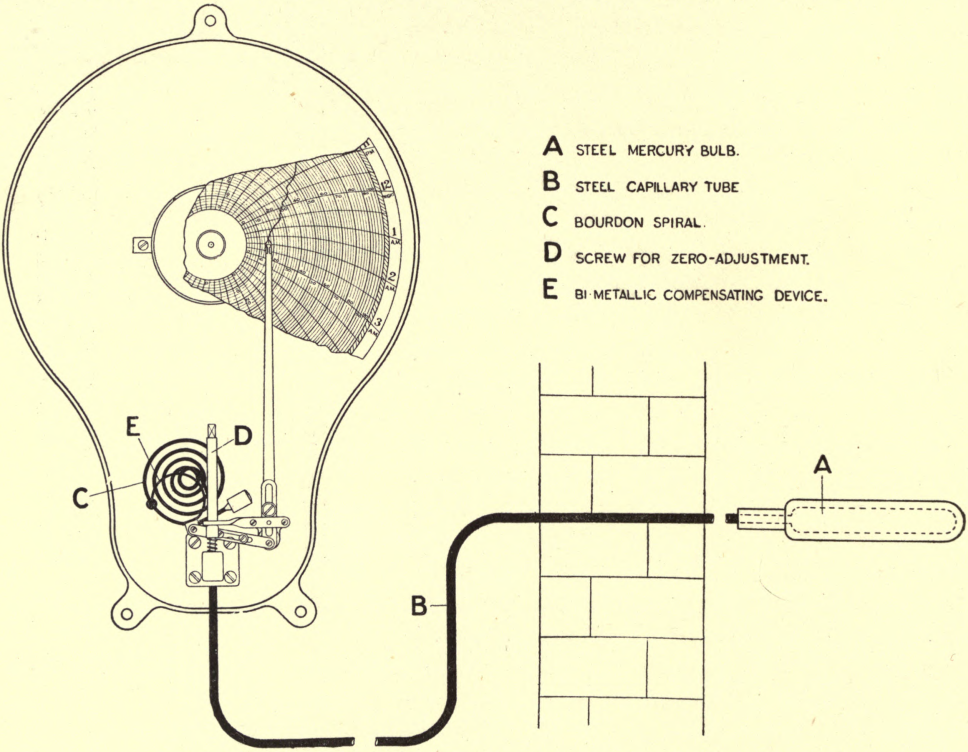


FIG. 52.—CAMBRIDGE MERCURY-IN-STEEL THERMOMETER.

Two main types of instruments are in common usage :—

1. In which mercury is employed as the expansible substance.
2. In which a gas or vapour under pressure is employed as the actuating body.

1. *Instruments containing Mercury*

Mercury boils at 360° C. under atmospheric pressure, but if it is maintained under a greater pressure its boiling point can be raised very considerably. Pyrometers containing mercury under pressure can be usefully employed to record temperatures up to about 540° C. The accuracy of the best instruments of this type is within 1·5 per cent. to 2·0 per cent. of the amount of the reading—*i.e.* within 10° C. at 500° C.

The Cambridge recording mercury pyrometer is a well-known instrument of this type. The operation of the apparatus is shown in fig. 52.

The steel bulb A forms the portion which is exposed to the temperature to be measured. It is connected by a capillary tube B to a special Bourdon spiral C. The bulb A, the tube B, and the spiral C are completely filled with mercury under pressure. The capillary tube is composed of steel and is $\frac{3}{16}$ inch external diameter and $\frac{1}{50}$ inch bore. A steel wire $\frac{1}{64}$ inch diameter is inserted through the whole length of the bore of the tube, thus nearly filling it. The expansion or contraction of the mercury in the bulb is thus transmitted to the spiral C by the merest film of mercury. The walls of the spiral C are within $\frac{1}{100}$ inch, and thus the total amount of mercury in the connecting capillary and spiral is always negligible compared to the amount in the bulb A.

The expansion or contraction of the mercury causes small movements of the Bourdon spiral C, which are magnified by the system of levers shown in the illustration.

Compensation for the effect of temperature changes in the atmosphere upon the capillary B and the spiral C is effected by the use of a bimetallic expansion strip included in the magnifying mechanism. This bimetallic strip straightens out as its temperature rises, and acts as a brake on the movements of the spiral C in such a way that the record is independent of the temperature of the latter.

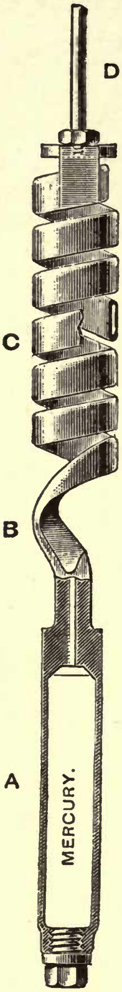


Fig. 53.
Steinle
Pyrometer
Coil.

Barometric changes are practically without effect upon the pyrometer.

The Steinle pyrometer is a somewhat differently arranged instrument of the same type. The recording or indicating portion of the instrument is of necessity fairly near to the bulb, owing to the design of the instrument.

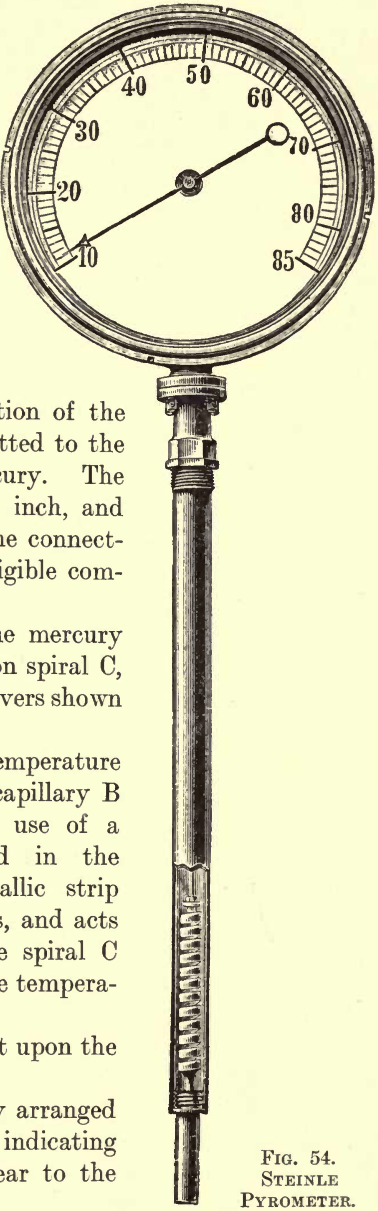


Fig. 54.
Steinle
Pyrometer.

The pyrometer bulb A (fig. 53) is composed of a strong mild-steel cylinder, closed at one end and tapered at the other to a very fine bore, which connects the bulb with steel spiral spring C. The latter is made from a solid-drawn steel tube with thin walls, which is rolled flat until the sides are within $\frac{1}{100}$ inch. The bulb and spiral spring are completely filled with mercury and the upper end of the spring is sealed. The expansion of the mercury, owing to the rise in temperature, causes the spring partly to uncoil, and *vice versa.* This rotary motion is magnified and transferred by suitable gearing to the indicating pointer or recording pen.

The flattened tube is usually about 21 inches long before coiling, and the coil is usually composed of nine turns.

A complete instrument is shown in fig. 54.

2. *Instruments containing Gas under Pressure*

These instruments are very similar to the mercury-in-steel pyrometers, and differ from the latter by the replacement of mercury as the expansible substance by a gas under pressure. The apparatus usually consists of a steel thermometer bulb, steel capillary tubing, and a steel Bourdon spiral, all of which are filled with gas under pressure. The use of a gas under considerable pressure enables a uniformly divided scale to be constructed by the use of suitable magnifying mechanism.

The magnifying mechanism in Simmance's distance pyrometer is exactly the same as that shown in fig. 32.

The weight W carried on the bent arm has an increased effect towards the upper limits of the scale, and by its increasing moment compensates for the compression of the upper limits which would otherwise occur.

Simmance's pyrometer is filled with nitrogen under pressure. In the low range instruments up to 400° F., the bulb, which is 2 inches in diameter and $6\frac{1}{2}$ inches long, is filled to a pressure of 50 lbs. to the square inch. High range instruments for temperatures up to 1000° F. are filled to a pressure of 150 lbs. to the square inch. The bulb in this case is $1\frac{1}{4}$ inch in diameter and $6\frac{1}{2}$ inches long.

Fig. 55 shows a recording pyrometer of this type.

The Cambridge ether-filled thermometer is an example of a different instrument of this class. The bulb of the thermometer contains liquid ether and is connected by capillary tubing to a Bourdon spiral. Changes in the temperature of the bulb cause changes in the vapour pressure, thus giving rise to movements of the spiral. These movements are communicated to a pointer moving over a dial graduated in degrees of temperature.

These instruments are only suitable for low temperature readings not exceeding 400° F.

Use of Mercury and Gas-filled Recording Pyrometers.—The instruments described above are usually constructed with standard lengths of capillary tubing, but if required for other lengths, the scales can be calibrated specially. This procedure does not, however, present any advantage, as there is no drawback to having a greater length of capillary tubing than is actually required.

Instruments of this type are not usually fitted with more than 40 feet of capillary tubing as a maximum. When the instrument is installed, care should be taken not to kink the capillary tube, and a change of direction should be arranged so as to avoid kinking the tube round any sharp corner.

It is sometimes necessary to employ mercury and gas pyrometers for measuring the temperatures of substances which would attack the steel bulb. Provided the temperature to be measured does not exceed about 300° C., satisfactory protection to the bulb can often be afforded by covering with lead.

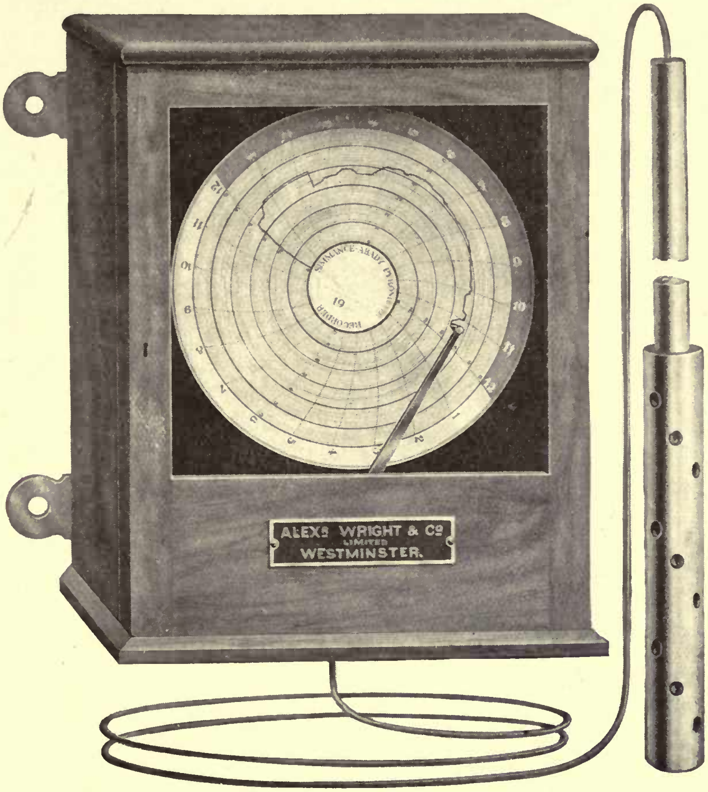


FIG. 55.—SIMMANCE PYROMETER.

B. ELECTRICAL PYROMETERS

1. *Resistance Pyrometers*

The electrical resistance of a pure metallic wire increases almost in direct proportion to the rise in its temperature, and consequently this property can be employed for the measurement of temperatures. The first resistance thermometer was constructed by Siemens, and consisted of a platinum wire wound round a fireclay cylinder, the whole arrangement being protected by an iron tube. It was found, however, that after exposure to high temperature, the resistance of the wire did not return to its original value. The platinum wire was attacked—probably by the silica in the fireclay—and its properties were therefore altered.

The question was taken up by Callendar, who showed that if a coil of pure annealed platinum wire were wound upon a mica framework and carefully protected from the action of hot gases, the temperature as deduced from the resistance of the wire was usually accurate to within $\frac{1}{100}^\circ$ C. This degree of accuracy is attainable for temperatures up to 500° C., and temperatures up to 1200° C. can be determined with a probable error of little more than $\frac{1}{10}^\circ$ C.

Measurements of anything like this degree of precision are of course not required in gasworks practice, and for this purpose attention is given rather to the production of as robust and simple an instrument as possible.

Callendar and Griffiths found that if R_o is the resistance of a piece of pure platinum at 0° C., then the resistance at t° C. is expressed by the equation

$$R_t = R_o (1 + at + bt^2).$$

This is an equation including three constants R_o, a, and b, the value of these constants can be calculated if the resistance of the coil at any three temperatures, not too close together, is known. Convenient temperatures for this purpose are afforded by the freezing and boiling points of water. The freezing point of pure tin affords a convenient standard for the determination of the third point.

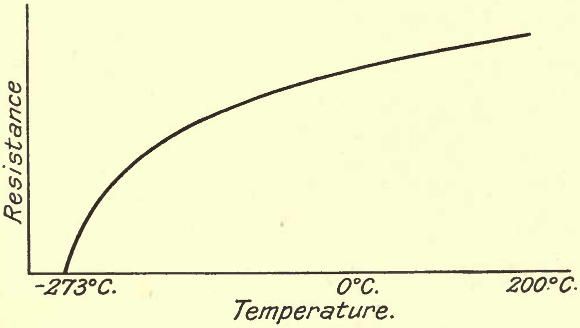


Fig. 56.—Variation of the Resistance of Pure Platinum with Temperature.

Dewar and Fleming have shown that the electrical resistances of pure metals, including platinum, decrease as absolute zero (—273° C.) is approached, thus leading to the conclusion that at —273° C. the resistance of a pure metal will be zero. This value, together with the observations of the resistance at the freezing and boiling points of water, is sufficient to enable the calibration to be carried out with sufficient accuracy for all ordinary purposes.

In this connection Callendar showed that more accurate results were obtained if the assumption were made that the electrical resistance of platinum became zero at —240° C.

The variation of the resistance of pure platinum wire with the temperature is shown in fig. 56.

The measurement of electrical resistances is an operation which can be performed with great exactitude, and this is one reason why the measurement of temperature by means of a platinum resistance thermometer can, if required, be made with very great accuracy.

The resistance of the thermometer may be measured by a Wheatstone bridge arrangement. The thermometer and its leads are made to form one arm of a Wheatstone bridge, see fig. 57; the other three arms r_1, r_2, r_3 being made of a material such as manganin, the resistance of which does not change with the temperature.

Current is supplied to the bridge by an accumulator. It is well known that if the resistances of the three coils and of the thermometer r_1, r_2, r_3, r_4 are such that $\frac{r_1}{r_2} = \frac{r_3}{r_4}$, there will not be any flow of current through the galvanometer (connected as shown), which serves for the temperature indicator or recorder.

The most accurate method of employing resistance thermometers is the "Null" method, in which the slide wire resistance is adjusted so that there is not any flow of current through the galvanometer, and the position of the contact on the slide wire is calibrated to read correctly in terms of temperature. This method also has the advantage of being unaffected by variations in the voltage of the battery.

The ratio coils r_1 and r_2 are adjusted to equality, and their resistance is adjusted to approximately the mean resistance of the pyrometer.

Temperature effects upon the leads connecting the pyrometer to the bridge would introduce errors unless compensated. The necessary correction is effected automatically by the use of compensating leads.

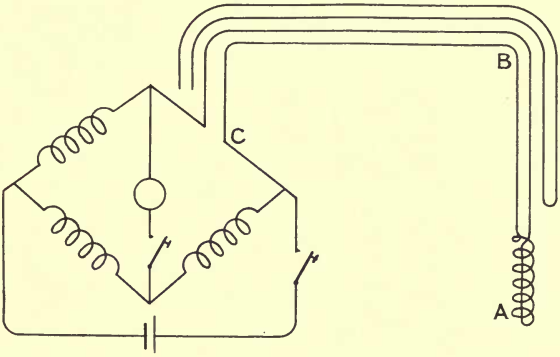


Fig. 57.—Diagram of the Wheatstone Bridge.

These are exactly the same as the thermometer leads and are mounted in the same protective covering as the latter throughout the whole of their length. They are connected to the opposite side of the bridge, and any change in the resistance of the leads will affect each side of the bridge equally, and its balance will be unaffected, as r_1 and r_2 are the same.

The resistance of the pyrometer and its leads is balanced by that of the compensating leads, the variable resistance coils and bridge wire on the other side.

The balancing of the bridge and the consequent deduction of the temperature is effected automatically in the Callendar recording pyrometer. The pen arm A is carried by a movable contact B, which slides to and fro on the bridge wire CC_1. (See fig. 58.)

This sliding contact tends always to move to such a position as will restore the balance of the bridge. This is effected in the following manner. The movement of the sliding contact, which carried the pen arm, is automatically effected by electro-magnets DD_1, which are brought into play by means of the current flowing through the galvanometer G connected between the arms of the Wheatstone bridge.

When the bridge is balanced, and hence current is not flowing through the galvanometer, the coil remains undeflected, but in the passage of a current, owing to the unbalancing of the bridge, the coil is deflected. The moving coil of the galvanometer carries two insulated wires EE_1 which make contact on one side or the other of a small platinum-rimmed wheel F (rotated by clockwork) according to the direction of the deflection of the moving coil. When contact is made, current is passed through one or the other of two electro-magnets. Each of these magnets is mounted on a clock, the movement of which is prevented by a brake controlled by the magnet. When the current passes through a magnet the brake is lifted, thus allowing the clockwork to revolve. The clocks drive a differential gear and cord attachment, by means of which the slider of the bridge " wire " is pulled in one direction or another, depending upon which brake is lifted. As already stated, the motion of the slider tends to restore the balance, and its movements are recorded by the pen on a chart scaled to read directly in temperatures. The total range across the chart, which is about eight inches wide, may be made equal to 5°, 50°, 100° C., or to other range by varying the resistance of the bridge " wire " or of the resistance pyrometer. The instrument is therefore suitable for delicate research work, or for temperature control in a gasworks.

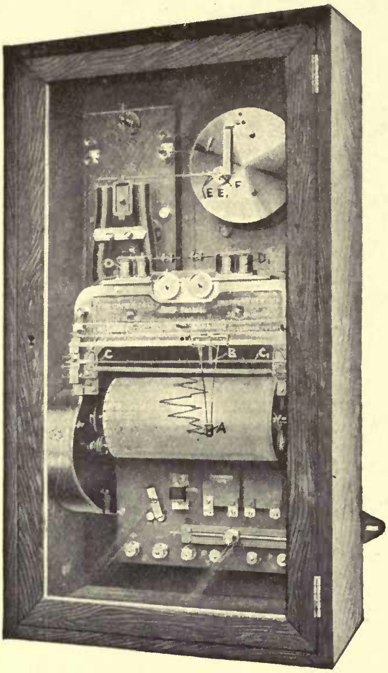


FIG. 58.—CALLENDAR RECORDING PYROMETER.

The degree of accuracy attainable with the Callendar recorder is not necessary in many cases, and the temperature of the resistance pyrometer bulb can be deduced with adequate accuracy by a deflexional method rather than a null method. According to this method of working the values of the resistance coils and of the resistance pyrometer are chosen so that the relationship $\frac{r_1}{r_2} = \frac{r_3}{r_4}$ is fulfilled at the commencing temperature of the range covered by the instrument. Any alteration in the resistance of the platinum pyrometer (due of course to change in temperature) will cause a corresponding current to flow through the galvanometer, the deflexion produced being recorded on a chart scaled to read directly in temperatures.

The instruments employed for recording the current produced in the deflexional method of employing resistance thermometers are usually moving coil galvanometers fitted with a zero adjustment. The record on the instrument will not be correct unless the voltage of the battery employed is constant, and in order to ensure that the instrument is correctly adjusted, it is usual to provide a fixed resistance of known value. A plug switch is provided whereby this fixed resistance is inserted into the arm r_4 in place of the pyrometer. This should cause the pen arm to move to a definite position on the chart. If it does not reach this position, the instrument is adjusted by means of the variable resistance provided, until the correct deflexion is obtained.

The galvanometer in the Cambridge instruments makes the visible record by means of the Thread Recorder device described in Chapter II. The complete recorder is shown in fig. 59. The Wheatstone bridge resistance coils are contained in a box forming part of the recorder case.

These Thread Recorders are sometimes fitted with a double thread frame, in which two threads of different colours are employed, and a rocking mechanism brings these threads alternately under the galvanometer pointer. The mechanism is caused to switch in successively two different thermometers, and the galvanometer thus traces two independent and differently coloured records on the same chart.

Double thread recorders are also constructed with two independent galvanometers which record side by side on the same chart, which is double the usual width. If the two-colour mechanism be added to this recorder it can be arranged to give four different records on the one chart. A recorder of this type is shown in fig. 60.

The apparatus is operated by a two- or four-volt accumulator of about 30 ampere-hour capacity. The consumption of energy is very small, hence the voltage fluctuations occur slowly, and the recorder only requires adjustment for this variation at intervals—say, when a chart is changed.

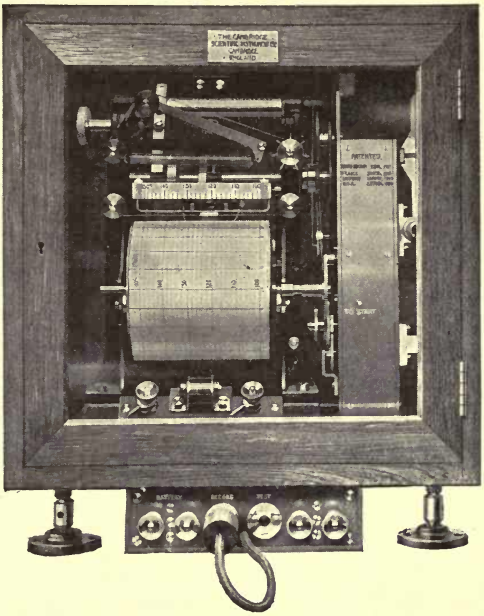


FIG. 59.—THREAD RECORDER.

The deflexional method of employing resistance pyrometers is suitable for gasworks practice, as the instruments are very robust and do not easily get out of order. The scale obtained is much more compressed than is the case of the null method. The deflexional method is largely employed for multiple-point distant outfits (*vide infra*).

The current employed for the operation of the resistance pyrometers must of necessity be very small. If too large a current be used, heat effects will be produced by the current itself and will cause the recorded temperatures to be too high. The limiting value of the current is about 0·01 ampere for 0·01 degree with platinum wire 0·15 mm. in diameter.

Construction of Platinum Resistance Pyrometers.—Platinum resistance pyrometers, as used with the Callendar recorder, are usually constructed by winding the wire on two strips of mica set crosswise and provided with serrated edges in which the platinum wire engages. The ends of the platinum winding, which is composed of fine wire about 0·2 mm. diameter, are fused to stout platinum or silver leads connected to terminals situated in the head of the mounting.

Pyrometers constructed in this manner can be employed up to 900° C. for continuous working or for occasional tests in the laboratory up to 1200° C., but at greater temperatures the mica framework disintegrates. Various types of mountings are employed for these pyrometers. Three types constructed for the Cambridge resistance pyrometers are shown in figs. 62, 63, and 64.

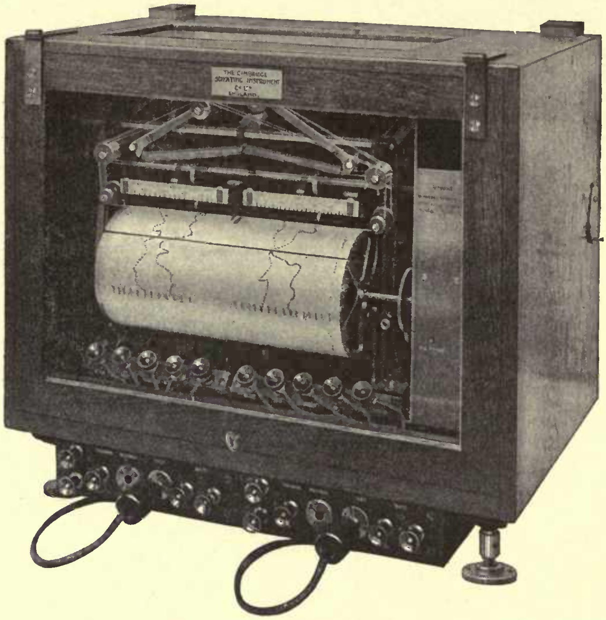


Fig. 60.—Double Thread Recorder.

In the mounting shown in fig. 62 the pyrometer "bulb" is protected by a porcelain or silica tube with an outer removable steel sheath. The terminals are enclosed in an aluminium head provided with a cover, and are therefore completely protected. A suspension device is also provided as shown.

The mounting illustrated in fig. 63 is similar to arrangement described, but the pyrometer head is composed of porcelain fitted with ordinary exposed terminals.

The mounting shown in fig. 64 is of a rather more complicated pattern, and is suitable for accurate determination of the temperature in hot blasts and the like. It is provided with a pair of compensating leads which are contained in the same protective flexible copper tubing as the pyrometer leads. These armoured leads are connected to a junction box and leads are continued from this box by flexible cord or lead covered cable.

Platinum resistance pyrometers constructed in the manner just described are rather fragile, and for industrial purposes where a lower degree of accuracy is sufficient, attention has been directed towards the production of a more robust instrument.

In the Cambridge resistance pyrometers the platinum wire is wound upon a thread moulded into the periphery of a small porcelain cylinder, the whole arrangement being covered by a protective glaze. The resistance of the platinum coil is high, and this construction dispenses with the necessity for compensating leads for ordinary work.

The porcelain cylinder and winding is shown in fig. 61.

Resistance pyrometers are particularly suitable for comparatively low-temperature measurements up to say 500° C. The Cambridge type of bulb cannot be employed above this temperature owing to the melting of the protective glaze.

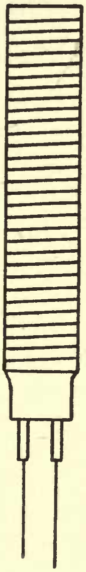


Fig. 61.—Bulb of Platinum Resistance Thermometer.

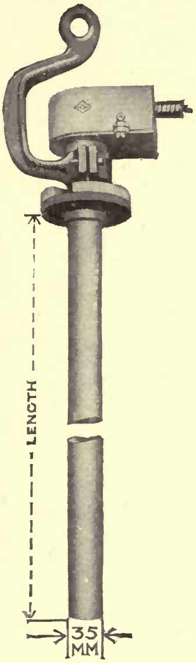


Fig. 62.—Pyrometer Mounting, with Aluminium Head.

Fig. 63.—Pyrometer Mounting, with Exposed Terminals.

A more open scale is obtained at the lower ranges than with thermo-electric pyrometers (*vide infra*), owing to the small E.M.F. generated by the latter at low temperatures. Thermo-electric pyrometers are to be preferred for the measurement of higher temperatures for industrial purposes.

Multiple-point Distance Outfits.—Resistance pyrometers are largely used for multiple-point outfits. In such an arrangement a number of pyrometers are installed in various positions on the plant, and any one or more can be connected to indicating or recording instruments by means of a suitably arranged plug switchboard.

If, for example, it is desired to have any two of, say, ten pyrometers connected to a double recorder, ten sockets are provided on the switchboard and two plugs. These two plugs can be inserted in any two of the ten sockets, thereby connecting the two corresponding pyrometers to the recorder.

A combined indicating and recording outfit is frequently desirable. In this case an extra plug is fitted to the indicator switchboard for each recorder point. A record can be obtained from any of the pyrometers by inserting one of the recorder plugs into the corresponding pyrometer socket on the switchboard. At the same time a reading can be obtained on the indicating instrument corresponding to any of the pyrometers which are not connected up to the recording instrument.

An example of an outfit of this description actually employed in a gasworks is afforded by a 50-point installation, comprising an indicating instrument on a switchboard fitted with fifty plug switches. Four extra plugs were fitted for connecting any four of the thermometers to a 4-point recorder.

The outfit was employed to indicate or record the temperatures of the large meters, inlets and outlets of the condensers, water cooler, air cooler, washer, scrubbers, exhausts, inlets and outlets of the purifiers, and inlets to the gas-holders.

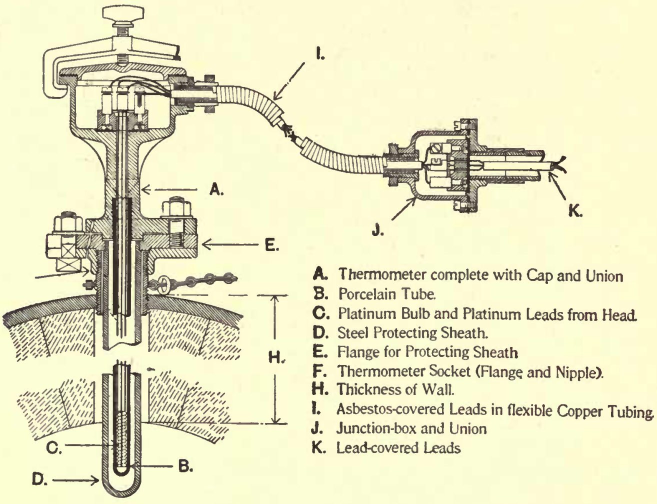


FIG. 64.—PYROMETER MOUNTING, FOR HOT BLAST.

Wiring of Multiple-points Outfits.—When an indicator or recorder is employed with a number of pyrometers, a separate lead is connected to each pyrometer, and a return wire common to all is brought back to the indicator or recorder. In the case of combined indicating and recording outfits, a separate return is brought back from each pyrometer to the indicator and a common return wire from the indicator to the recorder. In order that errors may not be introduced owing to differences in the lead resistances of the various pyrometers, it is arranged that the wiring circuit of each pyrometer shall have a definite resistance, for which purpose a balancing resistance is employed, thus enabling each circuit to be adjusted to the same value.

Test coils are employed for putting into the circuit at the end of the leads in place of the pyrometer, and serve to enable the various circuits to be balanced up accurately. The test coils are marked with a certain temperature, and when the indicator or recorder is in proper adjustment—that is to say, reading correctly on the " off " and " test " points—then the resistance of the leads should be adjusted so that the recorder reads accurately the temperature marked on the test coil when the latter is switched on the circuit.

Precautions to be observed in using Resistance Pyrometers.—(1) The records obtained are dependent solely upon the resistance of the pyrometer circuits. It is therefore essential that all electrical connections are thoroughly made.

(2) The various pyrometer circuits must be carefully adjusted by test coils, until their resistances are all equal to the same standard amount.

(3) Occasional tests must be carried out with the test resistance and the instrument adjusted to compensate for voltage fluctuations. This operation is best carried out when changing charts, provided that the latter are changed at least once a week.

(4) The accumulator cell employed should not be used immediately after charging. An interval of one or two hours should be allowed to elapse, which is required in order that the cells may attain a steady voltage.

(5) Plugs should not be inserted in sockets to which pyrometers are not connected up. This causes a violent deflexion which may injure the galvanometer.

(6) In cases where the measurements made are by the null method, it is only necessary to ensure that the pyrometer and leads are in good condition. The readings are, as stated above, independent of voltage fluctuations.

(7) Electrical recording instruments of the type required for electrical pyrometers are necessarily of a delicate nature; the moving portions in particular being very light and delicately supported. It is therefore important to ensure that the case is kept as free from dust and dirt of every description as possible.

2. *Thermo-electric Pyrometers*

If two wires composed of dissimilar metals or alloys are joined together at their ends, and if one of the junctions be heated, an electromotive force is set up which gives rise to a current in the circuit. The magnitude of the current and its direction depends upon the nature of the metals employed and upon the temperatures of the "hot" and "cold" junctions respectively.

If, therefore, a suitable galvanometer is introduced into the circuit, it is possible to determine the temperature of the hot junction from the deflection of the galvanometer.

This is the basic principle employed in temperature measurements by thermo-electric pyrometers. A simple thermo-electric circuit of this nature is shown diagrammatically in fig. 65.

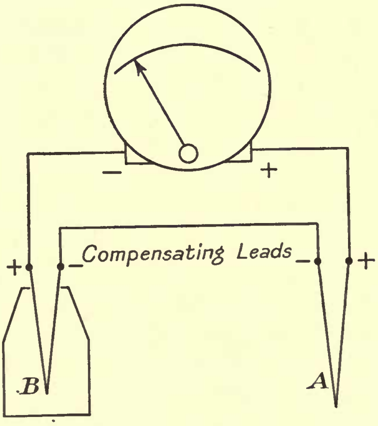


Fig. 65.—Simple Thermo-electric Circuit.

Although the principle enunciated above holds good generally for all metals, it does not follow that any pairs of metals formed into a thermocouple are suitable for temperature measurements. Generally speaking, a number of disturbing factors may be introduced which would render temperature measurements, based upon observations of the electromotive forces which are set up, entirely nugatory.

The most serious of these disturbing factors are :—

(*a*) *Thermo-electric Inversion.*—Suppose for the sake of example that the couple is composed of copper and iron wire. If the hot junction is maintained at 100° C. and the cold junction at 0° C., the current flows from the copper to the iron across the hot junction. If, however, the mean temperature of the hot and cold junctions is raised 30° C. there is not any flow of current in the circuit ; whilst if the mean temperature of the hot and cold junctions is raised still further, the current flows round the circuit in the reverse direction. This phenomenon is known as thermo-electric inversion and is exhibited by most pairs of pure metals. It is quite obvious that such a couple would be valueless for temperature measurements over any extended range. The phenomenon is not exhibited as a general rule in couples composed of a pure metal and an alloy of this metal with another metal of similar properties.

(*b*) *The Production of Parasitic Currents.*—Wires composed of certain metals, for example iron and palladium and their alloys, are not suitable for use for thermo-electric measurements, because when heated locally at various points parasitic currents are set up which are sometimes relatively intense. The cause of these currents is to be sought in a physical heterogeneity due to the heating. Different allotropic modifications are produced and may remain on cooling.

Platinum and its alloys with iridium and rhodium are free from these faults.

(*c*) *Errors due to Annealing.*—When a wire is heated at the point of junction of a hardened and an annealed portion, a current is developed the strength of which varies with the nature of the wire and the degree of hardness. Twisting suffices to produce this hardening effect.

(*d*) *The Presence of Traces of Impurities.*—The anomalous and irregular behaviour of certain couples was traced by the early workers on this subject to the presence of small quantities of impurities in the metals employed. These have a very disturbing effect, and in the case of base metal couples (*q.v.*) their constancy with continued use is affected very prejudicially.

Thermo-couples for industrial pyrometry must conform as nearly as possible to certain requirements, amongst which may be mentioned :—

1. Infusibility at the highest temperature to which the couple is exposed.
2. The generation of a relatively great electromotive force for a given temperature difference.
3. The couple should be easily reproducible when renewals are required.
4. The tendency towards the production of physical changes—*e.g.* production of allotropic modification or development of a crystalline structure should be very slight and, if possible, these changes should not develop even on prolonged heating.

As a result of a large amount of research work by a variety of workers, a number of different combinations have been developed which are suitable for the construction of thermo-couples for pyrometry.

The first satisfactory couple was due to Le Chatelier, and was composed of platinum and platinum alloyed with 10 per cent. of rhodium. Formerly platinum and platinum alloyed with iridium were employed, but this couple has been superseded by the Pt—Pt 10 per cent. Rd couple.

Effect of Heat and Chemical Action upon Metals of the Platinum Group.—The effect of continued heating upon the rare metals employed in resistance and thermo-electric pyrometers is prejudicial. Platinum and its alloys become brittle after prolonged heating at temperatures above 1000° C.—the effect being probably due to crystallization. Platinum-iridium alloy changes much more rapidly than platinum-rhodium. The effect is, however, slow in an ordinary atmosphere.

If platinum or its alloys be heated to a high temperature in a reducing atmosphere, they are readily attacked by any traces of metallic vapours or metalloid vapours, such as silicon, which may be present. Such vapours cannot exist in an ordinary atmosphere. The importance therefore of the protection of a rare metal resistance wire or thermo-couple by a non-porous sheath, as already mentioned, is obvious.

Couples composed of metals of the platinum group are generally known as " rare " metal thermo-couples, and are practically the only ones which can be employed for temperature measurements greater than 1000° C. Their high cost has led to the introduction of so-called " base " metal couples made of comparatively inexpensive wires. Certain of these are very largely employed in the construction of thermo-electric pyrometers for industrial purposes, suitable for all temperatures up to 1000° C.

The following table gives the electromotive forces developed by various thermo-couples, some of which are in general use for industrial pyrometry. The temperature of the cold junction is 0° C., and that of the hot junction 500° C.

Thermo-couple.	Approximate E.M.F. in Millivolts.
Platinum—platinum 10 per cent. rhodium	4·4
Platinum—platinum 10 per cent. iridium	7·4
Iron —nickel	12·0
Nickel —nickel 10 per cent. chromium (Hoskin's couple)	21·0
Iron —constantan (60 per cent. copper, 40 per cent. nickel)	26·7
Silver —constantan	27·6
Copper —constantan	27·8

The relationship between the temperature and the E.M.F. produced by a platinum—platinum 10 per cent. rhodium, and some other couples, when the cold junction is maintained at 0° C., is given by Holman's empirical formula

$$\log_{10}E = A \log_{10} T + B,$$

where E = E.M.F. generated in microvolts.

T = Temperature of the hot junction in degrees centigrade.

A and B are constants depending upon the wires employed.

The following are the values of A and B for certain couples :—

Couple.	A.	B.
Platinum—platinum 10 per cent. rhodium	1·19	0·52
Platinum—platinum 10 per cent. iridium	1·10	0·89
Silver —constantan	1·14	1·34

The following are the thermo-couples usually employed in the construction of industrial pyrometers suitable for the ranges indicated :—

Couple.	Range.
Platinum—platinum rhodium	0–1400° C.
Platinum—platinum iridium	0–1000° C.
Nickel —nickel chromium	0–1000° C.
Iron —constantan	0– 800° C.
Silver —constantan	0– 800° C.
Copper —constantan	0– 500° C.

The Cambridge "Titan" couple is constructed of iron-constantan and is protected by silica. It is suitable for use up to 1200° C.

Quite apart from the question of cost, the use of base metal couples is accompanied by several advantages not displayed by the rare metal couples. Owing to the relatively low cost of the base metals, the cross-section of the thermo-couple can be made very much larger than in the case of rare metal couples. This is very advantageous, as it means increased mechanical strength and reduced electrical resistance. Furthermore, the change of resistance with change of temperature is much less than in the case of rare metal couples, and hence the resistance of the millivoltmeter (or the compensating resistance) (*vide infra*) can be greatly reduced. The electromotive force generated is over four times as great as in the case of the platinum—platinum rhodium couple. The net result of these factors is that a total resistance of, say, 10 ohms is adequate in the case of base metal couples, whilst in the case of rare metal couples 100 ohms would be required for the same degree of accuracy. Hence, as the electromotive force generated is four times as great, the current flowing through the circuit for the same temperature will be about forty times as great in the case of the base metal couple. For this reason the construction of a millivoltmeter for use with these couples is much cheaper and more simple.

The relative advantages and disadvantages of base metal and rare metal couples may be summarized as follows :—

Base Metal.

1. Low cost of couple and low cost of renewals.
2. Strength of construction.
3. No necessity for special compensating leads (*vide infra*).
4. Low total resistance of circuit due to (*a*) low temperature coefficient ; (*b*) use of heavily constructed couples.
5. Low cost and robust type of millivoltmeter.

Rare Metal.

1. Can be employed for temperatures much higher than those which can be measured by base metal couples.
2. At temperatures up to 1000° the E.M.F. generated keeps constant for longer than in the case of base metal couples, and replacements are required less frequently.
3. Errors due to heat conduction along the pyrometer do not arise. This is a source of error occurring with heavy base metal couples which has to be corrected for by calibration.

Constancy of the Cold Junction.—Thermo-electric pyrometers are constructed and calibrated upon the assumption that the temperature of the cold junction is maintained at some constant value, usually 0° C. The value of the electromotive force generated depends upon the difference in temperature between the hot and cold junctions of the circuit, and it is therefore obvious that the temperature at the cold end must be known before the temperature of the hot junction can be determined.

Various methods are employed for maintaining the temperature of the cold junction constant, amongst which the following may be mentioned :—

(*a*) The cold junction is immersed in melting ice. This is the course adopted by the makers when calibrating the instruments. It is also universally adopted for research and other work in which a very high degree of accuracy is required.

(*b*) The cold junction is buried several feet in the earth. It is a matter of general knowledge that the earth temperatures prevailing at depths of 10 to 12 feet below the surface are subject to comparatively small fluctuations in their values taken over a period of a whole year. For this reason it was proposed as long ago as 1903 to bury the cold junction of the couple as a means of maintaining its temperature practically constant. The proposal is considered in some detail in a paper by Whipple (*Trans. Faraday Soc.*, vol. xiii., 1918), who gives the following temperature observations made upon a buried junction. The latter was contained in a glass tube and buried 10 feet underground underneath the floor of a building. The other junction was maintained at 0° C., and the electromotive force generated at intervals was carefully measured. The extreme range of temperature of the buried junction, as deduced from these observations, are appended :—

Period.	Max. Temp.	Min. Temp.	Range.
July 1911–June 1912 .	13·80	11·89	1·91
July 1912–June 1913 .	12·95	11·46	1·49
July 1913–June 1914 .	13·35	11·97	1·38
		Mean .	. 1·59

Further observations made showed that the temperature fluctuations are considerably less when the junction is buried under the floor of a building rather than in the open.

(*c*) The cold junction is immersed in a vacuum flask containing oil. It has been found in practice that, whereas the temperature of the surrounding air may change by 20° C. in twenty-four hours, that of the interior of the flask remains constant to within 1° C.

The arrangement is shown diagrammatically in fig. 66.

(*d*) In industrial pyrometry it may be assumed that the indicator or recorder to which the couple is connected is situated in a position free from considerable variations in temperature and not abnormally heated. The hot junction of the thermocouple is connected by suitable leads (see below) to the recorder, the temperature of which is taken as that of the cold junction. The temperature of the latter is therefore variable, but the amount of error thus introduced is on the average of no moment for many industrial purposes. This arrangement is usually adopted with base metal couples.

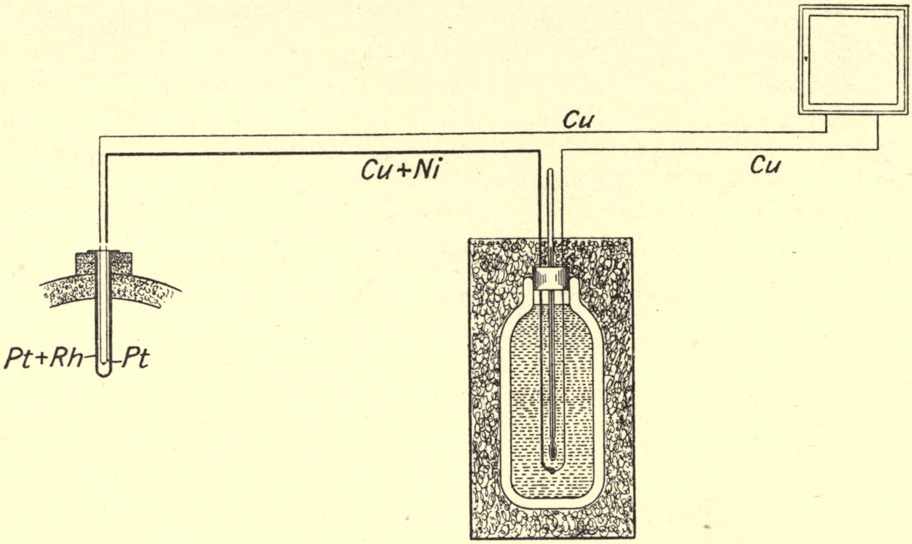


Fig. 66.—Vacuum Flask Arrangement for Cold Junction.

(*e*) The temperature of the cold junction is maintained constant by insertion in an electrically controlled thermostat. This method is occasionally adopted, and an electrical thermostat suitable for this purpose is described in Appendix II.

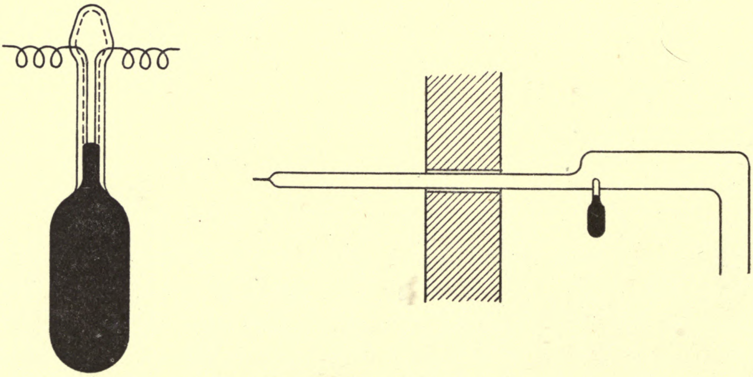


Fig. 67.—Bristol Compensator.

(*f*) *The Use of Bristol's Compensator.*—This appliance is an automatic device for controlling the temperature of the cold junction, and consists of a small glass bulb and capillary tube partly filled with mercury, into which a short loop of platinum wire is dipped.

This compensator is inserted in the circuit close to the cold junction. Temperature changes cause the mercury to expand or contract, thus introducing or cutting out resistance in the circuit. This acts in opposition to the change in E.M.F. with temperature at the cold junction, so that by correctly designing the appliance a balance is established. The construction of the compensator is shown in fig. 67. It is connected in series in the thermo-electro circuit. This method is not employed very largely.

Compensating Leads.—In the case of base metal couples, the prolongation to the cold junction can be, and is, constructed of the same materials as the thermo-couple itself. In the case of rare metal couples, however, such a course is quite impracticable owing to the cost of the metals employed. This difficulty has been overcome by the use of compensating leads constructed of inexpensive alloys, which are chosen so that they give the same E.M.F. temperature relations as the platinum-rhodium or platinum-iridium couples.

The resultant E.M.F. generated by this compound couple is therefore the same as if composed entirely of the rare metals.

The compensating leads employed in the Cambridge pyrometer consist of one wire of copper and the other of a nickel copper alloy, the nickel being present in small proportion—not more than 5 per cent.

The accuracy of the compensation is shown by the following table :—

Temperature. 0° C.	Pt—Pt-Ir Couple Millivolts.	Compensating Leads. Millivolts.
0	0	0
50	0·59	0·60
100	1·25	1·25
150	1·95	1·90
200	2·68	2·60
250	3·42	3·40
300	4·20	4·25

Construction of Thermo-couples

1. *Rare Metal Couples.*—The diameter of the wire actually employed in the construction of rare metal couples is either 0·6 mm. or 0·4 mm. The use of the latter reduces the cost of the material by one half, and such couples are, generally speaking, sufficiently robust. Before use, the wires of the couple should be rendered as homogeneous as possible by annealing them by electrically heating to a bright red heat.

The leads are insulated from one another, preferably by means of thin tubes of hard porcelain.

The arrangement employed is shown diagrammatically in fig. 68.

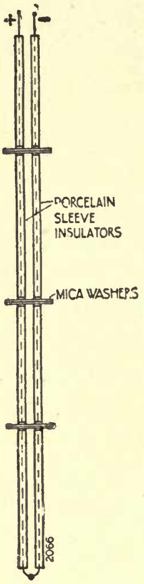


Fig. 68.—Rare Metal Couple and Leads.

2. *Base Metal Couples.*—These couples are, for the reasons given above, usually constructed of thick wire. A common method of construction is shown in fig. 69. An alternative method, which is sometimes employed for couples of very low resistance, is shown in fig. 70.

Instruments employed for the Measurement of the E.M.F. Generated.—Practically all indicating or recording instruments employed in conjunction with thermo-couples suitable for gasworks usage are special types of millivoltmeter.

The instruments are of the D'Arsonval type; that is to say, they consist of a coil of insulated wire, through which the current to be measured is passed, suspended in the field of a permanent magnet. The passage of the current through the coil produces a tendency towards rotation, which is controlled by a spring, so that the angle of rotation is a measure of the current flowing. The pointer or pen arm is attached to the moving coil, and moves over a scale or chart graduated to read temperatures directly.

There are two factors of very considerable importance in connection with the construction of millivoltmeters for pyrometry :—

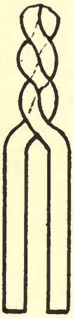


Fig. 69.—Base Metal Couple.

(*a*) The suspension of the moving coil.
(*b*) The resistance of the instrument.

(*a*) *The Suspension of the Moving Coil*

Three methods are employed for the suspension of the moving coil.

(i.) *Suspension by a Fine Wire.*—This method was adopted in the earlier designs of pyrometer millivoltmeters. The controlling force is furnished by the torsion of the wire suspending the coil. Frictional errors are avoided and a large deflection can be obtained with a very small current. The instrument must be very carefully levelled before use, and the support carrying the instrument must be quite free from vibration. For these reasons instruments with a suspension of this type are more commonly employed for laboratory purposes.

(ii.) *Double Pivoted Suspension.*—The coil in these instruments is pivoted between two jewels on hardened steel pivots. This suspension is always employed in cases in which the electromotive force for the full scale deflexion is not less than 10 millivolts, and is the general rule for base metal pyrometers in which the electromotive force is relatively large.

Fig. 70.—Base Metal Couple.

(iii.) *Single Pivoted Suspension.*—This method of suspension is employed when the E.M.F. for the full scale deflexion is less than 10 millivolts but not less than about 6 millivolts. In the Cambridge unipivot movement, the coil, which is circular in form, is provided with a vertical spindle carrying a fine pivot which rests in a jewelled bearing at the centre of a core of soft iron, around which the coil swings. The latter is balanced so as to be pivoted exactly at its centre of gravity.

The double pivoted suspension is of chief interest for general industrial purposes, and great attention has been given by various makers to the production of suspensions as free from frictional error as possible, and of robust construction. The instruments now available do not require accurate levelling up, and will withstand moderate vibration.

The sensitivity of pyrometer millivoltmeters may be expressed by stating the resistance of the galvanometer, for which a full scale deflexion would be produced by 1 millivolt. In the case of double pivoted instruments, this value is about 9 ohms, and the sensitivity is expressed as 9 ohms per millivolt. The case of a millivoltmeter calibrated to read 0–1400° C. with a platinum or platinum-rhodium couple may be taken as an example. The E.M.F. generated by this couple with the hot junction at 1400° C. is 16·14 millivolts, and the full scale deflexion must be given for that E.M.F. The resistance of the coil must therefore be $9 \times 16{\cdot}14$ ohms—*i.e.* 145 ohms approximately. The sensitiveness of the unipivot and suspended wire types are about 20 and 70 ohms per millivolt respectively.

(*b*) *The Resistance of the Instrument*

The resistance of the millivoltmeter must be high in order that any changes in the resistance of the circuit due to either the variable effect of heating the couple when immersed to different depths, or to temperature changes of the leads, may be negligible in comparison with the total resistance. For this reason it is necessary to include in the circuit a balancing resistance constructed of a material such as manganin, the resistance of which does not change with the temperature. The amount of the resistance thus added must be large enough to reduce the total probable change in the resistance of the circuit to about 1 per cent. The balancing resistance is usually contained in the case of the millivoltmeter of which it thus forms part.

In this connection the following table (*Practical Pyrometers*, Foster Instrument Co.) is instructive. The table gives the values of the resistances of the various parts of the circuit in the case of platinum—platinum-rhodium and nickel—nickel-chromium couples.

	Rare Metal.	Base Metal.
Resistance of thermo-couple stem when cold .	2 ohms	0·1 ohm
Probable variation of thermo-couple resistance, due to insertion to different depths and into furnaces at different temperatures	1 ohm	0·01 ohm
Resistance of copper cable	1 ohm	0·25 ohm

	Rare Metal.	Base Metal.
Resistance of copper coil in indicating millivoltmeter	24 ohms	2 ohms
Probable change in resistance of cable and coil due to change in atmospheric temperature	1 ohm	0·09 ohm
Therefore probable total change in circuit resistance	2 ohms	0·1 ohm
Minimum total resistance by addition of ballast in order that above change in resistance does not exceed 1 per cent. of the total resistance	200 ohms	10 ohms
E.M.F. of thermo-couple at 1000° C. . .	10 millivolts	40 millivolts
Current flowing in moving coil of indicating millivoltmeter, generating the operating force, in milliamperes	$\frac{10}{200}$=0·05 m.a.	$\frac{40}{10}$=4 m.a.

The current which actuates the instrument is many times greater with the base metal couple, and in actual practice is 30 and 40 times as great as in the case of a rare metal couple.

For this reason pyrometers for gasworks use are as a general rule constructed with base metal couples combined with a double pivoted low resistance millivoltmeter. It is also obvious that the resistance of the leads should be kept as low as possible, and this has the further advantage that such leads will be stronger mechanically than thinner leads of greater resistance.

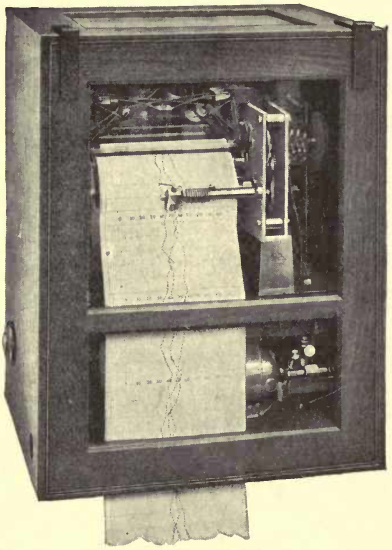


Fig. 71.—Cambridge Continuous Roll: Thermo-electric Pyrometer.

Typical Instruments.—The construction of the important features of thermo-electric pyrometers have been dealt with in some detail in the preceding paragraphs. The necessary features are all embodied in instruments constructed by the principal makers.

The Cambridge continuous roll recorder is shown in fig. 71. It consists of a Thread Recorder (see Chapter II. p. 22) driven by an electric motor in place of clockwork, and can be arranged to give simultaneous records on the same chart from either one, two, or three thermo-couples. The driving motor and reducing gear is situated in the lower portion of the case, which is separated by a partition from the upper part containing the millivoltmeter and recording mechanism. The millivoltmeter is of the double pivoted or unipivoted pattern and is fitted with a zero adjustment.

A centrifugal governor is fitted to one end of the spindle of the motor. The speed may tend to exceed the normal, but is kept constant by the governor, which intermittently closes a contact and shunts the armature. The contact is made between two platinum-iridium studs, and is practically sparkless, this result being obtained by connecting a high-resistance shunt across the contacts. The spindle of the motor carries a worm and has a ball-thrust bearing. Grease lubricators are fitted and the motor runs without attention for long periods. The reducing gear comprises a worm wheel and worm mounted on one shaft, and this shaft transmits power from the motor to a worm wheel on the cam shaft of the paper-feed mechanism. The timing of the motor is checked by noting the time of one revolution of the cam shaft. It is adjusted, if required, by a slight movement of the contact screw.

Foster's "Unit" recording pyrometer is illustrated in fig. 72. The mechanism employed to produce the record on a chart is described in Chapter II., p. 23. The millivoltmeter is a double pivoted instrument, and the recorder is intended for use in conjunction with base metal couples only.

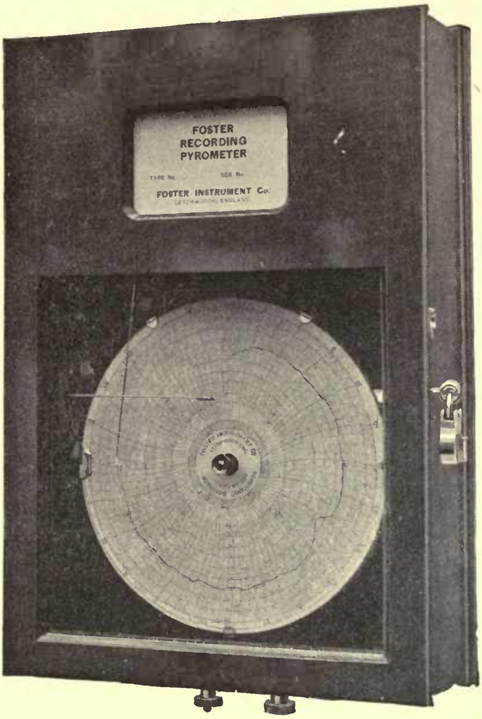


Fig. 72.—Foster's Recording Pyrometer.

Precautions to be Observed in the Use of Thermo-electric Pyrometers.—(*a*) It is very essential that all electrical connections be as perfect as possible. The voltages available are very small, and hence the slightest deviation from perfection in the contact becomes very serious.

(*b*) The hot junction of the thermo-couple must be inserted to such a depth that it reaches the temperature to be measured. Insertion to too great a depth is, however, undesirable, as it leads to premature destruction of the various portions of the thermo-couple and its mounting.

(*c*) The recording apparatus should be set up in a position as free as possible from dust and vibration.

(*d*) It is desirable to verify the reading of the pyrometer at intervals. This may be effected by replacing the used couple by a spare one, and noting if the same reading is obtained in a steady temperature. An alternative method is to observe the freezing point of a suitable substance. The pyrometer is immersed in the molten substance, which is allowed to cool slowly. When the freezing point is reached the temperature will remain constant for a considerable time and the reading obtained is compared with the standard temperature.

TABLE OF FREEZING POINTS

Substance.	Freezing Point in degrees C.
Pure Water	0
Pure tin	232
Pure lead	327
Pure zinc	419
Pure aluminium	657
Pure sodium chloride	800
Pure copper (in a reducing atmosphere)	1083

C. RADIATION PYROMETERS

Theory

The pyrometers described above all have one feature in common—it is necessary to bring some portion of the instrument into actual contact with the body the temperature of which is to be measured, this portion of the instrument acquiring the actual temperature in question.

It will readily be seen that this actual exposure to a very high temperature imposes a limit to the temperature which can be measured in this manner. This limit is that imposed by the impossibility of obtaining, in the present state of knowledge, sheaths and wires for the construction of the heated portion of the pyrometer which will withstand the destructive influences of continuous exposure to high temperatures for any length of time. This limiting temperature is about 1200° C., although it is possible to employ rare metal thermo-couples in special porcelain sheaths for short periods at as high a temperature as 1400° C. In cases where continuous records or frequent indications are required it is undesirable to expose the heated portion of the pyrometer to temperatures greater than 1200° C. for any length of time.

Radiation pyrometers operate upon a different principle. Not any portion of the instrument is actually exposed to the temperature to be recorded. The measurement of temperature is made by absorption of the radiant energy emitted from the heated substance, the temperature of which it is required to measure.

The relationship between the energy radiated by a heated body and its temperature has been the subject of numerous investigations both theoretical and experimental.

Kirchoff first propounded his conception of what he termed a " black body," which was defined as one which would absorb all radiations falling upon it and would neither reflect nor transmit any. He also pointed out the fact that the radiation from such a " black body " was a function of the temperature only, and was identical with the radiation inside an enclosure, all parts of which have the same temperature.

Substances of various natures, such as iron, porcelain, carbon, for example, do not emit the same amount of radiation when heated to the same temperature. If, however, they are heated inside a " black body " they then all emit the same radiation, and if viewed through a small opening in a furnace they will appear of uniform brightness.

The relationship between the total energy radiated by a hot body and its temperature was studied by various experimentalists, but the first important step forward was made by Stefan, who came to the conclusion that the energy radiated was proportional to the fourth power of the absolute temperature. This law received independent confirmation from Boltzmann, who arrived at the same result by thermo-dynamic reasoning. The conditions imposed by Boltzmann in his discussion were those described above as " black body " conditions.

The Stefan-Boltzmann law connecting the energy radiated and the temperature of a body heated under black body conditions is given by the following expression :—

$$E=K(T_1^4-T_2^4),$$

where E=energy interchange between the hot body and the pyrometer.
K=constant.
T_1=absolute temperature of hot body.
T_2=absolute temperature of the pyrometer.

Under ordinary conditions T_1^4 is so large compared with T_2^4 that the latter term in the above expression can be neglected without serious error. There is thus a direct relationship between the energy received by the pyrometer and the temperature of the hot body, and the instrument can therefore be calibrated to read the true temperature of a hot body when under black body conditions. It is fortunately the case that black body conditions are practically the same as those appertaining to ordinary furnace practice. The interior of most furnaces or ovens or the bottom of a closed tube thrust into the heated space closely approximates to black body conditions.

A pyrometer graduated to give correct readings under black body conditions is often said to read the black body temperature. This simply means that it reads the true temperature and that in other conditions it will not do so, but the readings obtained will be too low. The difference in the readings depends upon the composition of the hot body and on the degree of variation of the conditions of measurement from black body conditions. The apparent temperature of any material away from black body conditions always bears a fixed relationship to its true temperature, and it is therefore possible to employ radiation pyrometers for use in non-black body conditions, thus obtaining a reading which bears a fixed relationship to the true or black body temperature.

In gasworks practice, however, all measurements which are made by radiation pyrometers are effected under black body conditions.

Pyrometers operating by absorption of radiant energy may function by the absorption of all the radiant energy falling upon the sensitive portion of the instrument, or a portion of this energy may be employed selectively for obtaining the temperature measurement. In the former case the energy absorbed is chiefly composed of the invisible radiations of long wave-length—these instruments are commonly known as radiation pyrometers. In the latter case, the radiation employed is always a portion of the visible spectrum, and instruments of this class are usually called optical pyrometers—although, of course, they are also radiation pyrometers employing specially selected, rather than total, radiation.

Description of Instruments

The radiation received is translated into measurement of temperature in various ways.

1. *Expansion Pyrometer operated by Radiant Energy.*—In the Féry Spiral Pyrometer the radiation received by the instrument from the hot body is focussed on to a very small bimetallic spiral, an enlarged diagram of which is shown in fig. 73.

The bimetallic spiral is constructed of two strips of metal having different coefficients of linear expansion, the strips being closely united throughout their entire length. Any change in temperature will cause the two sides of the spiral to expand or contract by different amounts, thus causing the spiral to bend. The question of bimetallic strips employed for recording instruments is dealt with rather more fully in Chapter VI. p. 151.

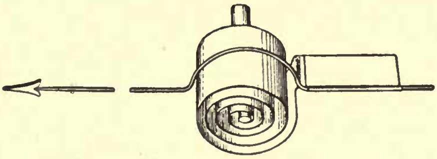


Fig. 73.—Spiral for Féry Expansion Pyrometer.

Féry's spiral is very thin, and the disposition of the two layers of metal is such that the spiral uncoils with rise of temperature. It is necessarily very small and actually measures less than $\frac{1}{8}$ inch diameter and $\frac{5}{64}$ inch long. The centre of the spiral is fixed and its free end carries a light aluminium pointer. The pyrometer is calibrated so that the pointer reads directly the temperature of the body upon which the instrument is focussed.

The mirror and focussing arrangements are the same as in the Standard Féry Radiation Pyrometer and are described below in connection with the latter instrument.

The expansion pyrometer is not much used now, as the instrument does not maintain a constant zero. It is less expensive than other types of radiation pyrometers.

2. *Radiation Pyrometers operating Thermo-couples.*—Instruments of this type are well known and widely used. The radiation from the hot body is focussed upon the hot junction of a small thermo-couple, and the current thus generated is indicated or recorded upon a galvanometer of the type already described, the scale of the galvanometer being calibrated directly in terms of temperature. The thermo-couple employed usually consists of two or three couples connected in series in order that a larger E.M.F. may be obtained.

The Féry Radiation Pyrometer.—This instrument comprises a telescope which is focussed on the hot body, the heat rays from the latter being received on a special concave mirror and brought to a focus on the hot junction of the thermo-couple.

The optical arrangement is shown diagrammatically in fig. 74. The heat rays A from the hot body are received on a concave mirror C and brought to a focus at N. The mirror C is pierced with a small hole at its centre, thus enabling the image produced to be viewed by the eyepiece E.

It is clear that the operation of the instrument depends upon the reflecting power of the mirror C remaining constant, and in this connection it should be noted that the effect of slight tarnishing or scratching is far less when, as in this case, the mirror is reflecting principally radiation of relatively great wave-length, than is the case when a mirror is employed for the reflection of visible radiation only.

The mirror C was formerly constructed of glass and gilded on its surface. Gold is a better reflector for radiations of long wave-length than silver, and, in addition, does not tarnish so readily. Lately this glass mirror has been satisfactorily replaced by one constructed of stainless steel. A further improvement consists in the protection of the reflecting mirror by a sheet of glass, the effect of which is easily corrected for by calibrating at three different points on the scale.

On looking through the eyepiece E, the observer sees an image of the hot body in the small mirror M, and is able to point the instrument on to the exact position of which the temperature is required and to focus it upon that spot.

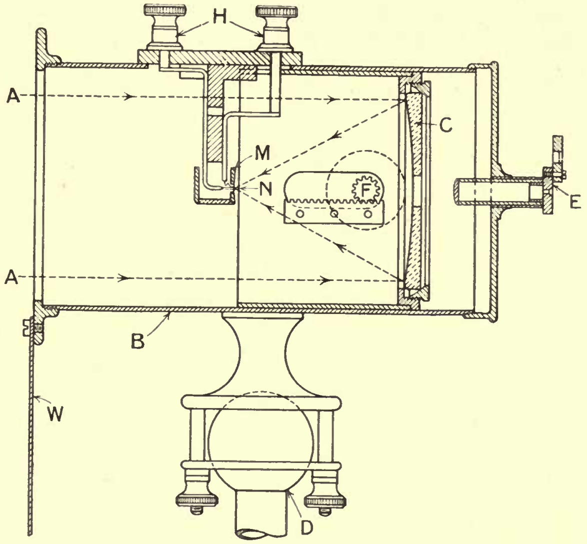


Fig. 74.—Optical Arrangement of Féry Radiation Pyrometer.

The thermopile N is situated just behind a small hole in the mirror M, and is heated by the rays passing through this hole.

Focussing the Instrument.—The operation of sighting and focussing is accomplished very simply in the following manner :—

The mirror M, in which the observer sees the image of the hot body, actually consists of two small, semi-circular, wedge-shaped mirrors fixed together. If the instrument is correctly focussed the appearance is as shown in the centre diagram of fig. 75, in which the outer circle represents the mirror, the shaded portion the reflected image of the hot body on which the telescope is sighted, and the black centre is the sensitive element of the pyrometer, which must be covered by the image of the hot body. If the focus is too short, the image appears split in two parts, as in the left-hand diagram, whilst if it is too long the appearance is similar but reversed, as in the right-hand diagram. Turning the knurled head attached to the pinion F (see fig. 74) causes the upper and lower half images to slide on one another, so that it is easy to get the exact focus, and personal error cannot creep in. The size of the aperture or body sighted on, and the distance of the telescope from it, do not, within wide limits, affect the temperature readings. It is only necessary for the body sighted on to be of a size such that its image will overlap on all sides the sensitive element in the telescope (see fig. 75).

To secure this with the Féry radiation pyrometer, the size of the object sighted on must be at least 1 inch (25 mm.) in diameter for every 2 feet (60 cm.) of distance between the telescope and the object, but except for this proviso, the record of the pyrometer is independent of its distance from the hot body.

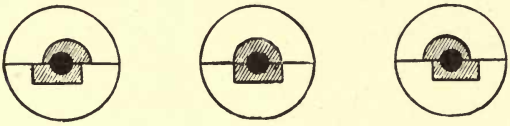


Fig. 75.—Focussing of Féry Radiation Pyrometer.

The thermopile in the Féry telescope is constructed of two iron-constantan couples connected in series. This pile is connected in the recording instrument to a thread recorder. The recording outfits may be calibrated to cover any particular range of temperature required above 500° C., but is usually constructed to cover one of the following standard ranges :—

500°–1100° C.
600°–1400° C.
800°–1700° C.

The relationship expressed by the Stefan-Boltzmann law, $E=K(T_1^4-T_2^4)$, shows that the energy radiated increases enormously with the temperature. Hence, neglecting T_2^4 in comparison with T_1^4, it may be stated that an increase of 1 per cent. in the absolute temperature of the hot body results in an increase of 4 per cent. in the energy received by the pyrometer. This results in the scale of a radiation pyrometer at higher temperatures being very open compared with the subdivision at lower temperatures. This will be seen in fig. 76, which shows the ruling of the chart employed. It is therefore evident that, in order to obtain the greatest sensitivity, the range of the instrument employed for any particular purpose should be so chosen as only just to cover the highest temperature to be recorded. A further advantage is that a change of 1 per cent. in sensitivity of the instrument results in a change of only one quarter of 1 per cent. in the temperature reading.

Where it is necessary to cover a very wide range of temperature, the telescope can be fitted with an additional diaphragm, which can be moved in or out of position by a lever on the outside of the case. This instrument is calibrated for two ranges, the change from one range to the other being made by moving the diaphragm lever.

Foster Radiation Pyrometer.—This instrument is one of the newer types and presents some novel features. It is of the so-called fixed focus type, and does not therefore require any focussing or adjustment. The instrument is pointed towards the hot body and receives a portion of the radiation therefrom.

The Receiving Tube.—The receiving tube of the pyrometer is shown diagrammatically in fig. 77. An aperture EF is situated at the front end of the tube MNPQ.

Radiation from the hot body AB enters the aperture EF and is received by the concave mirror C. The latter forms a focussed image of the aperture EF on the

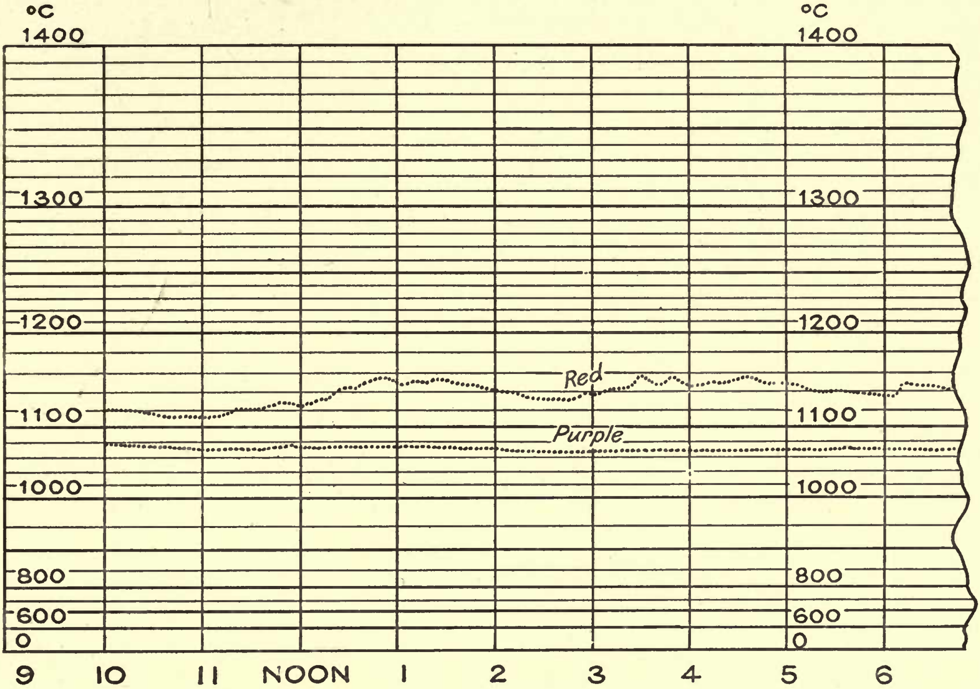


Fig. 76.—Chart used for Féry Radiation Pyrometer.

thermo-couple D. The thermo-couple D and the aperture EF are situated at the *conjugati foci* of the mirror C.

The action of the pyrometer is independent of its distance from the hot body, provided a certain so-called "working distance" is not exceeded. Consider the diagram shown in fig. 78. EF is the diaphragm aperture, C the concave mirror, and D the

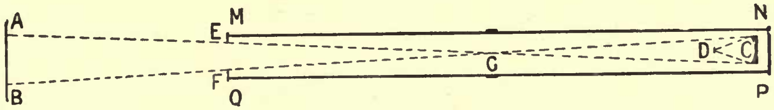


Fig. 77.—Diagram of Receiving Tube of Foster's Fixed Focus Pyrometer.

sensitive body. First let the hot body surface coincide with the plane EF. Then considering any very small elementary area H on the circumference of the mirror C, the cone EHF encloses all possible radiation from EF to H; and this will be reflected through the cone HD to the surface D. The same will be true for any other elementary area J, and for all the mirror surface.

If the hot body is now removed to the plane AB, the radiation received by D will be the same so long as AB coincides with a section of the cone EGF produced. The

Cone EHF produced strikes the hot body surface at BK. The cone KHB encloses all possible radiations from BK to H, and since this cone cannot enclose radiations in any direction different from those in EHF (because H is very small), these radiations must, when reflected, all fall within the cone HD, and so reach the sensitive body.

The intensity of radiation received by H from each elementary area of BK will vary inversely as the square of its distance from H; but the total area of BK, being a section of a cone with apex at H, will vary directly as the square of its distance. Therefore the total amount of radiation proceeding from BK to H will be independent of the particular distance of BK from H.

The same will be true for an oppositely placed area J, in this case the radiating surface being AL; and also for all other elementary areas of the mirror C. If we revolve the figure AEHJFB about the axis XY of the receiving tube, we shall circumscribe a space including all possible radiation that can proceed from a surface in the plane AB to the mirror C, and thence by reflection to D. Any surface larger than a section of the space AEFB cannot radiate any more heat to the mirror C.

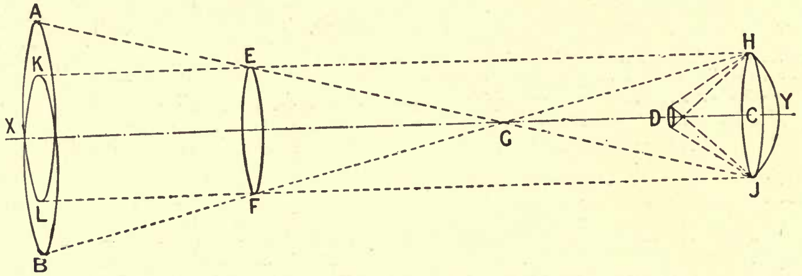


Fig. 78.—Theory of Foster's Fixed Focus Pyrometer.

It will be seen that the limiting space is conical in that part outside the receiving tube, and the apex of the cone is at G; therefore the radiation received by the instrument will be independent of distance, provided the hot body surface coincides with or overlaps a section of the cone EGF produced.

The working distance of the pyrometer, which must not be exceeded, is equal to the diameter of the hot body multiplied by a " distance factor " supplied by the makers. This factor is either 10 or 12. If, for example, the hot body is 6 inches in diameter, the maximum working distance in the case of an instrument—distance factor 10—is 5 feet. The working distance is measured from the surface of the hot body or the edge of the opening to the centre ring on the receiving tube. This distance need not be measured accurately, as any smaller distance will do equally well.

The receiving tube is shown in fig. 79. Diaphragms are fitted in the tube to prevent the sensitive part of the instrument, at the rear end of the tube, from receiving any direct or reflected heat whatever except that which enters correctly through the front diaphragm. The tube is slotted in the front portion to reduce conduction of heat, and also to allow the escape of furnace gases, smoke, or fumes, which may enter the front diaphragm, although, of course, it should be understood that, as the instrument is designed for working at a distance from the hot body, it is neither necessary nor desirable to insert it into the furnace or furnace gases. For rapid work, particularly under industrial circumstances, it is usually quite easy to judge the pointing of the tube by the unaided eye. The distance is not great, while the size of the hot body is usually large. To meet those cases where the distance may be large or the hot body is small, a special sighting device is incorporated, by means of which the user can see the image of the hot body, as viewed through the front diaphragm, and can therefore see at once if the tube is correctly pointed.

It is interesting to note that the efficiency of the receiving tube is so high that, when it is pointed at a hot body whose temperature is 1400° C., the electromotive force available to actuate the indicator or recorder is greater than that available with a platinum alloy thermo-couple actually subjected to a temperature of 1400° C.

The Thermo-couple and Recorder.—The thermo-couple is very small and is a type of base metal couple. It is connected to a recording galvanometer of type similar to that described above in connection with Foster's thermo-couple pyrometer.

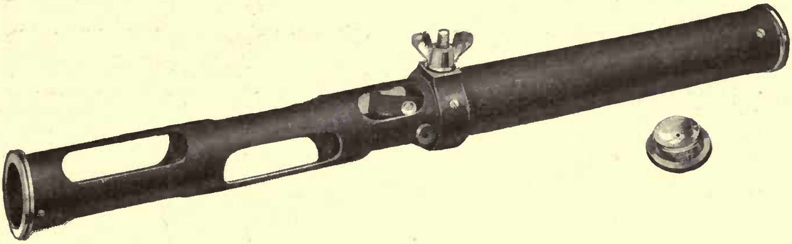


FIG. 79.—RECEIVING TUBE OF FOSTER'S FIXED FOCUS PYROMETER.

The pyrometer is extremely simple to use, but has the drawback that a considerable area of hot body is required in order that the whole of the aperture of the receiving tube may be filled with radiation. In gasworks practice the hot body is large, and this drawback is therefore of no consequence.

3. *Radiation Pyrometers operating by the Use of Specially Selected Radiation—Optical Pyrometers.*—Optical pyrometers do not, strictly speaking, come within the scope of this volume as they cannot in any circumstances be made into automatic recording instruments. They are simply direct reading instruments in which the measurement is made by personal observation. Instruments of this type are, however, of considerable utility in retort-house and similar operations, and in addition they are usually employed for purposes in which a recorder would not be required; even supposing that it were possible to make these instruments automatically recording.

The problem of measuring the temperature of hot bodies by comparison or estimation of their apparent brightness is not quite straightforward. The intensity of the light emitted by a hot body varies enormously with its temperature. If, for example, the intensity of the red light wave-length 0·0656 μ emitted by the hot body at 1000° C. is called 1, the intensity at 2000° C. will be 2100 (Wardman & Burgess

Optical Pyrometry, Bulletin No. 2, Bureau of Standards, U.S.A.). It would therefore appear at first glance that temperature measurements could be made by photometric comparison of the light emitted by the hot body with that emitted by a second hot body at a known temperature. The measurement could be made in this way if all bodies at the same temperature emitted the same amount of radiation. This, however, is not the case unless the hot body is heated under black body conditions, and hence optical pyrometers—just as in the case of other types of radiation pyrometers—can only be used when black body conditions prevail.

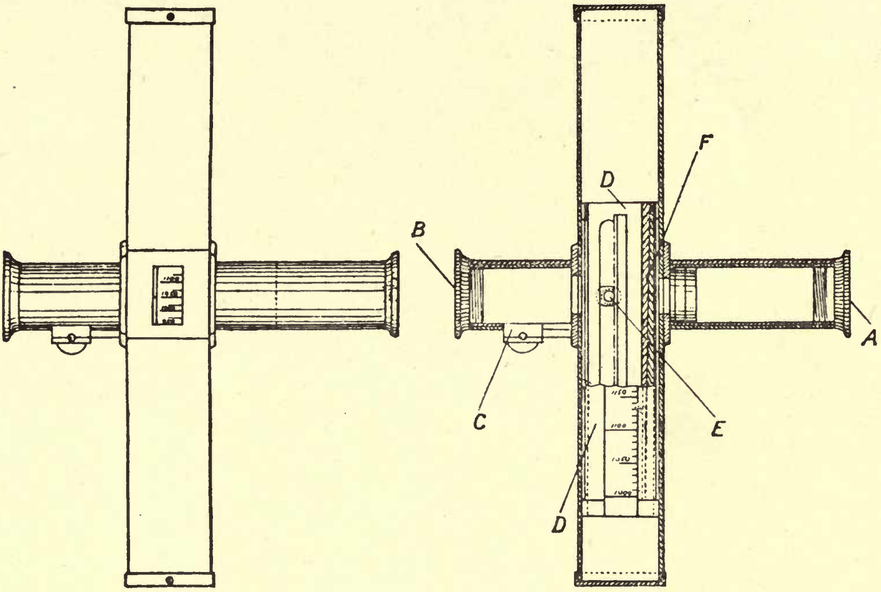


Fig. 80.—Wedge Pyrometer.

The Wedge Pyrometer.—This instrument consists essentially of a glass prism graduated in depth of colour, different depths of colour being required to eclipse the light emitted by bodies of different temperatures. It is not susceptible of very great accuracy, but, on the other hand, its simplicity and durability render it a convenient instrument for purposes where great accuracy is not required.

The construction of the apparatus is shown in fig. 80. The apparatus consists of a rectangular tube 9 inches long, across which a small telescope is fitted at right angles. A (fig. 80) is the eyepiece; B is the object-glass of the telescope, which is focussed by the rack and pinion C on to the hot body, the temperature of which is to be measured. A carrier D is fitted inside the rectangular tube, and can be moved up and down by a rack and pinion E. Two glass wedges F are attached to the carrier, and are arranged so as to move across the field of vision of the telescope. One of the wedges is composed of dark red glass and the other is made of plain glass, and is introduced in order to correct the effects of refraction.

When in use the telescope is pointed at the heated body, and the image of the

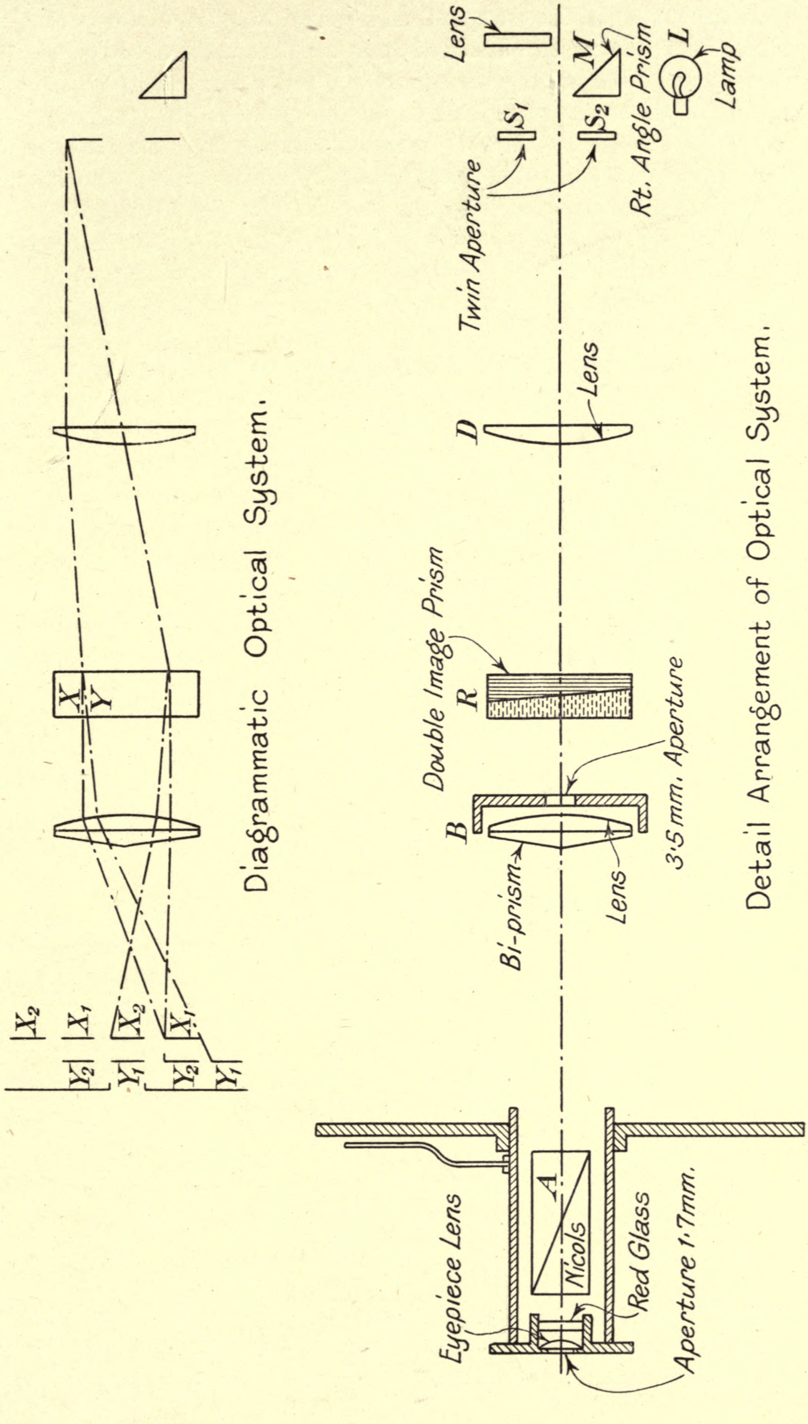


FIG. 81.—DIAGRAM OF CAMBRIDGE OPTICAL PYROMETER.

latter is viewed focussed on the wedge of dark red glass. The latter is then moved so as to increase the thickness of coloured glass between the hot body and the eye. As the wedge is moved the image gradually fades, and at the point of extinction the temperature is read off on the scale fixed to the instrument.

The Cambridge Optical Pyrometer.—This instrument is a modification of the Wanner pyrometer. It is a convenient appliance and is susceptible of great accuracy. It has been found that readings taken by different observers agree very closely indeed. The apparatus may be regarded as a photometer in which a selected beam of monochromatic light from the hot body is adjusted to equal intensity with a beam of similar light from an incandescent electric lamp.

The apparatus is shown diagrammatically in fig. 81.

The comparison light is a small incandescent lamp which illuminates a glass matt surface after reflection from the face of the prism M. The light from the hot body traverses a cover glass and the slit S_1, while the light from the comparison lamp L, after traversing a diffusing glass is reflected by the prism M into the slit S_2. The slits are at the focus of the objective D, and the beams proceeding from them are thus rendered parallel. The two beams then traverse the Rochon double image prism R which separates each of the beams into two beams polarized in planes at right angles to one another. Each of these four beams fall on both faces of the wide angle prism B and is thereby again divided into two portions. A monochromatic red glass, absorbing all light except that corresponding to wave-length 0·0656 μ, is situated in the eyepiece; the diaphragm of which cuts off all the light except a small patch from the hot body and from the lamp respectively. One half of the field of view is illuminated by plane polarized light from the hot body, whilst the other half is illuminated by light proceeding from the electric lamp, polarized in a plane at right angles to the other beam. The two halves of the field of view are adjusted to equal brightness by rotating the Nicol prism A between the diaphragm and the eye. The position of the Nicol prism is observed on a graduated circle, divided to read directly in degrees of temperature.

The accuracy of the instrument depends upon the constancy of the light from the electric lamp, and it is therefore essential that the current flowing through the latter should always be the same. An ammeter and a regulating resistance are therefore included, so that, notwithstanding voltage fluctuations of the accumulator, the current passing through the lamp is always constant. The constancy of the candle-power of the lamp over long periods as the filament ages is ensured by calibration at intervals against a standard amyl acetate lamp provided for this purpose. This calibration is carried out by placing the amyl acetate lamp in a fixed position in front of the slit S_1, and adjusting the reading of the ammeter so that the two fields of view appear equally bright, the fixed prism being set at an angle of 45°.

The scale of the instrument is open and the apparatus can be used for all temperatures above 700° C.

The complete appliance is illustrated in fig. 82.

The Cambridge Disappearing Filament Pyrometer.—This pyrometer is a photometric instrument of a rather different character. If a sufficient current be passed through the filament of an electric lamp the filament grows red at first; and as the amount of current is increased, the filament getting hotter becomes successively orange, yellow, and white. If now this heated filament is interposed between the eye and an incandescent body, the current through the lamp may be adjusted until a portion of the filament is of the same colour and brightness as the object. When this occurs, this part of the filament becomes invisible against the bright background, and the current passing as indicated on an ammeter becomes a measure of the temperature to be measured.

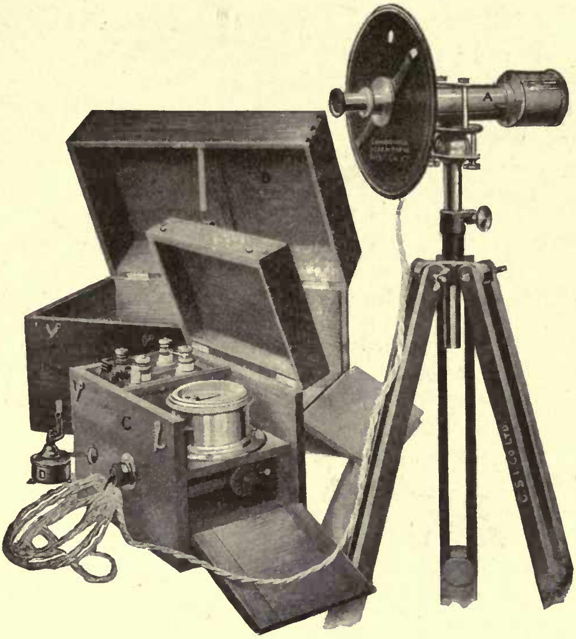


FIG. 82.—CAMBRIDGE OPTICAL PYROMETER.

The pyrometer is shown diagrammatically in fig. 83.

A small two-volt lamp L, with a horse-shoe filament, is mounted in the focal plane of the objective and of the eyepiece of a telescope provided with stops DDD and a focussing screw S. The lamp circuit consists of a two-volt cell, a resistance, and an ammeter. The telescope is focussed on the hot body, thus bringing its image into the plane AC. The current is then adjusted

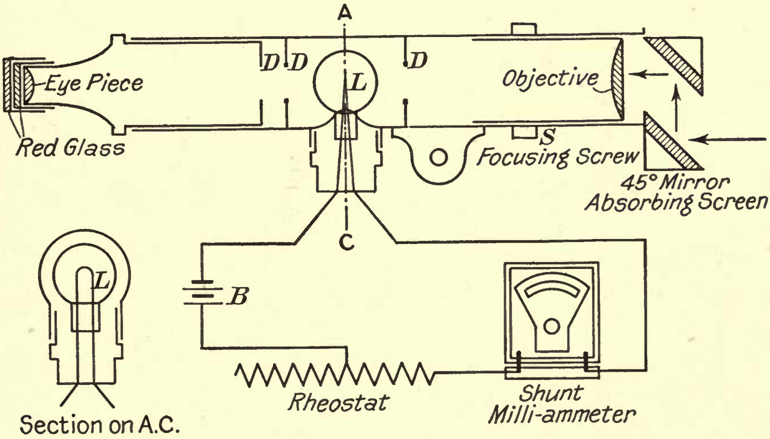


FIG. 83.—DIAGRAM OF DISAPPEARING FILAMENT PYROMETER.

by means of the resistance until the tip of the lamp filament disappears against the bright background.

The instrument is illustrated in fig. 84.

It will be seen that it is self-contained, the ammeter and viewing telescope being mounted together. The ammeter is of the moving coil type. It is damped to make the movements of the pointer dead-beat, and is calibrated to read temperatures above 700° C. The standard ranges are 700°–1400° C. for single scale instruments, and 700°–1400° C. and 900°–2000° C. for double scale instruments.

The eyepiece is provided with a rubber eye-guard to exclude extraneous light, and is made adjustable so that it can be focussed on to the lamp filament. The objective is also provided with an adjustment so as to bring the hot body into the correct focus.

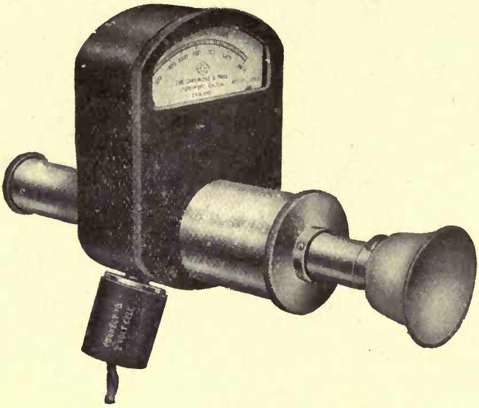


Fig. 84.—Disappearing Filament Pyrometer.

Immediately behind the eye-guard fixed to the eyepiece is a series of three stops, one being a plain hole which will be found most useful for viewing the filament against the hot body at low temperatures.

The second stop is provided with a monochromatic glass which will be found most useful when measuring temperatures at about 1000° C., the monochromatic glass reducing the amount of glare. The third stop is provided with an extra convex monochromatic lens, suitable for the higher temperatures. The introduction of these glasses into the optical system does not affect the scale or accuracy of the instrument, but is simply a convenience when matching the colour of the two objects.

If too much current is passing through the lamp filament, the latter appears as a bright line on a darker background; while if there is not sufficient current flowing, the filament appears as a dark line on a lighter background.

When the tip of the filament entirely disappears, and cannot be seen against the hot body under test, the indication given by the ammeter is the temperature of the hot body.

The lamps used in these pyrometers are never used at their maximum brilliancy under actual conditions. They are specially aged so that their brilliancy remains constant for very considerable periods.

The maximum working current is about 0·5 ampere.

An accuracy of within 1 per cent. is easily attainable even by persons without previous experience in the use of this instrument.

General Remarks upon the Use of Radiation Pyrometers

1. An ordinary furnace practically fulfils black body conditions, but it is often undesirable to open it in order to sight the pyrometer upon its interior. It is therefore sometimes convenient to build a closed fireclay or quartz tube into the furnace, which thus attains the furnace temperature.

The arrangement is shown in fig. 85, and gives almost ideal black body conditions.

The pyrometer is sighted upon the closed end A, and it is important to ensure that the outer end of the tube does not cut off any of the radiation emitted from the lower end. The tube should not be less than 10 cm. internal diameter.

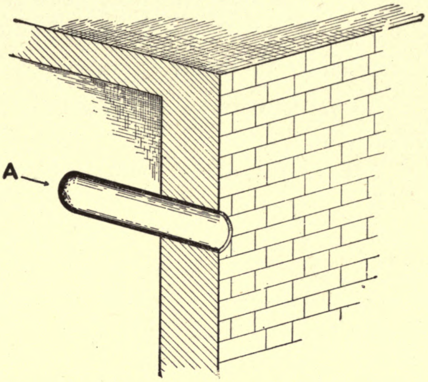


Fig. 85.—Sighting Tube Mounted in Furnace.

2. It is important to ensure that the pyrometer is not too far away from the hot body. So long as it is within a certain maximum distance the precise distance as already stated is immaterial. The maximum distance is given in the case of the Foster instrument by the working factor. The following table (Burgess & Foster) gives the maximum distances in the case of a standard Féry pyrometer.

Distance from Hot Body to the Pyrometer.	Diameter of Hot Body.
70 cm.	1·2 cm.
80 ,,	1·4 ,,
100 ,,	1·8 ,,
150 ,,	3·1 ,,
200 ,,	4·2 ,,
300 ,,	6.3 ,,
500 ,,	10·7 ,,

3. In the case of recording pyrometers, especially in situations in which the atmosphere is dusty, it is important to ensure that the surface of the mirror, or of the protecting window, does not become dirty. This alters its reflecting power and vitiates the readings.

4. The importance of black body conditions is not quite so fundamental in the case of optical pyrometers as in total radiation instruments, but the measurements will not be quite accurate unless black body conditions are observed.

The literature on the subject of pyrometry is extensive and very complete. For further information the reader is referred to the following text-books :—

Methods of Measuring Temperature. Ezer Griffiths.
The Measurement of High Temperature. Burgess & Le Chatelier.
Pyrometry. C. R. Darling.
Practical Pyrometry. Féry, Short & Collins.

And also to the following papers by R. S. Whipple :—

"Measurement of Temperature." *Journ. Oil and Colour Chemists Association, 1919,* (2) 77.

"Modern Methods of Measuring Temperature." *Proc. Inst. Mech. Eng., 1913.* 717.

CHAPTER V

APPARATUS FOR RECORDING SPECIFIC GRAVITY

THE advantages of a continuous record of the variation of specific gravity have been evident for many years; but nevertheless it is only within the last decade that a recording specific gravity apparatus has been invented. The *modus operandi* of the apparatus in question is entirely different to that of the various hand tests for specific gravity determinations, and as will be gathered from the sequel, the accuracy of the recorder is on the average greater than that attainable in hand determinations.

Determinations of specific gravity made by hand are usually carried out by some form of effusion test.

The effusion tests of Bunsen and Schilling and the Simmance Abady specific gravity bell, are instruments whereby specific gravity is determined by comparison of the rate of effusion through a very small orifice. (It should be noted that the term "diffusion" is also incorrectly applied to this phenomenon.)

The general equation for the effusion of gases from a small orifice, as deduced from the kinetic theory of gases, is

$$P=\tfrac{1}{8}\pi\rho v^2,$$

where P is the pressure, ρ the density of the gas, and v the mean speed of its molecules.

Hence, for two different gases under the same pressure P, we have

$$\tfrac{1}{8}\pi\rho_1 v_1{}^2 = P = \tfrac{1}{8}\pi\rho_2 v_2{}^2\,;$$

$$\therefore\quad \rho_1 v_1{}^2=\rho_2 v_2{}^2,$$

$$\therefore\quad v_1{}^2 : v_2{}^2 :: \rho_2 : \rho_1 :$$

ρ_1 and ρ_2 are densities referred to water. We can substitute in this expression s_1 and s_2, the specific gravities compared to air, because these are simply dependent on the pressure and temperature, and any cause which operates to increase the density of the gas will increase the density of air in the same ratio. The specific gravity compared to air remains the same, for the ratio $\frac{x\rho_1}{x\rho_2}$ is the same as $\frac{\rho_1}{\rho_2}$.

It should be noted that the law of effusion of gases holds true whether the gases stream into a vacuum or not. St Venant and Wantzel found that the back pressure

—*i.e.* the pressure of the atmosphere into which the gas streams—could be increased up to half the value of the pressure that forces the gas out, without alteration of speed.

The accuracy of the determination by means of an effusion test depends very largely on the accuracy of the timing of the rate of efflux. For example, suppose the times of effusion for air and gas are 80 seconds and 60 seconds respectively. (These are normal figures for the specific gravity bell.)

$$\text{Specific gravity of the gas} = \frac{60^2}{80^2} = 0{\cdot}5625.$$

If the times of effusion are 80 seconds and 59·5 seconds, the

$$\text{specific gravity of gas} = \frac{(59{\cdot}5)^2}{(80)} = 0{\cdot}5532.$$

Hence an error of 1 in the second significant figure is occasioned by an error in timing of 0·5 second.

In order to secure a result reliable to the fourth significant figure, it is necessary to time with an accuracy of a fifth of a second for a total time of effusion of about four minutes.

This is a degree of accuracy which is difficult to obtain in ordinary practice.

The gas in the Lux Balance is passed into a balanced globe, the varying displacement of which is observed. In this well-known instrument the specific gravity of the gas passing through is observed by the indication of a movable rider on the beam and of a pointer, which moves over a graduated scale.

Let the absolute weight in vacuo of the gas-globe be W.
,, ,, ,, of air filling the globe at N.T.P. be W_a.
,, ,, ,, of gas ,, ,, ,, W_g.
Weight of globe full of air at N.T.P. immersed in air $= W - W_a + W_a$
,, ,, ,, ,, ,, $= W$
,, ,, gas ,, ,, ,, $= W - W_a + W_g$;

therefore the force displacing the balance, when full of gas, is equal to a weight $W_a - W_g$; and this force is balanced by an adjustment of the rider and by an alteration of the position of equilibrium, as indicated by a movement of the pointer.

Now let the external conditions of temperature and pressure alter so that gas and air are x times as dense.

Weight of air displaced by globe is xW_a,
,, ,, gas in globe is xW_g;
therefore weight of globe full of gas is $W - xW_a + xW_g$.
Force displacing balance is $x\,(W_a - W_g)$,

and the indication of the balance will be x times as great as before—*i.e.* it will indicate density compared to a constant invariable standard.

It should be noted that it might be possible to make the Lux Balance into a recording appliance, by replacing the movable rider by a balance weight carried by a fixed support, so that its moment about the point of support of the beam varied according to the position of the latter. The position of the pointer would thus indicate the specific gravity without any rider adjustment. The record on the chart would have to be made by means of the Thread Recorder (see Chapter II. p. 22) or some similar device. A recording pen could not be employed owing to the friction of the chart, and also owing to the variable weight of the ink in the pen.

Such an instrument, even if perfected, would require to have the record corrected for variation in external conditions of temperature and pressure which, as will be gathered from the theory of the instrument, would cause errors of very considerable magnitude.

Simmance's Gravitometer is the only apparatus which has been devised up to the present time for continuously recording specific gravities, the record being automatically corrected for tabular number variations.

THEORY OF THE GRAVITOMETER

Consider a balanced bell A (fig. 86), the edges of which are sealed by an oil surface in an annular trough B. Let this bell be surrounded by a cover C, the edges of which are also sealed in the oil. Let the top of the cover be connected to a vertical pipe D

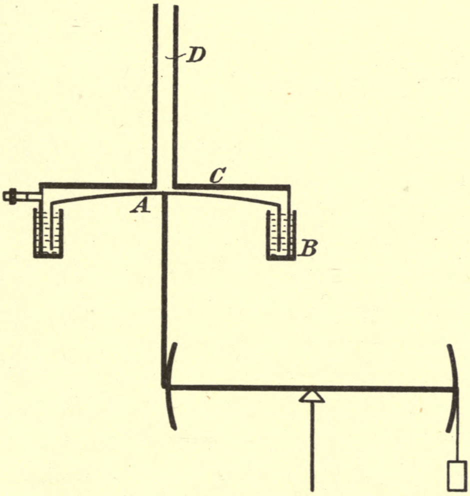


FIG. 86.—THEORY OF GRAVITOMETER.

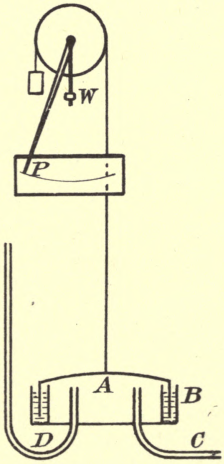


FIG. 87.—GRAVITOMETER BELL AND ASCENSION PIPE.

Let the diameter of the bell be d cm.

Let the distance from the crown of the bell A to the top of the tube D be h cm.

The weight acting upon the upper (and also the under) surface of the bell is that of a column of air of diameter d, and height equal to that of the superimposed atmosphere. If a slow stream of gas, of specific gravity s, be allowed to flow over the upper surface of the bell A and to escape from the top of the tube D, the weight acting upon the upper surface will obviously be diminished (assuming s to be less than 1) by an amount equal to the difference between the weights of two columns of air and gas respectively, the columns being of diameter d and height h.

Expressed in symbols this difference in weight is

$$\pi\frac{d^2h}{4}(1-s)w,$$

where w is the weight of a cubic centimetre of air *under the conditions prevailing.*

The bell may be maintained in equilibrium by balancing against the moment exerted by a fixed weight W (fig. 87), carried by an arm so arranged that the fixed weight moves upon an arc when the bell moves vertically up and down. With such an arrangement it is clear that any change occurring in the weight acting upon the upper or the under surface of the bell will cause a vertical movement of the latter until a new position of equilibrium is attained by the approach or recession of the centre of gravity of the balance weight (and pen P) to or from the centre of balance. This movement causes the motion of the pen P (carried on a suitable arm) across a chart, the amount of movement being proportional to the change in the weight acting upon the bell A—*i.e.* proportional to the specific gravity of the gas flowing over the bell.

This change in weight can (within limits) be made as large as desired by employing a bell of large diameter or a tube of considerable height, or both.

The diameter of the bell in the standard instrument is 9 inches, and the height of the vertical tube (called the ascension pipe) above the crown of the bell is 52 inches, when the instrument is working at 60° F. and 30 inches barometer pressure.

The weight of the air column $\pi\frac{d^2h}{4}w$ in these circumstances is 66 grams, and hence each 0·001 change in specific gravity causes an alteration in the weight acting upon one side of the bell of 0·066 gram—an amount which will easily affect the movement of delicately balanced mechanism.

Exactly the same argument applies if the bell is arranged as shown in fig. 87. The bell A is sealed in oil contained in the annular trough B. Gas is admitted by the inlet tube C and flows gently away through the outlet tube D, which is carried vertically to a height h above the crown of the bell A. The weight acting upon the under side of the bell will be reduced when gas of specific gravity s is introduced by

$$\pi\frac{d^2h}{4}(1-s)w \text{ grams.}$$

The balanced bell, arranged as shown in fig. 87, which is more convenient from the point of view of neatness of construction, constitutes the fundamental conception of the gravitometer.

Correction for Variation of Prevailing Conditions of Temperature and Pressure

It has been shown that the actuating force in the gravitometer is

$$\pi\frac{d^2h}{4}(1-s)w.$$

These factors are all constants with the exception of w, which depends upon the actual temperature and pressure prevailing.

Unless, therefore, some compensating device is employed, the arrangement of the gravitometer described will be affected considerably by variation in tabular number, and will only be correct in certain conditions of temperature and barometric pressure.

The gravitometer is for this reason provided with automatic compensation for these changes.

If the conditions are such that w the weight of 1 c.c. of air at N.T.P. becomes $\frac{w}{\mathrm{K}}$, then the actuating force becomes

$$\pi\frac{d^2h}{4}(1-s)\frac{w}{\mathrm{K}}\cdot$$

If, therefore, in these circumstances h is changed reciprocally to Kh, the force is

$$\pi\frac{d^2\mathrm{K}h}{4}(1-s)\frac{w}{\mathrm{K}},$$

i.e. it remains unaltered.

The compensation of the gravitometer depends upon this principle; the length of the vertical pipe, measured from the crown of the bell to the top of the tube, is automatically altered to Kh cm. when conditions change so that w becomes $\frac{w}{\mathrm{K}}$ grams.

This is effected in the following manner.

Consider two chambers A and B (fig. 88) of equal diameter. A is a fixed chamber connected to B, which is movable, by rubber tubing.

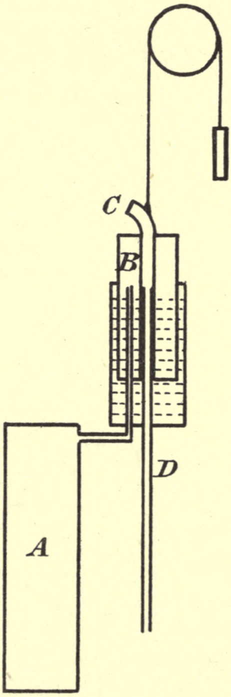


Fig. 88.—Compensator for Gravitometer.

Chamber B is balanced, suspended in a tank containing water, and simply acts as a balanced gas bell. A tube C is fixed vertically into the top of chamber B and slides loosely over the tube D which passes up through the water tank. The tubes C and D together form the vertical tube or ascension pipe of the gravitometer, and their combined vertical height will obviously depend upon the position of the bell. The position of the latter is adjusted so that at 60° F. and 30 inches barometer the combined lengths of the air columns in A and B are equal to h, the height of the ascension pipe.

If the conditions change to tabular number n, the combined lengths will become $1000\frac{h}{n}$, and as A is fixed, the whole of this change of length will be obtained by a vertical movement of B in the tank. As the upper portion of the ascension pipe is carried by the bell, it is easy to arrange so that the length of the ascension pipe also becomes $1000\frac{h}{n}$.

But in conditions represented by tabular number n, w becomes $\frac{nw}{1000}$; in other words, the actuating force remains unaltered.

Detailed Description of the Gravitometer

(*a*) *The Balanced Bell System.*—The gravitometer bell A, 9 inches in diameter (fig. 89), is composed of aluminium. Its lower edge is sealed in an annular trough containing a specially prepared oil. The latter has a negligible vapour pressure at ordinary temperatures, and thus does not evolve any volatile constituents into the gas flowing through the bell. The surface of oil exposed to the air is, owing to the annular shape of the trough, very small, and hence stripping action on the gas is not to be apprehended. The balance, from one side of which the bell is suspended, consists of a wheel C borne upon an axle which rotates upon the anti-friction rollers.

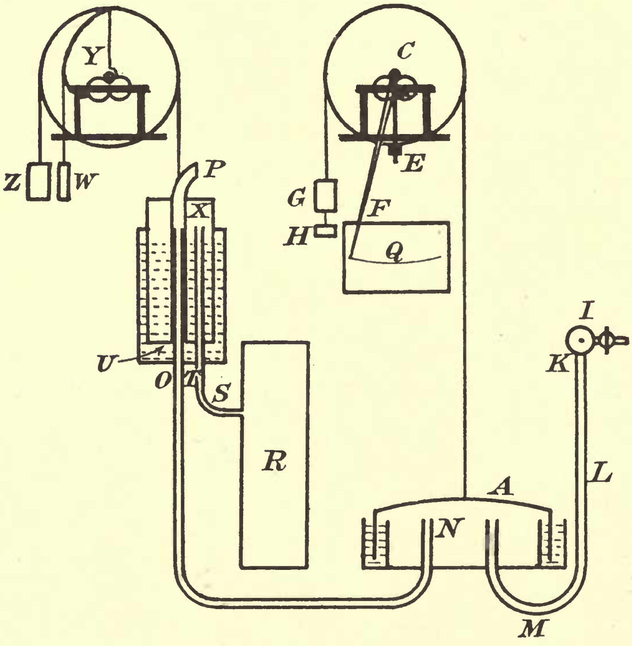


Fig. 89.—Diagram of Gravitometer.

A "gravity bob" E and a pen arm F are rigidly connected to the axle of the wheel C, so that any rotation of the latter displaces the pen and causes the centre of gravity of the gravity bob to move nearer to or farther away from the centre of balance of the wheel C. The weight of the bell A and its supporting chain is balanced by the counterweight G, which is suspended from the side of the wheel C opposite to the bell A.

An auxiliary weight H is attached to the bottom of the counterweight G. This weight is equal to 0·3 of 66 grams. As already stated, 66 grams is the weight of the balancing air column of diameter equal to that of the bell and height equal to that of the ascension pipe—viz. 52 inches at N.T.P.

The addition of the weight H, 0·3×66 grams, is therefore equivalent to the passage of a gas of specific gravity 0·7 through the bell. The use of this weight enables the edge of the chart to finish at 0·7 specific gravity, and thus restricts the range inscribed to that actually required in practice.

The rising or sinking of the bell A under varying load causes the gravity bob to move nearer or farther away from the centre of support, thus altering its moment about the latter, until the system is again in equilibrium.

The pen swings across the chart Q in accordance with the motion of the bell, and thus inscribes the specific gravity on the chart.

The gas enters the apparatus through a small diaphragm governor I. The weight K of the latter projects slightly through the cover so that the governor can be put out of action if desired, in order that the bell and pipes may be cleared quickly.

The gas passes from the governor down the pipe L to the standpipe M, from which it enters the bell. It passes away from the latter through the outlet standpipe N, which is provided with a U bend, and carried upwards to the ascension pipe O. After it has passed up the latter, the gas is burnt at steatite burner P provided with a gauze top.

The whole of the outlet and ascension pipes are of large diameter so as not to offer any resistance to the flow of the gas away from the bell.

(*b*) *The Compensation Device.*—The compensation for variation in tabular number conditions is made in two portions, one fixed and the other movable. The fixed portion R (fig. 89) consists of a cylindrical vessel about 4 feet high and 4½ inches in diameter. This is connected by means of a rubber tube to a standpipe which rises through the water tank T. The movable portion consists of a balanced bell U which rises and falls in the water tank T. The bell U is supported by a cord passing over the pulley Y, the axle of which is carried on anti-friction rollers; its counterweight Z is attached to the other end of the cord.

Compensation for the variation in the buoyancy of the bell according to the amount immersed in water is ensured by an additional weight W which is borne by a cord carried on a curve, which is the involute of a circle. This, as is well known, increases the moment of the weight W about the point of support of the pulley, as the bell rises out of the water in such a manner as to compensate exactly for the increased weight of the bell due to the diminishing amount which is submerged, and *vice versa*.

The ascension pipe O passes up centrally through the water tank T, and the moving bell U is provided with a central tube X which fits loosely over the top of the pipe O. The total height of the ascension pipe is thus determined by the position of the bell, which in turn depends upon the expansion and contraction of the air contained in the vessels R and U.

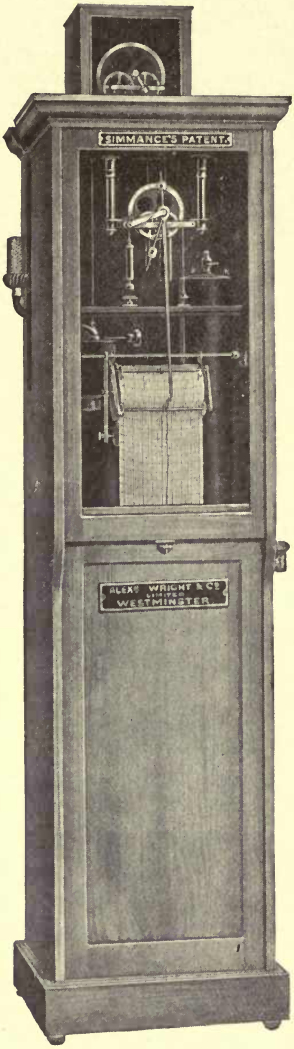


FIG. 90.
SIMMANCE GRAVITOMETER.

The chamber R is fitted with a vent-cock, and a combined thermometric and barometric scale is provided, so that by opening the cock the position of the bell can be set to the scale by the pointer which it carries, according to the prevailing conditions of temperature and barometric pressure.

When this adjustment has been made, the cock is closed. The combined lengths of the air columns in the chamber R and in the bell U is 52 inches when the bell is set for 60° F. and 30 inches barometer. It will be understood that as the compensation device works automatically, the record of the instrument is a record of the specific gravity of the gas automatically corrected for variations in tabular number.

The complete apparatus is illustrated in fig. 90, which shows the disposition of the variation portions of the instrument described in detail above.

PRECAUTIONS TO BE OBSERVED IN USING THE GRAVITOMETER

1. The apparatus should be set up and levelled in a position free from draughts, and not subject to violent fluctuations of temperature.

2. The pressure on the gas supply to the instrument should be at least 1 inch.

3. The surface of the water in the compensator should be covered with about $\frac{1}{6}$ inch of oil to prevent evaporation.

4. It must be borne in mind that when gas is passing through the apparatus the balance and its fittings are in a very delicate state of equilibrium similar to a sensitive chemical balance, and the smallest amount of air entering the ascension pipe will instantaneously destroy the prevailing conditions. The balance will swing back to its air position, the bell sucking in more air down the pipe as it rises; it must therefore be very carefully handled when working. The door should be raised very gently so as not to cause a sudden suction of air over the top of the bell, and when changing a chart the pen should be gently lifted forward while the clock is taken out of its supports.

5. The moving bell part of the compensator must be set to the *reciprocal* of the tabular number, and should be checked and reset if necessary on the day after setting up, when the various parts of the compensator air chamber have acquired an equal temperature ; care must be taken to open the vent cock if any adjustment is made, and to close it afterwards.

6. When the instrument has been set up and adjusted, it requires no further attention other than the necessary changing of the chart and an occasional filling of the pen.

CHAPTER VI

RECORDING CALORIMETERS

The calorific value of a gas is expressed as the number of units of heat obtained by the combustion of a fixed volume of the gas measured under standard conditions.

If the products of combustion of the gas are cooled thoroughly before they leave the calorimeter so that the latent heat of condensation of the water vapour produced is imparted to the calorimeter, the value for the calorific value thus obtained is termed the *gross* calorific value.

If the amount of water condensed, corresponding to the combustion of the fixed volume of gas, be measured and a deduction be made from the gross calorific value on account of its latent heat of condensation, a lower value, termed the net calorific value, is arrived at.

Until a comparatively few years ago one or the other of these values, as measured in a flow calorimeter of any standard type, was taken as the calorific value of the gas. A little consideration, however, will show that the gross calorific value as formerly determined will not represent the true calorific value of the gas, for the following reasons :—

1. The gas and inlet air required for its combustion will vary in their degree of humidity according to the prevailing atmospheric conditions.

2. The products of combustion (excess air, nitrogen and carbon dioxide) issuing from the calorimeter are usually at a temperature different to that of the inlet air or of the inlet gas.

Let V^a = volume of air entering the calorimeter per cubic foot of gas burned.
V^p = volume of products leaving the calorimeter per cubic foot of gas burned.
T^a = temperature of air entering the calorimeter in degrees Centigrade.
T^p = temperature of products leaving the calorimeter in degrees Centigrade.
S^a = water equivalent in kilograms per cubic foot of inlet air.
S^p = water equivalent in kilograms per cubic foot of products.
W^a = weight in grams of water vapour required to saturate 1 cubic foot at T^a.
W^p = weight in grams of water vapour required to saturate 1 cubic foot at T^p.
Q = percentage saturation of air entering the calorimeter.

Then the error due to (1) $= 0{\cdot}6\left(V^pW^p - \left(\frac{QV^a}{100} + 1\right)W^a\right)$ . . . . . (α)

and the error due to (2) $= (V^pS^p - (V^a+1)S^aT^p - T^a)$. . . . . . ($\beta$)

If the values resulting from either of the above equations are positive, the amounts of heat must be added to the observed gross calorific value; if negative, they must be subtracted. In connection with these expressions it should be noted that :—

(*a*) The gas burned in the calorimeter is fully saturated owing to its passage through a wet meter.

(*b*) The specific heat of the gas has been taken as equal to that of the inlet air. This assumption does not introduce any sensible error.

The Gas Acts of 1914 and onwards specify that the "total heat" value shall in future be the standard of calorific value, as may be seen from the following clause taken from one of the Acts, which is practically followed in all the other Acts.

"The apparatus for testing the calorific power of the gas shall be the most suitable for ascertaining—and in making the test shall be used in such a manner and under such conditions as to ascertain, after *any necessary calculations* have been made—*the total heat value* of the gas."

It is therefore evident that if a flow calorimeter of the ordinary type—giving gross calorific value—is employed, knowledge of all the factors in equations (α) and (β) are required in order to make the "necessary calculations" for arriving at the total heat value.

Q is obtained by the use of a suitable hygrometer.

V^a and V^p can be determined by means of the following determinations :—

(*a*) The percentage of carbon dioxide in the products $= p$

(*b*) The amount of carbon dioxide produced per 100 vols. of gas $=$ P.

(*c*) The contraction per 100 vols. experienced by the gas on complete combustion $= c$.

Then
$$V^a = \frac{\frac{100\,P}{p} + C - 100}{100}$$
$$V^p = \frac{P}{p}.$$

It will thus be seen that the calculation of the total heat value from the gross calorific value involves the determination of a number of factors, and requires a much longer time than the actual determination of the gross calorific value itself.

If the calculations embodied in equations (α) and (β) are omitted, the uncorrected gross value may easily be 2 or 3 per cent. lower than the true or total heat value. As the margin allowed by Parliament between the calorific standard and the penalty point in many cases is only 5 per cent., the importance of applying the corrections is obvious.

If, however, a calorimeter be designed so that the inlet air enters the calorimeter fully saturated and at the temperature of the inlet water, then $Q = 100$.

$$(\alpha) \text{ becomes } 0{\cdot}6\,(V^pW^p - (V^a+1)W^a)$$

owing to the contraction experienced in combustion, V^a+1 is always greater than V^p, and hence the products of combustion are allowed to leave the calorimeter at a temperature slightly higher than the temperature of the inlet water; thus W^p is slightly greater than W^a and V^pW^p becomes approximately equal to $(V^a+1)W^a$.

This slight difference between T^p and T^a will lead to the heat expressed by equation (β) possessing a small positive or negative value. As a result of experience with gas of average composition, if $T^p-T^a=1{\cdot}5°$ C., the algebraic sum of (α) and (β) is negligible; in other words, the corrections for "total heat" have been automatically applied by—

1. Complete saturation of the inlet air.
2. Reduction of the inlet air temperature to that of the inlet water.
3. Permitting the products to escape about 1·5° C., above the temperature of the inlet water.

Special flow calorimeters, termed total heat calorimeters, have now been designed, so that the inlet air enters the calorimeter fully saturated and at the temperature of the inlet water. At the same time the products of combustion are so well cooled that they leave the calorimeter at not more than 0·5° C. above the temperature of the inlet water. When such an instrument is employed the calculations involved in equations (α) and (β) are entirely obviated, and the observed calorific value is the true or total heat value of the gas.

When a determination of calorific value is made by *hand*, observations are taken of the volume of the gas consumed, its temperature and the barometric pressure; of the volume of water flowing through the calorimeter during the combustion of the gas, and of the rise in temperature experienced by the water during its passage through the calorimeter.

In the case of a *recording* calorimeter, it is quite obvious that, in order to obtain a record which shall remain accurate over considerable intervals of time, many factors must be taken into consideration which do not arise in the case of determinations made by hand.

$$\text{The calorific value}=\frac{\text{weight of water heated}\times\text{rise in temperature}}{\text{corrected volume of gas burnt}}.$$

In the case of a hand test, all these factors are variables, and in addition the observed volume of gas burnt is subject to correction for temperature and pressure.

It is quite obvious, therefore, that in a recording calorimeter two of the three variable factors in the above equations must be so controlled as to remain constant, or to give a constant multiple for the third factor, which is variable. For example, the conditions will be satisfied if the ratio $\dfrac{\text{corrected volume of gas burnt}}{\text{weight of water heated}}$ is maintained constant.

The change in the one variable (which is a direct function of the calorific value) is recorded. This change, by the use of a suitably inscribed chart, gives direct readings in terms of calorific value.

The variable quantity which is recorded is the rise in temperature experienced by the substance to which the heat of combustion of the gas is imparted.

If the weight of the substance heated and the corrected volume of gas are kept constant, or maintained in constant ratio, this rise is directly proportional to the calorific value—*i.e.* each 1° increase in temperature corresponds to a fixed number of B.T.U.'s of calorific value.

A recording calorimeter must therefore fulfil the following desiderata :—

(*a*) It must automatically consume such a volume of gas that after reduction to standard conditions of temperature and pressure this volume is always constant, and this must be effective under all conditions of atmospheric temperature and pressure, and despite all variations in the specific gravity of the gas.

(*b*) The flow of the substance to which the heat of combustion of the gas is imparted through the calorimeter must be absolutely constant.

(*c*) The method of recording the differential temperature existing between the heated and unheated portions of the calorimeter must be extremely sensitive and must be unaffected by changes in conditions external to the calorimeter.

(*d*) Alternatively to maintaining each of the quantities referred to in (*a*) and (*b*) absolutely constant, the requirements will be fulfilled if the ratio of these quantities is maintained absolutely constant despite all variations in atmospheric conditions and specific gravity of the gas.

Several different types of recording calorimeters have been devised. In certain of these the above-mentioned requirements cannot be fulfilled owing to the design of the instrument. In other cases, as will be gathered from the detailed descriptions which follow, a very satisfactory result has been achieved. Recording calorimeters can be divided into two main types :—

(*A*) Instruments in which the whole of the heat produced by the combustion of the controlled volume of gas is imparted to the substance which flows through the calorimeter at a constant rate, losses due to radiation, etc., being nullified as far as possible. The rise in temperature due to this heat is recorded.

Instruments of this type differ inasmuch as in some cases the corrected volume of gas and the flow of substance through the calorimeter are both maintained constant, and in others the ratio of these two quantities is invariable.

(*B*) Instruments in which only a portion of the heat of combustion of the controlled volume of the gas is imparted to some substance the temperature of which is thereby raised. A balance is established between the heat imparted to the heated substance and radiation and convection losses. The rise in temperature of the heated body —being the result of a balance between heat gains and losses—is connected with the calorific value of the gas by an empirical relationship, and the record is calibrated empirically for this reason.

CLASS A 1. GAS AND WATER FLOWS BOTH MAINTAINED CONSTANT

Simmance Total Heat Recording Calorimeter

Simmance's recording calorimeter was described in the *Gas Journal*, 16th October 1917, and has since been modified in regard to several small details, but the main principles of the instrument have been retained unchanged. The appliance has been the subject of two official tests. One test was carried out by the Fuel Research Board of the Department of Scientific and Industrial Research, and issued as Technical Paper No. 2. The other was conducted by the Research Sub-committee of the Gas Investigation Committee of the Institution of Gas Engineers (Report, 24th May 1921).

The calorimeter was very favourably reported upon in both of these tests, which are referred to later on in the detailed description.

The apparatus comprises a water-flow calorimeter combined with mechanism for continuously recording calorific value of the gas upon a chart. The record obtained shows the calorific value of the gas when reduced to standard conditions—viz. 60° F. and 30 inch barometer, or 0° C. and 760 mm. if required for metric measurements, and is unaffected by variations in atmospheric conditions or by changes in the specific gravity of the gas.

Although the instrument is automatic, an independent check test can be made at any time without interrupting the continuity of the record. The instrument is designed so that the flow of water through the calorimeter, and the amount of gas burnt when reduced to standard conditions, are both maintained constant. The calorific value will thus be directly proportional to the rise in temperature experienced by the water during its passage through the apparatus.

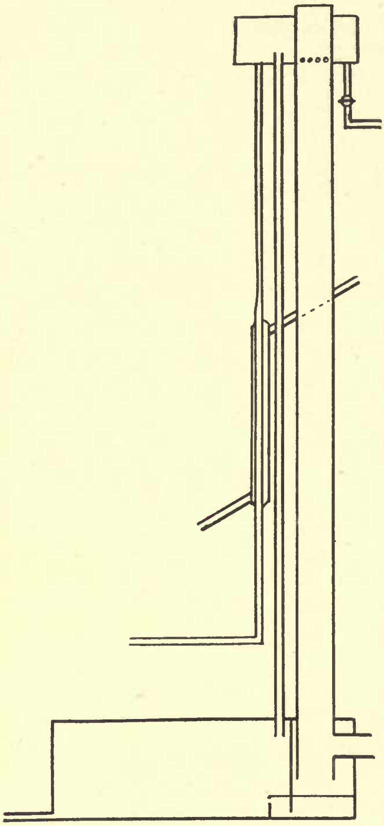


FIG. 91.—WATER FEED FOR SIMMANCE RECORDING CALORIMETER.

1. *The Flow of Water through the Calorimeter.*—The stream of water flowing through the instrument performs two distinct functions. Part serves as the body to which the heat of combustion of the gas is imparted, and part is employed to saturate the inlet air supply and to reduce its temperature to that of the inlet water. It has already been stated that the rate of flow of water through the calorimeter is maintained constant. The method whereby this is achieved will be readily understood by reference to the diagram (fig. 91), which shows the portion of the instrument through which the water flows until the regulated flow reaches the body of the calorimeter.

The water enters the calorimeter at the base and passes upwards to the top of the saturating tower, where it is exposed to the air in the small reservoir. It then divides into three streams.

(*a*) The first stream flows through fine perforations into the interior of the saturating tube, thus providing a thin annular stream of water which serves to saturate the inlet air (all of which has to come down this tube) and to reduce its temperature to that of the inlet water.

(*b*) The second stream passes down the tube, and is the surplus water over that necessary to maintain a constant head in the reservoir. This stream may be reduced to the smallest trickle, as it serves only as an indication of the constant head and runs to waste.

(*c*) The third stream passes first to a weir valve, which maintains a constant head of water over a jet. The controlled quantity of water passing this jet is led to the calorimeter proper, and the excess passes over the weir through a connecting tube leading to the cold member of the recording mechanism. After flowing round this member, it is conducted to the safety gas-cock to maintain the gas flow.

The jet referred to above is composed of a specially coned gold plate, which is unaffected by corrosion, and which has been found in practice to be free from all tendency to " build up " and alter in size by the gradual deposition of matter from the water.

The water discharges freely from the gold jet into a glass tube, which carries the inlet water mercury thermometer employed for hand tests of the calorific value.

The water at first rises in the inlet tube to a certain point which is noted and marked by a pointer, the height to which the water rises being such that the head is sufficient to discharge all the water which enters the calorimeter through its outlet.

This device enables the accuracy of the water flow to be checked at any time at a glance. Should the jet become partly stopped up in any way, the water flow will drop and the level of the water in the glass tube will fall below the mark. The jet should then immediately be cleaned with a soft wood stick.

If, on the other hand, the resistance of the calorimeter to the flow increases, the head will automatically build up in the inlet tube until sufficient pressure is obtained to restore the flow to its former rate.

This automatic variation also eliminates all errors due to viscosity of the water, as changes in the latter will be accompanied by concomitant alterations in the inlet water head.

The automatic head will maintain the flow of water constant to within plus or minus 1 per cent. over long periods. The nature of the water supply will, however, form the chief factor in deciding how long the calorimeter can be run before cleaning becomes necessary.

The water has been exposed to four heads open to the air before actually entering the body of the calorimeter. It falls from each of these to the next head by gravity alone. Air bubbles suspended in the water have ample opportunity to escape at these open heads, and thus air-locks, leading to considerable inaccuracy, are completely obviated.

The water passes from the chamber containing the inlet water thermometer and bulb of the differential down a pipe (fig. 92) to the base of the calorimeter. It then enters a shallow ring, from which it emerges on the side opposite to the inlet, and is guided to the top of the calorimeter through a spiral path which is so limited in width that irregularities due to convection, with the consequential variations in the outlet water temperature, are completely avoided.

The water at the top of the calorimeter enters a spiral passage in a massive casting, and finally emerges from a central hole, $\frac{7}{64}$ inch diameter. The top of the casting is fitted with a screw thread, and the outlet bulb of the differential thermometer is fixed to it. The water passes up through the central passage of the bulb and over the bulb of the outlet mercury thermometer, coming again to an open head under a loosely fitting wooden cover for the liberation of air, then down on the outside of the bulb and up through a tube to the outlet spout.

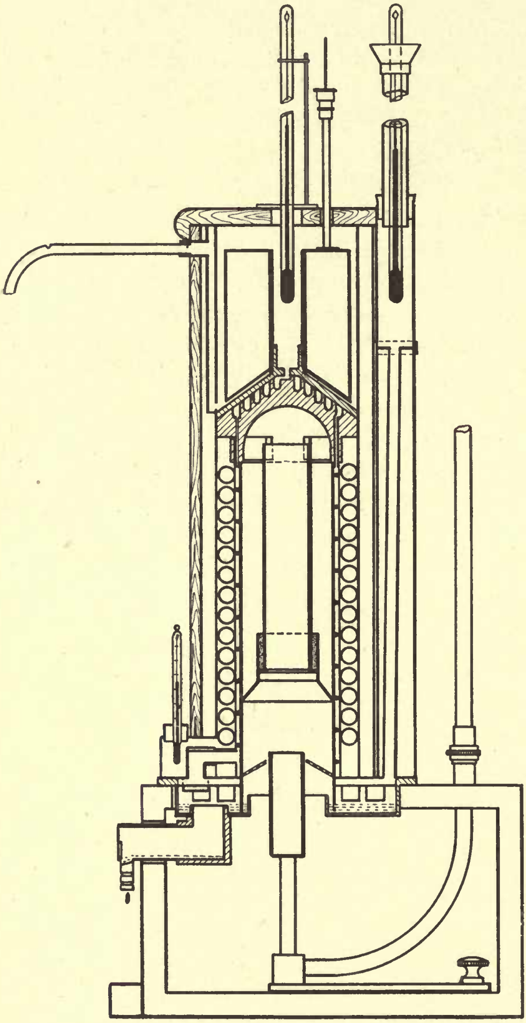


FIG. 92.—SECTION OF HEAT INTERCHANGER OF SIMMANCE RECORDING CALORIMETER.

The body of the calorimeter is lagged by a wooden jacket and cover and a ½-inch space filled with non-conducting material to reduce radiation losses to a minimum. This method of lagging is not perfect, as small radiation losses do occur.

The calorimeter when employed for hand determinations is, however, in agreement with Junkers & Boys calorimeters (after the necessary corrections for "total heat" readings to the latter instruments), and the lagging is therefore as effective as in these instruments, both of which are largely employed as standard calorimeters.

2. *The Flow of Air through the Calorimeter.*—The air required for the combustion of the gas enters the calorimeter at the top of the saturating tower, which is about 4 feet long and 2 inches in diameter. The inlet water (as stated above) enters by the holes near the top and forms a continuous film on the inner surface, which serves to saturate the air and reduce its temperature to that of the inlet water. The cooled air falls by gravity, and is also drawn into the burner box by the draught caused by the rising column of the hot products of combustion over the burner. As the cooled air falls it is replaced by fresh air from the room, which in its turn becomes saturated and cooled. The cooled and saturated air enters the burner box at the back and flows round a baffle plate and then over the burner. It then passes through a perforated plate in the base of the calorimeter, which serves to break it up and prevent draught on the flame.

After its passage over the burner, the inlet air becomes heated products of combustion, mixed with excess of air. These rise to the top of the combustion chamber and then pass through rectangular ports into an annular space parallel to the walls of the combustion chamber, and separated from the latter by a water space (see fig. 92).

The heated gases are thoroughly cooled, the process of heat transference being assisted by coils of wire soldered to the water-jacket and projecting into their path. The products of combustion and excess air pass downwards and finally emerge through two circular openings about 1 inch in diameter near the base of the calorimeter.

The combustion chamber (fig. 92) is composed of a silica tube 7 inches by $1\frac{1}{4}$ inches by $\frac{1}{4}$ inch thick, which serves to carry the products of combustion to the top of the calorimeter. Formerly a metal combustion chamber was employed, and this led to trouble owing to detached particles—the results of corrosion—falling on the gauze top of the burner. The use of the incorrodible silica tube obviates this trouble.

The products of combustion leave the calorimeter in a saturated state and at a temperature of about 1·5° C. above the temperature of the inlet water. This slight amount of heat is allowed to leave the calorimeter in order to compensate for the contraction experienced on combustion (see p. 106).

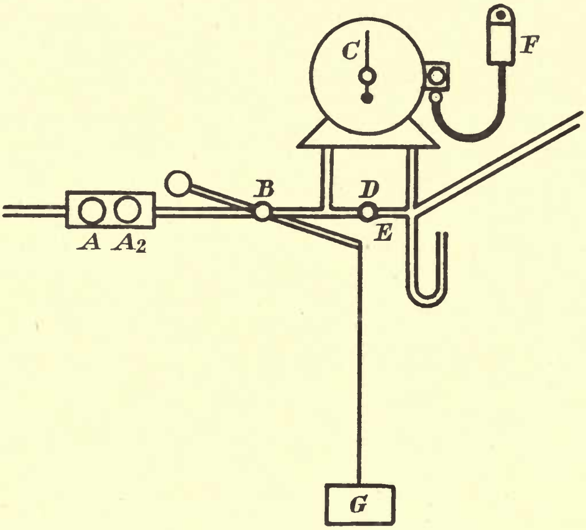


FIG. 93.—METER AND SAFETY COCK, SIMMANCE RECORDING CALORIMETER.

3. *The Flow of Gas through the Calorimeter.*—The gas enters the calorimeter through a $\frac{1}{2}$-inch brass tube, and then passes through two small dry governors A_1 A_2 (fig. 93), $2\frac{1}{4}$ inches in diameter, connected in series. These governors maintain the pressure constant to within about $\frac{1}{20}$th of an inch, and as $\frac{6}{10}$th of an inch water pressure increase will only augment the gas rate by 0·5 per cent., errors due to varying gas pressure cannot occur.

The gas next passes through a safety cock B (fig. 93). This device consists of a bucket G which is kept filled with water from the surplus overflow. Should this overflow cease (and this will occur automatically before the calorimeter supply stops), the bucket empties through a perforation in its base, and the cock B is automatically turned off as the empty bucket is overbalanced by the counterweight on the opposite side of the cock lever.

The calorimeter is thus prevented from injury should the water supply accidentally fail through any cause; and should the supply be resumed, the overflow falls clear of the bucket until reset by hand.

The gas, after passing the safety cock, goes through the meter C (fig. 93), or alternatively, it may be passed through the by-pass D by means of a cock E which cuts the meter in and out of the circuit as required.

The meter is provided for carrying out the hand determinations of calorific value. It has a capacity of $\frac{1}{10}$th cubic foot per revolution, and is of a very simple pattern. Except for the hand determinations, the meter is not required, and the by-pass referred to above is provided so that the meter can be cut out of the circuit except when it is desired to carry out a hand test.

The object of this is to reduce the frequency with which it is necessary to correct the water-line of the meter. Water for adjustment of the water-line of the meter is obtained from the reservoir F. If however the meter is by-passed, the gas contained therein will be stale, and when a hand determination is to be made, it is necessary to allow about fifteen minutes to elapse to give time for the stale gas in the meter to be replaced.

After leaving the meter, the gas is passed through the gas cooler—a jacket surrounding the pipe conveying the inlet water to the calorimeter. The gas cooler lowers the temperature of the gas and condenses out some of the water, leaving the gas saturated with water vapour at the temperature of the inlet water. The gas passes from the gas cooler through a metal pipe to the inlet valve of the gravity governor.

Description of Gravity Governor.—The discovery of the principle upon which the gravity governor works and the invention of the appliance are due to Simmance. The governor is a unique device for the volumetric control of the gas supplied to the burner.

The adjustment of the flow is automatic and is regulated by the changes of specific gravity, and atmospheric conditions of temperature and pressure—the actual variations for which it is designed to compensate.

It will always deliver a volume of gas that, when it is reduced to standard conditions (60° F. and 30 inches barometer, or 0° and 760° C. for metric measures), will be constant notwithstanding changes in atmospheric temperatures and pressure, or of the specific gravity of the gas itself. Owing to this control, the record inscribed on the chart does not require any correction for changes in tabular number.

The top of the inlet passage (fig. 94) is countersunk to form the seating for the inlet valve. The latter is attached to an equal lever arm which is slightly cranked and pivoted in two steel bearings. A small roller E receives the thrust of the valve tappet, the face of which is composed of plate glass. The balanced bell A is made of aluminium, and is rigidly attached at one end of a balanced beam which is carried by two hardened steel pivots engaging in a cone and V respectively. The bell is counterpoised by two brass cylinders, each of which are threaded on to fine screws. The larger serves for the coarse adjustment, and the smaller gives the final fine adjustment.

The bell is sealed in an annular trough BB^1 which is filled until it overflows into the outer chamber, which serves as a catch-pot. The oil employed is specially selected for non-volatility, freedom from acids, and from tendency to "gum" on long exposure to air. In addition, the surface tension and viscosity should be low, so that free movement of the bell under slight changes of load is not impeded, especially at low temperatures.

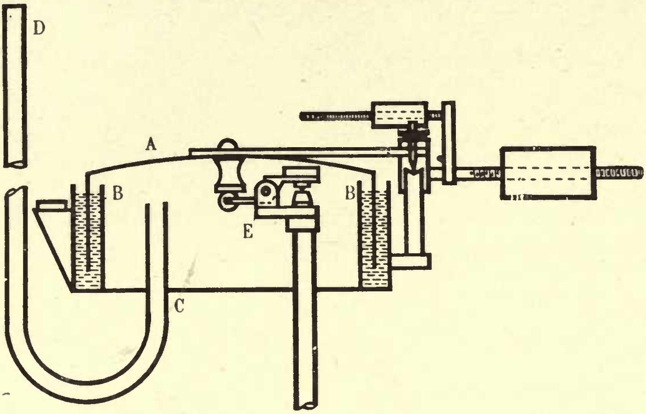


FIG. 94.—SECTION OF SIMMANCE'S GRAVITY GOVERNOR.

The surface of oil exposed to the gas inside the bell is very small, so that errors are not introduced either through absorption of some of the constituents of the gas or through liberation of hydrocarbon vapours from the oil.

The gas leaves the bell through a $\frac{1}{2}$-inch pipe, which passes down the burner box at the base of the calorimeter, and is connected to the burner by a short length of rubber tubing.

The burner is made in two portions, the upper telescoping over the lower. This arrangement enables the flame to be brought well up into the calorimeter, thus reducing radiation losses from the burner and preventing any slight reheating of the products of combustion as they leave the calorimeter. The burner box is of wood and is provided with a glass door. An inclined mirror suitably placed inside the box enables the flame to be observed without the necessity of opening the box, which as already stated, is practically air-tight.

Theory of Gravity Governor.

1. *Correction for Variation in the Specific Gravity of the Gas.*—The balanced bell and the tank G form a delicate *pressure* governor which gives a constant pressure as usual in governors of this type.

The chief forces acting upon the governor bell are :—

1. Its weight acting downwards.
2. The weight of the counterpoise acting upwards.
3. The buoyancy effect of the portion of the bell immersed in oil and the surface tension of the oil.
4. The upwards thrust of the valve roller on the valve tappet.

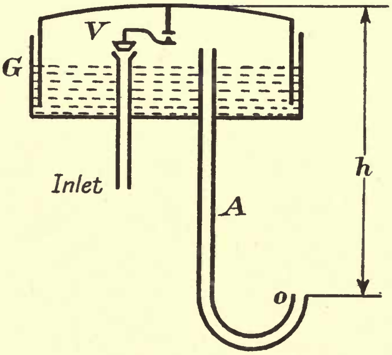


FIG. 95.—THEORY OF SIMMANCE GRAVITY GOVERNOR.

These forces may be represented by a resultant force acting downwards at the centre of the bell. This force is a constant for each instrument and is of the order of 20 grams.

If this resultant force is W grams and the area of the horizontal projection of the bell is a square inches, then gas pressure at governor

$$= \frac{W}{a} \text{ grams per square inch.}$$
$$= \text{say } P.$$

Owing, however, to the position of the burner orifice relative to the crown of the bell, the effective pressure at the orifice O is either increased or decreased by the addition or subtraction of a force, the value of which is dependent upon the specific gravity of the gas in the tube A.

Observations of the gas pressure at different levels in a vertical pipe show a progressive variation which is proportional to the distances from any point. The arrangement is similar in this respect to the balancing columns of air and gas referred to in the descriptions of the gravitometer (see Chapter V.), and the pressure at the orifice O differs from the pressure at the crown of the bell by an amount equal to the difference in the weights of the columns of air and gas of unit area and of height equal to the distance between the orifice O and the crown of the bell.

Let P_0 equal orifice pressure.

P ,, gas pressure at governor $\left(\frac{W}{a}, \text{ see above}\right)$.

h ,, distance between the orifice O and the crown of the bell.

w ,, weight of unit volume of air at N.T.P.

s ,, specific gravity of the gas (air=1) at N.T.P.

Then
$$P_0 = P - hw(1-s). \quad . \quad . \quad . \quad . \quad . \quad . \qquad (\alpha)$$

For gases specific gravity less than 1, $hw(1-s)$ is positive and the pressure at the orifice is less than at the governor.

The efflux of a gas through an orifice under conditions which are constant, except for changes in pressure and specific gravity, is proportional to the square root of the pressure, and inversely proportional to the square root of the specific gravity, or

$$\text{volume} = K\sqrt{\frac{P_0}{s}}\cdot$$

If the governor functions correctly and passes a constant volume of gas irrespective of changes in specific gravity,

$$\text{then} \quad V = K\sqrt{\frac{P_0}{s}} \text{ must be a constant,}$$

$$\text{or} \quad \frac{P_0}{s} = \text{a constant,}$$

$$\text{or} \quad P_0 = K^1 s \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (\beta)$$

From (α).
$$P_0 = P - hw(1-s)$$
$$= P - hw + hws.$$

Hence in order to satisfy (β) $P-hw$ must be zero.

$$\therefore \quad P = hw$$
$$\text{or} \quad P_0 = hws. \quad . \quad . \quad . \quad . \quad . \quad . \qquad (\gamma)$$

That is to say, if the governor bell is balanced so as to give a pressure equal to that exerted by a column of air of height "h," then the orifice pressure is always proportional to the specific gravity of the gas passing, which is the condition required for the passage of a constant volume notwithstanding specific gravity changes.

2. *Correction for Changes in Atmospheric Temperature and Pressure.*—The argument enunciated above does not take account of barometric and temperature changes —*i.e.* variations in the tabular number corresponding thereunto.

Let the conditions be such that unit volume at N.T.P. becomes N under other conditions.

Let P_{0_N} = orifice pressure under these conditions.

From (α) we have

$$P_{0_N} = P - hw(1-s)N, \quad . \quad . \quad . \quad . \quad . \qquad (\delta)$$

since air and gas volumes are equally affected by pressure and temperature changes.

When the bell is balanced so that $P = hw$

$$(\delta) \text{ becomes} \qquad P_{0_N} = hw - hw(1-s)N.$$
$$= hw(1-N) + hw\,sN.$$

In other words, a change from N.T.P. to " N " conditions (presuming " N " to be less than 1·000) alters the orifice pressure :—

(1) By decreasing P_0 proportionally to the change to " N."

(2) By increasing P_0 by the addition of a weight of a volume of air also proportional to the change to " N."

From the formula

$$\text{Volume} \qquad Q = K\sqrt{\frac{P_0}{s}}$$

$$\text{We have} \qquad Q = K\sqrt{\frac{hw(1-N)+hwsN}{sN}}$$
$$= K\sqrt{\frac{hw(1-N+sN)}{sN}}.$$

This expression must be multiplied by N to give the volume at N.T.P.

Therefore volume corrected to N.T.P.

$$= \left[K\sqrt{\frac{hw(1-N+sN)}{sN}}\right]N$$

$$\text{or } Q_{\text{N.T.P.}} = K\sqrt{\frac{hw(1-N+sN)N}{s}}$$

hw is a constant.

$$\therefore \quad Q_{\text{N.T.P.}} (\infty) \frac{(1-N+sN)N}{s} .$$

Note.—The density of the gas is altered absolutely by a change in temperature and pressure although its destiny relative to air, subjected to the same conditions, remains constant.

The change in orifice pressure due to change in conditions is, from (γ) and (δ),

$$hws - hw(1-N) + hwsN$$
$$= hw(1-N)(1-s).$$

This expression is positive for tabular numbers below 1000 and negative for tabular numbers above 1000—P_0 is *increased* when N *decreases*, and *vice versa.*

It is thus evident from equation (γ) that Simmance's gravity governor performs automatically the paradoxical task of increasing the orifice pressure when an increasing density is due to *constitutents,* and decreasing the orifice pressure when an increasing density is due to changes in temperature and pressure, and *vice versa.*

The following table gives the values of the expression $\frac{(1-N+sN)N}{s}$ for various specific gravities, and values of the tabular number. The numbers in the table show the variation of gas flow on unit volume at N.T.P.

(*Density Relative to Air*=1)

Tabular Number.	·1	·2	·3	·4	·5	·6	·7	·8	·9	1·00
950	1·1737	1·0677	1·0300	1·0100	·9987	·9908	·9850	·9808	·9773	·9747
960	1·1400	1·0551	1·0245	1·0087	·9992	·9928	·9881	·9847	·9820	·9798
970	1·1099	1·0422	1·0188	1·0067	·9995	·9942	·9911	·9885	·9865	·9849
980	1·0754	1·0288	1·0128	1·0046	·9998	·9965	·9942	·9924	·9910	·9899
990	1·0388	1·0147	1·0065	1·0024	·9999	·9983	·9970	·9962	·9958	·9949
1000	1·0000	1·0000	1·0000	1·0000	1·0000	1·0000	1·0000	1·0000	1·0000	1·0000
1010	·9587	·9847	·9932	·9974	·9999	1·0016	1·0028	1·0040	1·0043	1·0050
1020	·9090	·9687	·9861	·9947	·9998	1·0032	1·0056	1·0074	1·0088	1·0099
1030	·8671	·9521	·9787	·9917	·9995	1·0047	1·0083	1·0116	1·0132	1·0149
1040	·8158	·9347	·9710	·9887	·9992	1·0061	1·0111	1·0147	1·0175	1·0198
1050	·7599	·9165	·9630	·9855	·9987	1·0075	1·0130	1·0182	1·0219	1·0247

The area enclosed by the lines in the diagram (fig. 96 herewith) shows graphically the limits of tabular number and specific gravity within which the variation in the quantity of gas passed by the gravity governor referred to N.T.P. is less than plus or minus 1 per cent. The variation in the area outside the black lines is about 1·1 per cent.

It will be observed that, whilst accurate compensation for temperature and pressure changes is not possible for all specific gravities, the area enclosed by the heavy lines in fig. 96 covers all conditions normally to be met with.

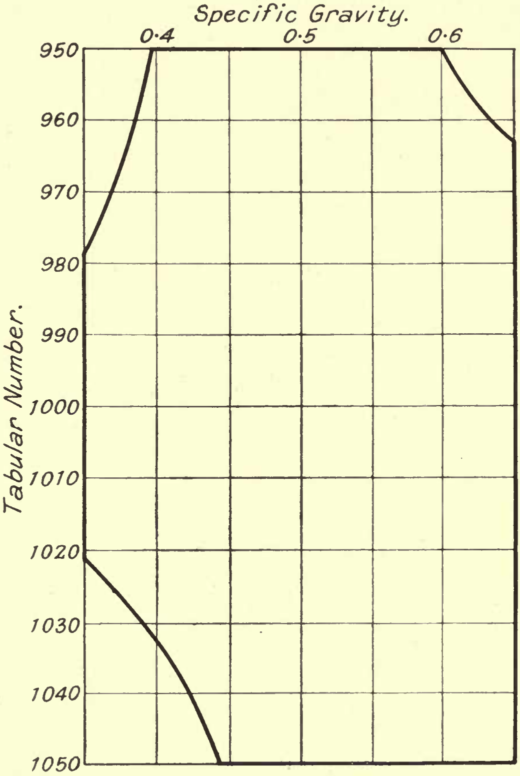


Fig. 96.—Limits of Accuracy of Simmance Recording Calorimeter.

Furthermore, most town gas mixtures have a specific gravity in the neighbourhood of 0·5, the condition for which the temperature and pressure correction is perfect over the greatest range.

The gravity governor is " rated " by the makers, by so adjusting the loading, that gases of widely differing specific gravities, such as hydrogen, coal gas and air, all pass at exactly the same rate at N.T.P.

3. *The Recording Thermometer.*—It has already been shown that as the gas and water flows are maintained absolutely constant, the rise in temperature experienced by the water during its passage through the calorimeter is proportional to the calorific value.

The rise in temperature is necessarily small, as if it be large, considerable errors due to radiation losses would result. The precise rise is of course dependent upon the amount of water flowing through the calorimeter, but is usually about 10° C. in the case of a gas of 500 B.Th.U.'s. Hence each $\frac{1}{10}^\circ$ C. corresponds in this case to 5 B.T.U.'s.

The rise in temperature is recorded by a differential air thermometer which inscribes the rise in temperature on the chart, which is calibrated to read directly in calorific value corrected to N.T.P.

The thermometer, as fitted to the earlier instruments, consists of two cylindrical vessels A and B (fig. 97) of stout tinned copper each about 800 c.c. in capacity. These form the hot and cold bulbs respectively. They are connected by fine copper capillary tubes to two sets of aneroid chambers C and D. The aneroid chambers consist of six compartments (fig. 97 only shows four, but is merely diagrammatic), and are securely fastened to a strong framework E.

They are fastened to each end of a stout rod F, which is connected to the pen mechanism at G. The two diaphragms work in opposition to each other along the rod, which is free to move in a direction parallel to its length. Any movement is therefore occasioned by differential changes in the temperature at the bulbs A and B. The slight movement thus produced is magnified by the lever system and communicated to the recording pen.

The mechanism is loaded so that the moving portions are always maintained in a state of tension, thus avoiding any back-lash.

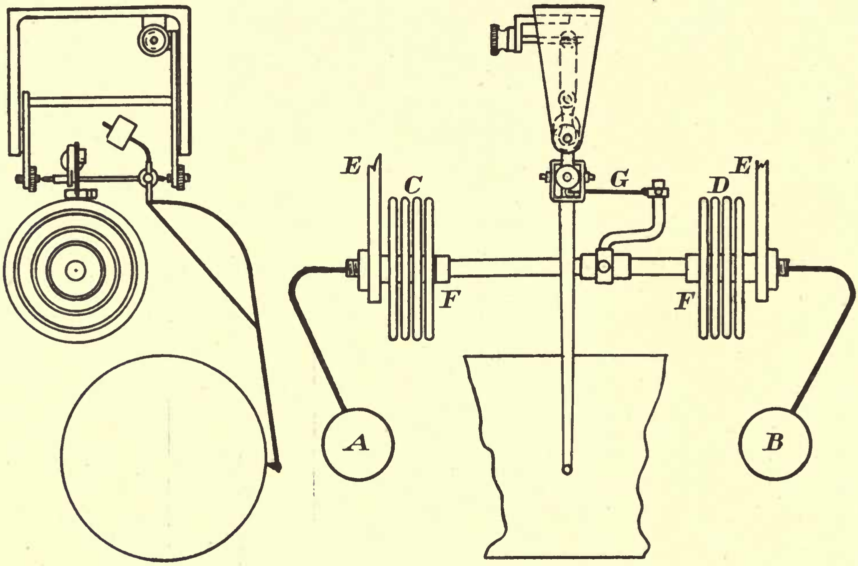


Fig. 97.—Simmance Differential Thermometer (Early Pattern).

Simmance has recently devised a different form of recording thermometer which displays several advantages over this earlier pattern. The thermometer bulbs are connected to the two aneroid chambers AA_1 (fig. 98), which are mounted one above another in a framework B, and are fixed by their bases to horizontal brackets C and D. The lower bracket D is pivoted and can be tilted up or down by rotating a set-screw E. This movement affords the zero adjustment. The upper face of the top chamber carries the horizontal portion of a metal stirrup F. The latter carries a horizontal spindle G, which is mounted in bearings attached to the lower end of the arms of the stirrup. The upper face of the lower container is connected to this spindle by means of an adjustable link and crank H. The pen arm I is fixed to the spindle G.

The horizontal portion of the stirrup F is connected by a link to a lever K, which is pivoted on bearings on the upper portion of the frame. The other arm of the lever is provided with an adjustable counterweight L.

So long as the pressures in the two aneroid chambers are equal the spindle G will not be rotated, since any increase of pressure in the upper chamber will raise the stirrup to an extent exactly equal to that to which the outer end of the crank H of the spindle is raised by the same pressure acting upon the lower chamber. Any differential pressure (which is due to the difference in the temperatures of the "hot" and "cold" bulbs) will cause relative vertical movement between the stirrup F and crank H.

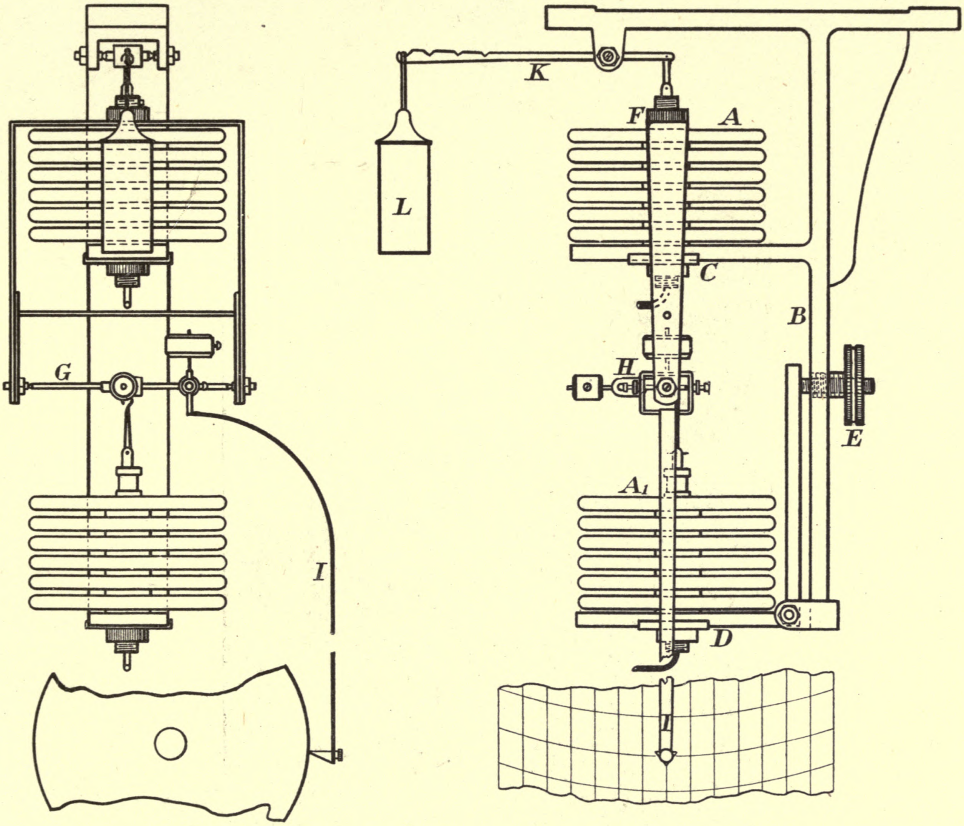


Fig. 98.—Simmance Differential Thermometer (Latest Pattern).

The spindle will therefore be rotated and will thus cause the pen to move across the chart.

The differential thermometer is, as will be gathered, provided with a controlling force due to the adjustable weight L which is additional to that due to the natural resiliency of the aneroid chambers. This arrangement has several advantages :—

(*a*) The arrangement is more sensitive.

(*b*) The movement can be arranged to take place over that portion of the range in which the expansion is regular for equal increments of pressure.

(*c*) The difficulties of exactly matching the two chambers are overcome.

The foregoing detailed description covers the whole of the instrument, which is shown complete in fig. 99.

The disposition of the various portions of the instrument relative to each other will be gathered from this figure, and from the sectional diagram (fig. 100).

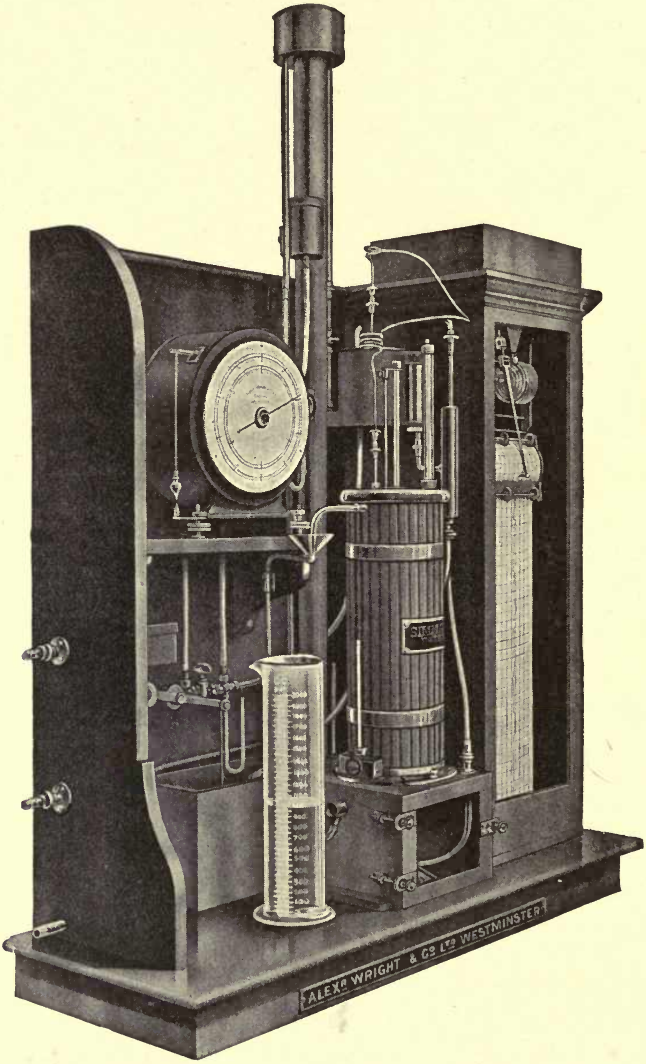


Fig. 99.—Simmance Total Heat Recording Calorimeter.

Precautions to be observed in using Simmance's Total Heat Recorder.—1. It is very desirable to maintain the temperature of the room in which the recorder is installed as constant as possible, and if possible to within plus or minus 5° F. of 60° F. Inspection of the table on p. 116 shows that if this is effected, the reliability of the gravity governor will be increased. In addition to this, radiation gains or losses (which occur with all flow calorimeters to some extent, whether recording or not) will be reduced to a minimum. The flow of inlet air past the gas burner will be maintained constant if the temperature is fairly steady. This is desirable, as if the rate of flow alters materially the consumption of gas is affected to some extent.

2. The instrument should be protected from draughts, which may otherwise cause local changes leading to irregularities in the record, and must not be exposed to direct sunlight.

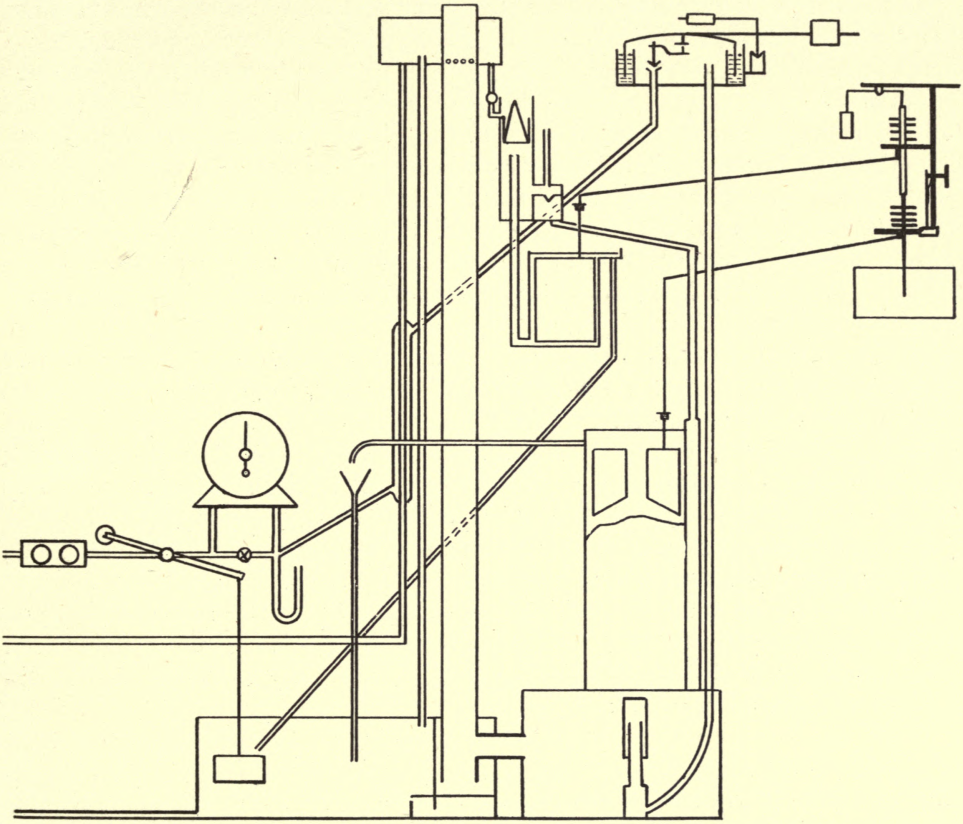


Fig. 100.—Diagram of Simmance Total Heat Recording Calorimeter.

3. The inlet water should be supplied at a fairly constant temperature, and for this purpose should be either drawn direct from the main or from a storage tank fed directly from an underground supply. It should be noted that *gradual* temperature fluctuations of the inlet water are immaterial, as there is ample time for these to be communicated to the outlet thermometer. Sudden temperature changes must be avoided, as these will be communicated to the inlet thermometer before the outlet thermometer is affected, thus resulting in a temperature difference which is not due to the combustion of the gas.

4. A constant suction should be maintained on the gas supply, so that the portion consumed in the calorimeter is always fresh and any changes are rapidly shown. The gas consumption of the calorimeter itself is only 2 cubic feet per hour, which is insufficient to ensure the necessary clearance of the supply pipe. For this reason an auxiliary burner—quite independent of the calorimeter—is required to produce the necessary draught on the supply.

5. Before checking the calorific value by a hand determination, care must be taken that the water-line of the meter is correct. If the meter has been by-passed, the gas should be allowed to pass through it for at least 15 minutes before making a test.

Precautions necessary to maintain the Instrument in Working Order.—1. Certain varieties of water tend to deposit upon the nipple dissolved matter which slowly alters the flow. Occasional observations of the amount of water flowing through the calorimeter in three minutes should be made. If this amount varies *at all*, the nipple should be cleared by passing a soft match stick very gently through the nipple from above. This is turned round once or twice, thereby removing any deposit. The rate of water flow will then be found to have returned to its normal value. The nipple is soft, and care must therefore be taken not to enlarge it permanently.

2. Similar deposits in the calorimeter do not, as explained above, alter the rate of the water flow as the head in the inlet tube of the calorimeter automatically adjusts itself to the resistance offered. Should the obstruction in the calorimeter become too great, as evidenced by a considerable increase in the " head " on the inlet tube, a little dilute hydrochloric acid is added to the inlet water. This dissolves any deposit without injury to the body of the calorimeter.

3. The gold nipple at the base of the burner tube should be examined occasionally, and if dusty, should be cleaned with a splinter of soft wood.

Owing to the combustion chamber being composed of silica there is little or no tendency for any products of corrosion to drop on to the gauze top of the burner. It is, however, desirable to examine the latter occasionally to ensure its freedom from all foreign matter.

4. The safety cock must be maintained in working order, as if never moved it may stick and not function when required. It may be turned on and off rapidly by hand at any time without extinguishing the gas or interfering with the apparatus in any way. This will ensure its necessary freedom of movement.

The fact that Simmance's recording calorimeter has been the subject of two separate official investigations of a very complete nature was referred to above. The conclusions arrived at in these reports are of considerable interest, and are therefore given below.

A. SUMMARY TAKEN FROM THE FIFTH REPORT OF THE RESEARCH SUB-COMMITTEE OF THE GAS INVESTIGATION COMMITTEE OF THE INSTITUTION OF GAS ENGINEERS.

" The following summary is based upon our Investigation of and experience with the instrument (Simmance's Total Heat Recorder), and considerations of the result obtained.

"1. Firstly, as to the control of the gas rate—an essential point in a recording calorimeter.

"The governor automatically compensates satisfactorily within certain limits for changing specific gravity of gas supplied to it, and for changes in atmospheric temperature and pressure. The range of temperature and pressure over which the governor is satisfactory depends upon the specific gravity of the gas. Theoretical considerations indicate the following maximum systematic changes in the gas rate for an instrument adjusted at 60° F. and 30 inch barometer, and subjected to temperature changes ranging from 50° to 70° F., and barometric changes of 28·5 to 30·5 inch :—

"For specific gravity 0·4 (*e.g.* rich coal gas) +0·5 per cent. to −0·6 per cent. or plus or minus 0·5 per cent. about a mean value.

"For specific gravity 0·5 (*e.g.* ordinary town gas) +0·6 per cent. to −1·8 per cent. or plus or minus 1·2 per cent. about a mean value.

"For specific gravity 0·6 (rather abnormal) +1·4 per cent. to −2·9 per cent. or plus or minus 2·2 per cent. about a mean value.

"With the much smaller variation of laboratory temperature likely to be experienced over a period such as a day or a week, this error would be decreased to a corresponding degree.

"The change in gas rate caused by a change in the specific gravity of the gas, for given conditions of temperature and pressure, may be determined by interpolation, using the data given in Table VII. for the specific gravities 0·4, 0·5, and 0·6. The changes will in general fall within the limits given above.

"2. Our tests have shown at times a further change in the gas rate due to slight mechanical defects, mainly in the burner, limited to about plus or minus 1 per cent., if the burner received daily attention, but otherwise liable to be progressive. It is, however, believed from our observations that with a later type of calorimeter this difficulty will not be encountered, and that the variation in governing will only slightly exceed that indicated under (1), even with the wide variations of temperature and pressure taken.

"3. Control of room temperature is desirable and improves the governing, but the precautions necessary to secure closer regulation than plus or minus 5° F. are not accompanied by a commensurate improvement in governing. Closer regulation is necessary for other reasons, connected chiefly with radiation gains and losses from the calorimeter.

"4. With respect to the water rate, which should be constant, this had a tendency to slow down gradually, and could not be depended upon to remain constant within 1 per cent. for more than a day or two.

"With the water used at Birmingham, derived chiefly from moorland sources, there was a more or less regular decrease in the water rate of 0·5 to 1·0 per cent. per twenty-four hours, due to a deposit of slimy material.

"This seriously restricts the period over which the instrument may be left unattended, without the errors accumulating over a permissible amount, while the water passages of the instrument are not easy to clean in a satisfactory manner.

“ 5. Excellent provision has been made for freeing the water from air, and no irregularities in the water rate have been traceable to air-locking with the instrument examined.

“ 6. On account of changes in viscosity of water with temperature there is a change in the water rate of approximately 0·7 per cent. per ° C. (0·4 per cent. per ° F.) change in temperature of the inlet water.

“ There is also a change in the water rate of 0·3 per cent. for each ° C. change in the difference between inlet and outlet water temperatures.

“ 7. With respect to errors under (4) and (6), a later modification of the recorder offers a prospect of the control of the water rate within plus or minus 1 per cent. over considerable periods.

“ 8. The air saturator eliminates errors due to variable humidity of the atmosphere.

“ 9. The recording mechanism indicates satisfactorily the temperature differences between inlet and outlet water.

“ 10. We had great difficulty, which may be experienced elsewhere, in obtaining a water supply which will yield a steady and satisfactory inlet temperature. Errors in the charted C.V., due to fluctuating inlet temperature, may be very considerable.

“ 11. Given a steady inlet water temperature, the outlet temperature is steadier in this than in any other calorimeter we have yet examined, presumably owing to the special construction of the calorimeter head.

“ 12. The calorimeter is liable to radiation gains and losses equivalent to plus or minus 1·5 B.Th.U. per cubic foot for each °F. difference between the mean temperature of the calorimeter body and that of its surroundings.

“ 13. The direct results obtained with the non-recording calorimeter agree with those from the Junker & Boys calorimeters when the results of the latter are fully corrected for atmospheric humidity, within the limits of experimental error—*i.e.* the same C.V. to plus or minus 0·5 per cent. should be obtained whichever of the three instruments is used for a determination.

“ 14. The Simmance recorder responds extremely well to changes in C.V. of the gas supplied to it, and changes of plus or minus 25 B.Th.U. are fully established on the chart in from ten minutes to a quarter of an hour from the time at which the gas of altered quality reached the calorimeter.

“ 15. With respect to the instrument as a continuous recorder, it is not possible to make a statement which shall be unconditionally true and apply unreservedly to the various conditions of use likely to be encountered in practice.

“ The behaviour of the governor and temperature recording device is in good general agreement with the makers’ statement ; errors introduced by corrosion of the burner, and more especially by the character of the water supply, are not regular nor subject to precise mathematical expression, and individual experience is likely to vary greatly.

“ 16. For control of gas manufacture for large consumers of gas and for research purposes, where the necessary staff is available for daily inspection and adjustment (if necessary) of the recorder, it is likely to prove a valuable instrument.

“ Under such conditions the record may be relied upon to within plus or minus

1 to 1·5 per cent. over twenty-four hours, and, therefore, if adjusted every day, will continue to be correct within those limits.

"17. With respect to longer periods and general conditions of use no definite statement is possible; if left unattended, for example, under the conditions of testing at Birmingham (by no means abnormal), the recorded calorific value would be doubtful at the end of a week, and almost certainly useless at the end of a month. It will be readily understood, however, from the preceding analysis of the way in which the errors arise, that if the instrument can be used on gas of specific gravity 0·40 to 0·45 with a suitable water, and with very small temperature variations in water and surrounding air, the liability to error is greatly diminished thereby, and satisfactory records may be obtained over considerable periods without the amount of attention necessary under less favourable circumstances.

"18. Although so good an instrument in many respects, the recorder we tested could not in our opinion have been rightly made the basis of monetary charges or penalty clauses under the Gas Regulation Act, unless installed under special conditions and subjected to continuous skilled supervision."

In respect to these conclusions, it should be noted that the trouble experienced with the alteration of water rate referred to in paragraph (4) is completely obviated with the new automatic-head device described in the context and the nipple construction. This was not fitted to the calorimeter examined.

For reasons already explained, the later arrangement also eliminates the errors due to changes in the viscosity of the water referred to in paragraph 6.

This automatic head is the modification referred to in paragraph 7.

The mechanical defects and the attention to the burner referred to in paragraph 2, and also the corrosion of the burner mentioned in paragraph 15, are eliminated by the use of the silica combustion chamber, which was not fitted to the instrument examined. These improvements greatly lengthen the periods over which the recorder can be relied upon without adjustment, and will modify considerably the statements in paragraph 17.

B. Summary taken from Technical Paper No. 2, Fuel Research Board. Report on the Simmance Total Heat Recording Calorimeter

"Considering the many difficulties to be overcome in designing a reliable recording calorimeter, the degree of accuracy attained by the instrument under discussion is remarkable; under working conditions in a laboratory where the room and water temperatures are not controlled artificially the errors have, as a rule, not exceeded 2 per cent., and an extended experience of its operation encourages the hope that further developments on the lines suggested will reduce the limits of error considerably.

"*Summary*

"The recording calorimeter was installed in a basement room where the air temperature remained remarkably uniform, and was left to operate on town gas for five months, with occasional adjustment. During this period the readings of the recorder were compared with the results of the determination of the calorific value carried out with the calorimeter, which forms a part of the instrument. The differences observed were usually less than 10 and seldom reached 15 B.T.U. ; on two occasions, when the recorder showed 20 to 30 units lower than the directly determined numbers, the conclusion was drawn that the flow of gas had been restricted by accumulations of oxidized metal which had collected on the top of the burner. Apart from the formation of deposits on the gauze of the burner, and the undoubted evidence of corrosion in the form of copper sulphate at the exit part for the waste gases, there was nothing of interest to report. The recording mechanism worked quite smoothly and gave no trouble.

" The instrument was subsequently installed in the Laboratory of H.M. Fuel Research Station, where it was supplied from a holder with a homogeneous coal gas of constant consumption. For this gas were substituted consecutively, without any adjustment of the instrument, mixtures of coal gas and water gas ; specific gravity ·460, calorific value 426 ; water gas, specific gravity ·528, calorific value 326 ; coal gas and hydrogen, specific gravity ·303, calorific value 427 ; the recorder responded well to these extreme changes of density and calorific value, thus showing that the inventor's claim for the gravity governor is substantially true. The greatest difference between the recorded value and that determined by an independent calorimeter was 16 B.T.U. (in the case of the almost pure water gas of calorific value 326 B.T.U.).

" When allowed to run on homogeneous gas, periodic variations, occurring at intervals of about an hour and amounting to about 5 units, were observed. These were explained by restriction of the flow of water, caused by the gradual accumulation of air bubbles and the subsequent sudden restoration of the flow by the coalescence and removal of the air. Occasional irregularities, amounting at times to as much as plus or minus 20 B.T.U., were caused by restriction of the water flow by particles of scale, rust, etc., and these indicate the need to exercise care in the provision of a suitable water supply.

" In addition to these spasmodic errors, regular variations of the order plus or minus 10 units occurred, and experiments were made to ascertain their cause.

" These experiments showed :—

" 1. That the graph representing variations of the recorded calorific values was roughly parallel with that of the reciprocal of the ' gas factor ' (the factor for correcting the gas volume to 60° F. and 30 inches pressure), and that the parallelism with the graph representing variations of room temperature was even closer.

" 2. That the rate of flow of the gas through the meter varied proportionately with the gas factor, and that the claim that the gravity meter automatically applies a correction for the varying and pressure of the gas is substantially true.

" 3. That variations of the temperature of the external air altered the balance of the heat exchange between the calorimeter and its surroundings, and that the change of the recorded calorific value was plus or minus 1·4 B.T.U. per plus or minus 1° F.

" 4. That the change of viscosity of the water with temperature affected the amount of water flowing through the calorimeter in unit time by plus or minus 0·21 per cent. per plus or minus 1° F., and that the total effect on the recorder reading of a change of plus or minus 1° F. in the water supply may amount to nearly plus or minus 1 per cent.

" 5. That there was no evidence of incomplete combustion.

" The variations of the recorder seldom exceeded 2 per cent., notwithstanding the fact that the temperatures of the air and the water were not artificially controlled, and there is a prospect that the limits of error may be substantially reduced. A method of obviating errors, due to changes of the temperature of the external air, is suggested."

With regard to these conclusions it should be noted that the instrument employed was not fitted with the automatic-head device or with the silica combustion chamber. As already stated, the use of these modifications eliminates the trouble due to deposits upon the burner, change of water rate and errors due to the variable viscosity of water.

Boys Recording Calorimeter

This instrument is primarily designed for use on gas which has to be maintained within certain limits of a declared calorific value. The chart is provided with a middle line which represents this declared value ; the lines on either side of the middle line represent percentage departures therefrom.

The quantity of water employed is adjusted so that for any declared value it will be raised in temperature exactly 10° C. by the combustion of a definite flow of the gas, if it is of that value. The chart is ruled so that departures up to plus or minus 20 per cent. from the declared value can be recorded—a departure of 1 per cent. being represented by spacing of $\frac{1}{10}$ inch on the chart.

The calorimeter is designed so that " both the water and the gas are doled out positively at the correct rate, and the correction for gas volume as affected by temperature and pressure, and contained water vapour is effected by a positive operation " (Boys, *Proc. Inst. Gas Eng.*, 1922).

Measurement of Water.—The water measurement is effected in the following manner :—The water flows from a tank, in which the level is maintained constant, as explained on p. 134, into an eccentric bucket K (fig. 101), constructed of celluloid. The latter is proportioned so that, after a certain quantity of water has entered, it overbalances and thus discharges its contents into a water-box. The bucket is held in its overbalanced position by a catch L, so that it may drain, and is released automatically every half-minute. The disengagement of the catch whereby the bucket is released is effected by an arm actuated by a projection on the water wheel (*vide infra*). The bucket, when released, rights itself against an adjustable stop N so that the precise amount of water required to cause it to overbalance can be varied at will. This variation is necessitated in order that the amount of water delivered per half-minute is such that the 10° C. rise, referred to above, is exactly obtained. If, for example, the declared value of the gas is 540 B.Th.U. per cubic foot, the water required is 2 ozs. per half-minute. The adjustment is also employed should the gas meter drum (*vide infra*) deviate slightly from its correct capacity. If for example, its capacity is 1 per cent. too large, the stop is adjusted so that the bucket delivers 1 per cent. too much water.

The fixed quantity of water delivered every half-minute from the bucket flows into a celluloid box comprising four compartments O, P, Q, R. It flows from the first compartment O into the second compartment P, through a small hole, and it leaves P through a second small hole, whence it flows into the calorimeter body (*q.v.*). The passage of water through the two small holes serves to render the flow to the calorimeter uniform, although the water is, as explained above, delivered in sudden rushes at uniform intervals.

Motive Power.—The jet of water from the tank misses the bucket K when the latter has overturned and is held by the catch. It then flows into the other two "waste-water" compartments Q and R, which are similar to O and P. The water flowing from the waste-water compartments Q and R, amounting to about 1½ ozs. every half-minute, passes over a small overshot water-wheel T (fig. 101), constructed of celluloid. This water-wheel makes one turn every half-minute, and supplies the motive power to drive, through a coiled spring which serves as an elastic connection, the escapement of a one-wheel pendulum clock Z ticking half-seconds, which thus controls the speed of the wheel. The water-wheel also turns, through special gearing described below, the spindle of the gas meter on which the measuring drum is loose (*vide infra*).

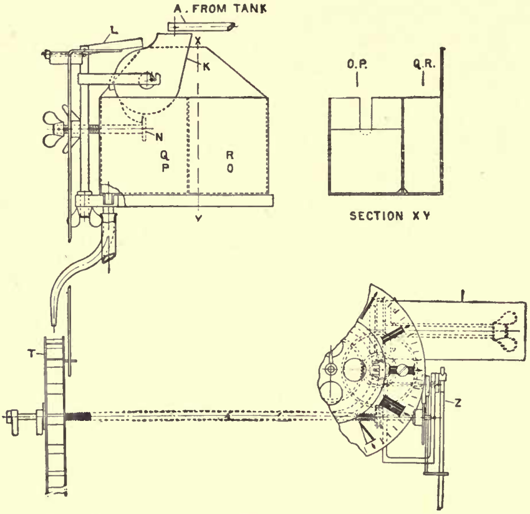


FIG. 101.—WATER FEED AND WATER CLOCK, BOYS RECORDING CALORIMETER.

Measurement of Gas.—The gas is measured out by a novel design of wet meter (*vide infra*). The drum spindle of the meter is geared to the water-wheel. When the conditions are those corresponding to a tabular number of 1000, a reduction of speed of 6 to 1 occurs between the wheel and the meter spindle, the speed of revolution of which is thus controlled by the pendulum. Any errors due to specific gravity variations are thus avoided by the delivery of the gas burned through a wet meter, the speed of revolution of which is controlled.

Correction for Tabular Number.—The mechanism, whereby the water-wheel is geared to the meter spindle, is automatically changed by alterations in tabular number so that the reduction of speed of 6 to 1, referred to above, can be continuously varied through a range of 10 per cent. fast or slow, according to the conditions prevailing. In other words, the meter spindle is driven faster or slower than its speed at N.T.P. according to whether the gas is expanded or contracted by the joint temperature and pressure conditions prevailing. The variable gear mechanism is constructed as follows :—

The water-wheel is geared to a shaft carrying an epicyclic double reduction gear by means of a chain engaging in sprocket wheels. The second portion of the shaft is pivoted at the centre of the gear and is connected at its other end to the drum spindle by means of a Hook's joint, which forms a convenient coupling (see fig. 102).

The reduction gear is also connected to a small ball-disc-cylinder mechanism (see fig. 102).

The disc D is set at an angle of 60° to the axis of cylinder C, and the ball B, which is composed of bronze, rolls in the groove comprised between the face of the disc and the periphery of the cylinder. When the position of the ball B is such that it is situated exactly at the centre of the disc, the rotation of the latter does not affect it, and consequently the cylinder C remains at rest. If, however, the ball B is displaced by rolling along the groove on one side or the other of the centre of the disc. it will also rotate and communicate its motion to the cylinder C, which will thus also move. The direction of rotation of the cylinder C will depend upon the direction of the displacement of the ball B.

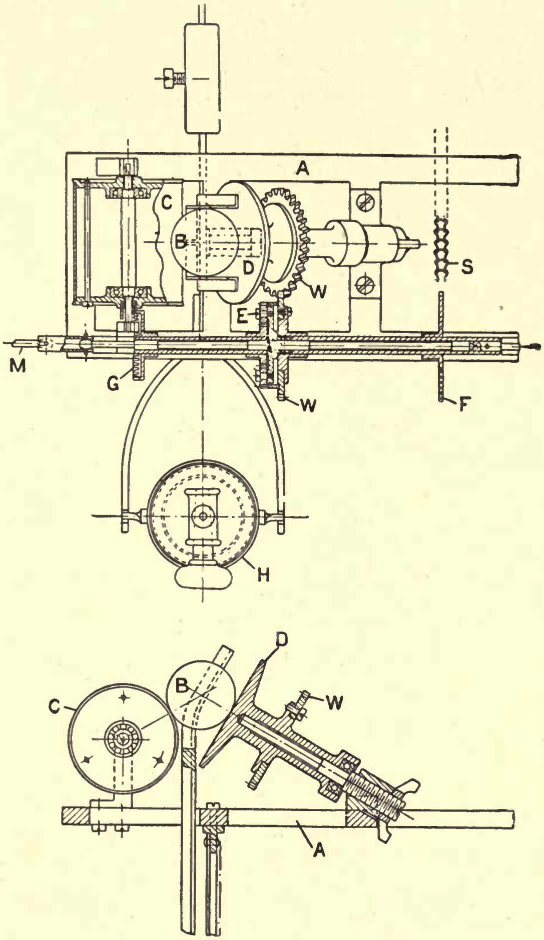


Fig. 102.—Variable Gear: Boys Recording Calorimeter.

The movement of the ball B is controlled by a fork which is connected at right angles to a balanced arm (see fig. 102). A glass bell H, provided with a stopcock, is carried at one end of the arm. This bell is suspended over mercury and contains moist air. The volume of the contained air will vary according to tabular number, and thus the bell H (which is balanced by a counterweight carried at the other extremity of the balanced arm) will rise or fall. This movement will cause a horizontal deflexion of the fork, which will thus roll the ball B along the groove between the disc and the cylinder. The position of the ball, and hence the direction and speed of rotation of the cylinder

C, is thus determined by the position of the glass bell, and hence by the tabular number.

Returning now to the second part of the shaft, driving the meter axle (fig. 102), this is also connected through gear wheels to the cylinder C of the ball-disc-cylinder mechanism. When the cylinder C is at rest (*i.e.* at N.T.P.) the motion of the shaft of the meter axle is simply that due to the controlled water-wheel drive, transmitted through the epicyclic gearing. If, however, the cylinder C is moving, the motion of the spindle is the algebraic mean of the two motions. The proportions of the various parts are adjusted so that the speed variation produced is exactly that required to compensate for the tabular number variations.

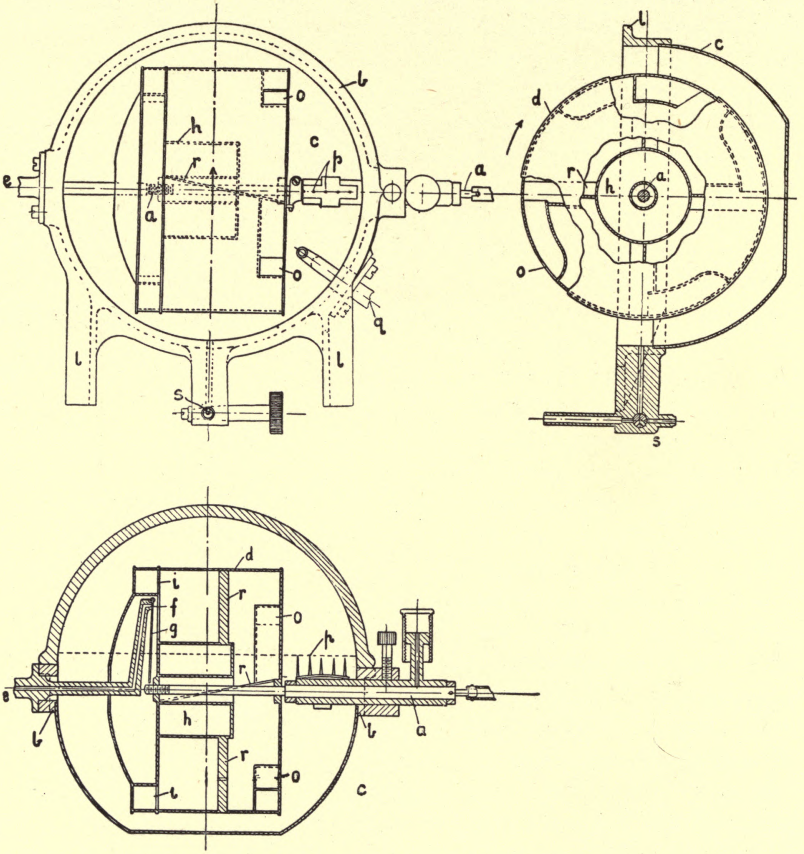


Fig. 103.—Gas Meter: Boys Recording Calorimeter.

Description of Meter.—The meter is constructed in a novel manner, and differs considerably from the known types of wet gasmeter. The casing consists of a cast brass ring mounted upon a spun copper bowl. The upper flange of the ring is turned plane and carries the top, which consists of a glass bell with a ground edge, as used for the receiver of an air-pump. The ground edge is smeared with vaseline and rests directly upon the turned flange (fig. 103). The junction is below the water-level so that escape of gas is impossible. At the same time there is not any tendency for the water to leak out by this joint, which is exposed to only about one inch of water pressure. The axle of the drum works in a long sleeve, which slides into a hole in the brass ring and is clamped in position. The axle and sleeve are both made water-tight by vaseline. The whole of the interior of the meter is visible, and the appliance can easily be taken apart should necessity arise. The water-level of the meter is indicated by one or more upturned points differing in level by a few thousandths of an inch. The gas, before entering the meter, is saturated by its passage through a bottle containing wet material, and the water-line is therefore kept constant.

The drum of the meter is constructed of celluloid, and the inlet and outlet aprons of the usual type are replaced by discs which close the front and back of the four compartments. The gas enters and leaves the latter through passages, half an inch square in cross-section, situated at the periphery of the drum. About two-thirds of the length of the drum from the front end is closed by a buoyancy chamber, from which the four sloping partitions radiate. The weight of the drum is thus mostly carried by the water and not by the axle, which merely serves to locate the drum. It will also be noted that the gas in any compartment, at the moment at which it is trapped and measured, is contained in a chamber, of which the ends, sides, roof and about two-thirds of the floor are defined and independent of the water-level; and thus a change in the latter has relatively little effect upon the capacity of the meter. The drum is loose on the axle but screws on to it, so if both drum and axle rotate at the same speed there is not any endlong movement. If, however, the drum does not rotate at the same rate as the axle, it screws along one way or the other according to whether it is travelling faster or slower. This endlong movement is employed to control the gas inlet orifice. The latter is altered by the movement of the strip G (fig. 103), which normally hangs vertically. This strip is pushed up to the inlet when the drum is turning faster than the axle and when, therefore, the gas supply should be reduced, and *vice versa.*

It will be gathered from the foregoing description that the meter supplies the gas at the requisite rate at atmospheric pressure—irrespective of the specific gravity—and by means of the variable gear mechanism, the gas volume is automatically varied to compensate for tabular number variations.

The gas flows from the outlet of the meter to the burner, which consists of a plain open-ended silicia tube $\frac{1}{8}$ inch to $\frac{3}{16}$ inch in diameter, situated in the interior of the heat interchanger.

Calorimeter Body and Heat Interchanger.—The water from the compartments of the water-box is led into an open tube 2 (fig. 104), three inches in diameter, in which the "cold" thermometer is placed. The water flows down to the base and enters a ring at the bottom of the hot water compartment 3. The heat interchanger 7 is situated in this compartment. It is constructed of thin sheet lead folded radially into fifteen zizgags round a central combustion space, thus producing a set of very narrow waterways on the outside, and a set of comparatively voluminous passages for the products of combustion on the inside. A flat ring is soldered round the interchanger near its lower end, and is clamped between a thick brass ring and a woodite ring on the base casting so as to make a water-tight joint. All joints on the interchanger are autogenously soldered. A small dome of fused silica is carried at the top of the interchanger, and a dome of sheet lead is welded over all. The use of lead in the construction of the interchanger avoids troubles due to corrosion. The interchanger is shown in section and plan in fig. 104.

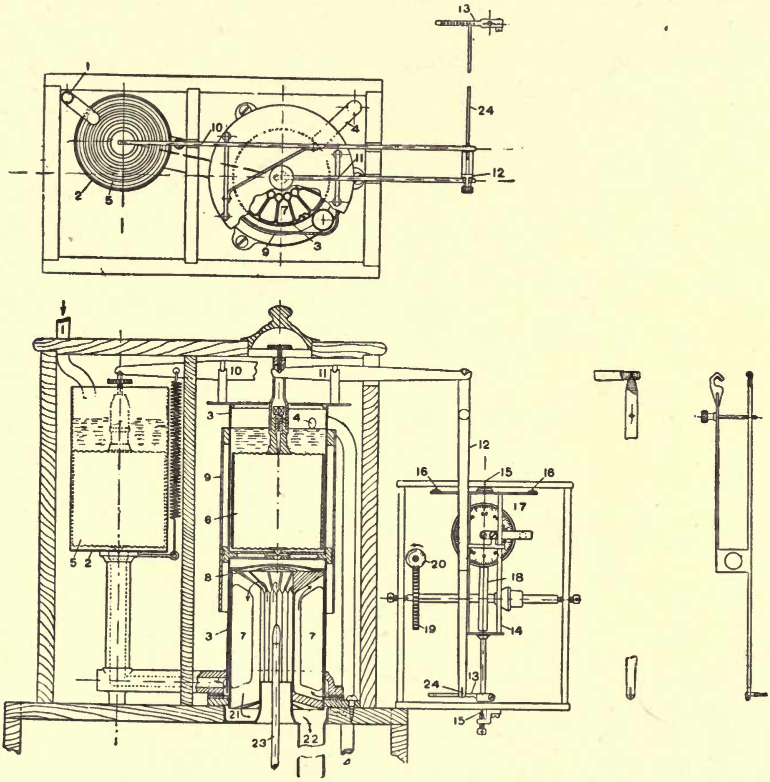


Fig. 104.—Heat Interchanger: Boys Recording Calorimeter.

The "hot" water compartment is divided in the middle above the interchanger, the two parts being joined by a narrow neck, through which the water flows. The "hot" thermometer is placed in the upper compartment 6. The condensed water is drained out through a lead pipe 22, and runs away to waste.

The heat insulation of the hot-water compartment is of greater importance than usual owing to the small amount of gas burned ($\frac{1}{2}$ cubic foot per hour), and also to the relatively large surface to be jacketed. The insulation is effected by the following device. A brass ring is soldered near the top of the hot-water compartment and a split wood ring is tied round the neck. A sheet of thick copper is wound very tightly round these and wired on, and the insulation is tied to the outside of this copper. The copper reaches below the neck and down to that level at which the rising hot water is increasing in temperature very rapidly. This construction has the effect of surrounding the hot-water compartment by a jacket of about exactly the same temperature as itself, and a small part of the lower end by a jacket of higher temperature. The small amount of heat which traverses the insulation is derived from the hot water, after it has done its work and is about to leave the instrument.

The Recording Thermometer.—The hot and cold bulbs are identical in construction, and each consists of a piece of brass tube 3 inches long and 2⅞ inches in diameter, with its upper and lower ends closed by corrugated lids carefully soldered on. A small brass cone is soldered to the middle of the lower end of each, and serves to support the bulb. The thermometers are filled with amyl alcohol, which has a high coefficient of expansion and does not alter or corrode the bulbs. The differential expansion of the two bulbs is magnified by a lever system as shown in fig. 104. The top of the hot-water compartment is closed by a disc of brass carrying two pairs of pillars notched at the top, which form the fulcra of two parallel primary levers each magnifying 2⅓ times. These reach outside the casing. A balanced bell-crank lever hangs in a vertical direction from one of these (the hot one) by an edge at one end of its short arm, while at the other it is caused to press up against the end of the other primary lever, which is held down on its fulcrum and on the point of the cold thermometer by a strong spring.

The bell-crank lever is continuously adjustable as to its magnification by having its short arm controlled in length by a screw. The lower end of the bell-crank lever is connected by a tie to a point on the short arm of the pen lever. Any differential expansion causes the vertical spindle (*vide infra*) carrying the pen arm to rotate, thus causing the latter, which is fixed at right angles to the spindle in a horizontal position, to sweep across the chart.

Recording and Integrating Mechanism.—The axis of the pen arm is (as already mentioned) vertical, and also carries an integrating drum which is rotated by the clock once every day. The integrating disc rests lightly on the drum, and when the record is on the central line of the chart (the gas therefore being of its declared value) the plane of the disc is at right angles to the plane of the drum, and the rotation of the latter does not cause any movement of the integrating disc. If, however, the record is not on the central line, the inclination of the disc to the drum will be altered, and the direction of rotation will depend upon whether the deviation from the declared value is positive or negative. The circumference of the integrating disc is divided into 100 parts, and the dimensions are arranged so that each division represents 1 per cent. deviation for one day. Divisions on one side represent excess of calorific value, and on the other side they show deficiency. The figure shown at any time therefore indicates the total deviation in a positive or negative direction from the declared value.

Safety Devices.—The construction of the calorimeter embodies a number of safety devices designed to prevent injury to the instrument or escape of gas due to various accidental occurrences.

(*a*) If the axle of the meter is prevented from turning (as, for instance, by stopping the clock), the drum screws along and shuts off the gas.

(*b*) If the gas is cut off, the drum screws along the other way up to a stop on the axle; after which the axle, in attempting to turn the drum, meets with such resistance, in the absence of gas supply, as to stop the clock. If thereafter the gas supply should be resumed, the drum screws along to the other end and shuts off the gas.

(*c*) Should the tilting bucket for any reason fail to right itself, the water continues to flow into the second compartment supplying the water-wheel. The increased supply of water to this water-box raises the level of the water therein, and the excess escapes through a hole into the first water-box, and thus supplies the calorimeter, thereby preventing its destruction.

(*d*) A No. 2 or No. 3 Bray burner is included between the meter and the calorimeter burner. This prevents the accidental extinguishing of the flame by the slamming of a door.

Adjuncts of the Calorimeter.—(*a*) *Water Circulation.*—The water, after leaving the heat interchanger, is circulated through a coil of lead pipe which is exposed to the draught of a fan. This has the effect of cooling the water down to its original temperature. It then runs into a tank from which it is pumped to the top supply tank which feeds the calorimeter. The same water is thus used over and over again, and difficulties due to hardness, acidity or other causes are avoided.

A " hot-air " engine is employed to work the fan and pump the water to the top tank. The engine is actuated by a gas flame, which also serves to maintain the necessary draught upon the supply to the calorimeter. The gas consumption of the engine is about $1\frac{1}{2}$ cubic foot per hour. The gas supply to the engine is controlled by a float in the upper tank, so that the pumping is maintained at such a rate that the water-level in the top tank remains constant.

(*b*) *Gas Volume Record.*—The fork which controls the rolling ball on the variable gear carries a pointer moving over an aerothormeter scale, so that the position of the air bell can be verified and corrected if required. The movements of the pointer are recorded upon a drum which, by special gearing, is caused to make one revolution per month. It is driven by the water-wheel.

(*c*) *Clock.*—A time clock is fitted to the instrument, and is also driven by the water-wheel.

CLASS A 2. RATIO OF GAS AND WATER FLOW MAINTAINED CONSTANT

Fairweather Recording Calorimeter

The main feature of this instrument is the method adopted for maintaining the ratio of the water flow to the corrected volume of gas burnt constant. Owing to the construction of the apparatus the corrected volume of the gas is variable, and the flow of water is automatically adjusted to compensate for the variation due to changes in atmospheric conditions.

The instrument comprises a water flow calorimeter of the Boys type, arranged to give a continuous record of the total heat value of the gas reduced to standard conditions of temperature and pressure (60° F. and 30 inches barometric pressure).

1. *The Flow of Water through the Calorimeter.*—The devices employed are intended—

(*a*) To supply to the calorimeter a definite and measured flow of water.

(*b*) To adjust automatically this flow to compensate for alterations in the external conditions of temperature and pressure to which the gas is subjected.

A definite flow of water is supplied to the calorimeter by passing the inlet water through a small orifice subjected to a head of pressure. Fig. 105 illustrates diagrammatically the apparatus employed.

Water is supplied by a pipe *w* to an open vessel D, connected by a pipe W^1 to a second vessel E, from which depends a tube *e* fitted at the lower end with a small orifice, and dipping into a cup F into which the water flows, filling the cup and overflowing the rim thereof. The water overflows the vessel D, which thus acts as a weir and determines the level of the water in the vessel E—such level being, of course, constant. The orifice at the bottom of the tube *e* is consequently under a head of pressure equal to the vertical height between the level of the water in the vessel E and that at the rim of the cup F (both of these being at atmospheric pressure). With such an arrangement the flow of water through the orifice in unit time is given by the following formula :—

$$V=K\sqrt{h}$$

where V=volume in c.c. in unit time.
h=the head of pressure.
K=a constant, depending upon the size of the orifice.

The cup F is carried by a float G supported in an oil chamber A^1, the level of the oil—which, of course, indicates the position of the cup—being shown on a gauge TG. The amount of water flowing through the orifice will depend upon the position of the cup which determines the head, and to which the orifice is subjected. The gauge is graduated to show proportional flows—*i.e.* the relative flow of water at different levels of the oil. The cup is so set upon the float that with the gauge reading 1·000 the water flow per 4 minutes is exactly 2000 c.c. If the oil level be altered to any other reading the flow is altered accordingly—or, in other words, the flow is always 2000 times the gauge reading, thus :—

Gauge Reading.	Water Flow. (c.c.'s. in 4 min. at 15° C.)
1·000	2000
1·035	2070
·941	1882

It will be gathered from the above description that the method of controlling the water supply is such that an invariable amount is delivered with the cup in any particular position, and that the actual amount delivered will depend upon the position of the cup which determines the effective head to which the orifice at the base of *e* is subjected.

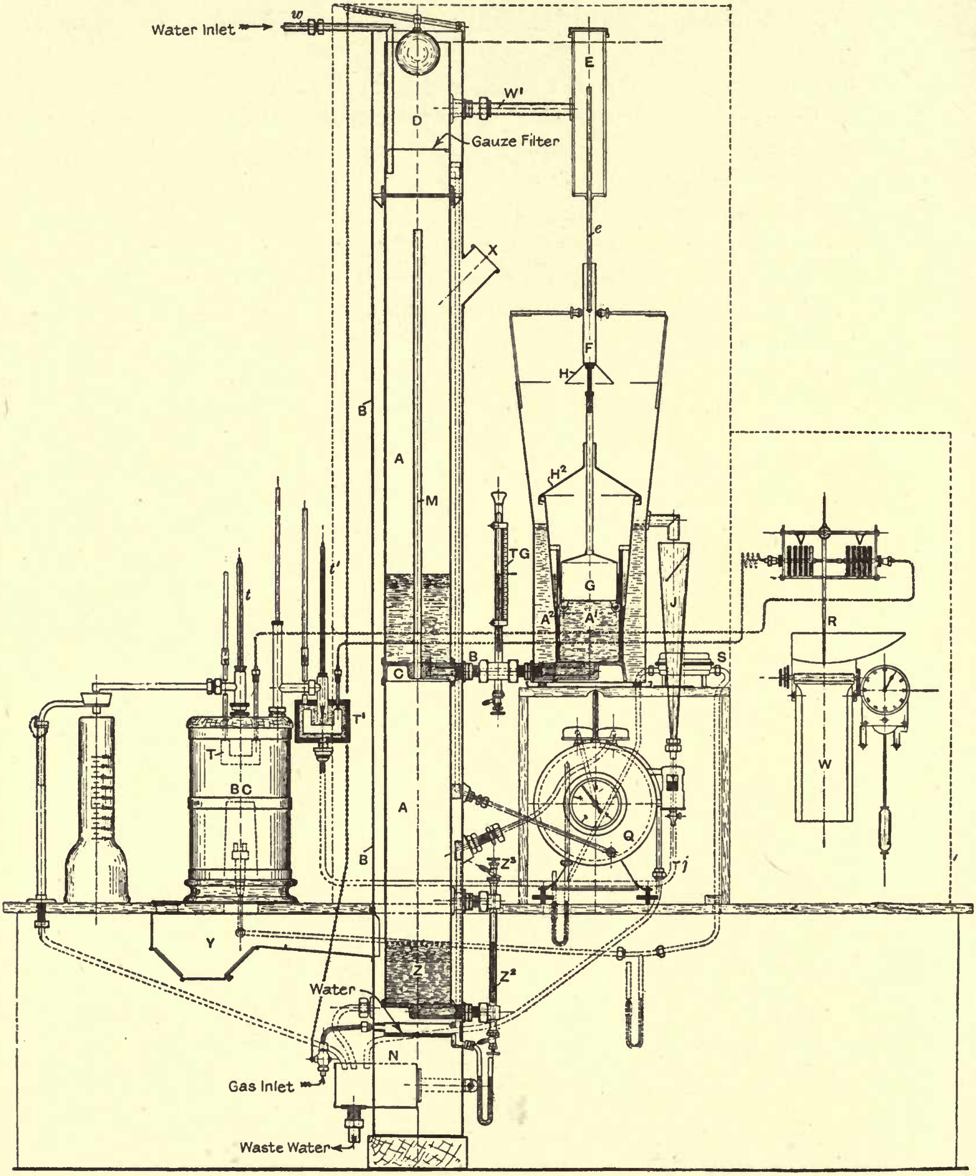


Fig. 105.—Fairweather Recording Calorimeter.

The adjustment of the position of the cup is effected automatically to compensate for the tabular condition of the gas (*i.e.* the particular conditions of temperature and barometric pressure to which it may be subjected). The oil is exposed to a volume of saturated air enclosed in a vessel A supporting the vessel D. This air is brought to the water temperature by the excess water overflowing the vessel D, passing down the sides of the vessel A; and is also subjected to atmospheric pressure through the oil (the float chamber A^1 being open to the atmosphere). Consequently the level of the oil is raised or lowered as the air expands or contracts, owing to changes in the temperature and atmospheric pressure. The tabular number of a gas is merely the reciprocal of its volume relatively to the corresponding volume under standard condition of temperature and pressure (60° F. and 30 inches). Hence the gauge can be fitted with a *tabular* scale—*i.e.* the air vessel and gauge can be employed as an aerothormeter. To adjust the water flow to compensate for the tabular number, —*i.e.* to make it exactly proportional to the tabular number, it is only necessary that the proportional flow scale on the gauge should itself constitute the tabular scale. This is effected by the special design of the float chamber outlined on the diagram. Although the oil is moved by the air, the gauge can be, and actually is, set to the tabular number of the gas as measured in the meter, in the manner explained below.

The water delivered by the orifice and overflowing the cup F is diverted by a baffle H and cover H^2 into a vessel A^2 surrounding the float chamber, and passes thence through a funnel J and pipe *j* to the calorimeter.

The excess water from D, after passing down the sides of the vessel A, runs away to waste as shown in the diagram.

Adjustment of Water Flow for Tabular Number.—This adjustment is effected in the following manner:—The air valve Z^3 is opened, and the vessels A and A^1 are filled with oil until the bottom of the meniscus is slightly lower than the figure 1·000 on the tabular scale.

The cup F is filled with water, with the result that the weight so added depresses the float slightly, and the oil level is now adjusted to coincide exactly with the figure 1·000 on the tabular scale.

The air valve Z^3 is left open, and water is run into the bottom of the air chamber at Z until the water-line coincides with the line marked on the water gauge Z^2.

Correct adjustment of the air capacity of the vessel A must be made by the user. The tabular conditions (in Great Britain) do not, as a general rule, alter sufficiently in a short period to enable the makers accurately to adjust the instrument in this particular respect. Periodical observations should be taken, and adjustments made, until the correct water-line is ascertained. If the movement of the oil is restricted as compared with the scale of numbers set out on tabular gauge TG, it means that the air volume is insufficient, and water should be run out by means of the valve at the bottom of the gauge glass Z^2. On the other hand, if the oil moves over a greater range than is called for, it indicates that the air volume is beyond that actually required, and more water should be introduced to compensate for this inaccuracy.

When either operation is performed, the air valve Z^3 must be opened, allowing the oil to move to the mean position at tabular number 1·00; and after the water-line is altered, air should be introduced or withdrawn, to bring the oil level to correspond with the prevailing tabular number, after which air valve Z^3 is again sealed.

The chamber A^2 is filled with water, and the water supply turned on. The amount of water flowing through the calorimeter in four minutes is accurately determined by means of a graduated measure. The flow should be 2000 c.c., but if less than this amount, the head of pressure above the orifice tube *e* is insufficient, and the cup F should consequently be lowered. Conversely, if the flow be too great, the pressure must be lessened by raising the cup.

The latter can be adjusted by unscrewing the lock-nut beneath the coned baffle, and raising or lowering the cup by means of turning on its threaded spindle. The lock-nut should always be tightened up after any adjustment. An adjustment of the cup by $\frac{1}{10}$ inch alters the flow by 5 c.c.

It is advisable to check the water flows covering the tabular scale TG. This can be done by creating artificial tabular conditions—*i.e.* by introducing or withdrawing air from the air chamber by means of the mouth and a rubber tube connected to the limb of air valve Z^3. This will alter the oil level, and after allowing sufficient time for the air to obtain a uniform temperature, a water flow should be taken. The actual result should be 2000 times the corresponding reading shown on the tabular scale.

2. *The Flow of Air through the Calorimeter.*—The air vessel A is surrounded by a casing B fitted with an elbow X, through which the air required for the combustion of gas is drawn. The air, during its passage down the annular space between A and B, is exposed to the surface water overflowing from D and surrounding the exterior of the vessel A.

This has the effect of reducing its temperature to that of the inlet water and saturating it with water vapour. In this manner, as already explained, the heat of combustion given up to the water flowing through the calorimeter will represent the total heat value of the gas, provided the products of combustion and surplus air are cooled nearly down to the inlet water temperature before they leave the calorimeter.

After passing through the space between A and B, the air is drawn into a closed channel Y beneath the calorimeter, and then into the calorimeter itself. The channel Y is provided with a door which can be opened for lighting the burner. A mirror is fixed in a suitable position so that the flame can always be seen if required.

3. *The Flow of Gas through the Calorimeter.*—It was explained in connection with the adjustment of the water flow that the variation in the quantity of gas consumed, due to alteration of tabular conditions, is compensated for by concomitant alterations of the water flow. The other variable affecting the quantity of gas consumed is the specific gravity.

Errors due to changes in specific gravity are overcome by delivering the gas through a wet meter the rate of revolution of which is controlled by a pendulum escapement connected to the drum spindle by a coil spring.

As the meter drum is constrained to move at an invariable rate in this manner, it must always deliver the same volume of gas in unit time—the volume of gas delivered being quite independent of its specific gravity. The escapement meter is more fully described in connection with the Beasley calorimeter (*vide infra*), for which instrument it was first devised.

The gas, on entering the instrument, first passes through a cock, the lever of which is connected by a chain to a ball valve immersed in the vessel D. Should the water supply accidentally fail, the ball valve sinks and the cock is automatically closed, thus shutting off the gas supply. The gas then passes through a cooling box N in which it is exposed to a surface of water, thus saturating it with water vapour, and from thence to a two-stage governor fitted on the top of the meter O, by which the inlet meter pressure is reduced to $\frac{4}{10}$ inch water gauge. The meter is fitted with a water jacket through which an auxiliary supply of water from the vessel D passes, and then runs away to waste.

This ensures that the gas is measured at a temperature closely approximating to that of the inlet water. The loss of water from the meter by evaporation is largely eliminated and the water-line only requires occasional resetting.

The meter is timed to pass 5 cubic feet per hour, and the hand should therefore make a complete revolution in sixty seconds. If the rate is incorrect, it is adjusted by altering the length of the pendulum, and it should be correct to within two seconds in ten minutes.

The gas, after leaving the meter, passes through an anti-fluctuator S. This is a governor which suppresses the fluctuation which would otherwise be produced at each stroke of the pendulum. It then travels to the burner in the Boys calorimeter.

4. *Recording Mechanism.*—This is similar in principle to the early pattern of differential thermometer in Simmance's recorder. The Boys Calorimeter BC is fitted with the usual pair of mercury thermometers tt^1, and in addition with two thermometric air boxes T and T^1 arranged respectively in the inlet or cold and outlet or hot water flows. These boxes are connected by fine copper tubing to a pair of aneroid chambers VV, which work in opposition and operate a pen R, which thus registers the difference between their respective motions.

The chart is driven forward by means of a feed wheel which marks the record with a series of dots. It has a fixed position relatively to the pen mechanism, and thus the line of dots constitute a datum line. Normally this coincides with the centre line of the chart, but it may be slightly displaced owing to inequalities in the paper. The real movement of the pen is from the datum line; hence the reading should be corrected if necessary for any deviation of the datum line from the centre line of the chart.

The precautions referred to in the description of Simmance's recording calorimeter with respect to uniformity of temperature of inlet water, draught on the gas supply, uniformity of room temperature, etc., etc., are equally important in the case of the Fairweather instrument, and non-attention to these points will cause the same difficulties.

Precautions required to maintain the Fairweather Calorimeter in Working Order.—

1. The guide rollers for the cup F must be inspected periodically to ensure that they are running quite freely.

2. The water-line of the meter must be adjusted periodically. The pointer should just touch the water-line when the meter is open to atmospheric pressure. The correct position for an adjustment of the water-line is between the pulsations caused by the rotation of the drum.

3. The timing of the meter should be checked against an accurate watch or clock—preferably a stop-watch.

4. It is advisable to clean out the Boys calorimeter once a month. The air-box connections are uncoupled and the outlet mercury thermometer is removed. The calorimeter body is removed from the casing, immersed in a weak solution of sodium carbonate for about half an hour and washed finally in water. The chimney and the inside of the casing are cleaned, and the calorimeter is reassembled. A new washer should always be used when the air-box connections are recoupled up. The soundness of these connections can be verified by inspection of the record after several hours' run.

If sound, the pen line will represent a characteristic slightly wavy appearance; but if either connection be not perfectly tight, the line will show a somewhat stepped appearance, with a decided tendency towards a high (or low) reading. A high reading would show a leak on the cold-air side, and *vice versa* for a leak on the hot-air side.

THOMAS RECORDING CALORIMETER

This instrument (which was developed in America) is designed upon principles totally different to those embodied in the appliances previously described. In the latter the heat of combustion of the gas is imparted to water. This, as has been shown, necessitates either invariable flows of both gas and water, or else an automatic adjustment of the water flow to compensate for changes in the gas volume due to variations in "tabular" conditions.

In the Thomas calorimeter the heat of combustion is imparted to air, with the result that any variation in the corrected volume of gas consumed due to tabular variations is accompanied by concomitant variations in the volumes of air supplied for the combustion of the gas and for the absorption of the heat of combustion. In other words, whereas in Simmance's and Boys' calorimeters both gas and substance heated are maintained constant, and in Fairweather's calorimeter the ratio of these two quantities are maintained constant *automatically*; in the Thomas calorimeter the necessary adjustment is effected *naturally*, without the use of any automatic apparatus.

The difficulty due to specific gravity variations in the gas consumed is surmounted by the delivery of the gas by means of a wet meter mechanically driven, which thus delivers a volume per revolution which is invariable with respect to changes in the specific gravity of the gas.

The apparatus consists of two separate and individual portions—the calorimeter itself and the recording mechanism.

Description of the Calorimeter.—The calorimeter itself is shown diagrammatically in fig. 106. It comprises a tank which is filled with water to a certain level; in which three water-sealed drums, which are geared together, rotate. The drums are carried on a base common to all, and are driven by means of a small electric motor. The drum shown on the right supplies the gas, the drum on the left supplies the air required for the complete combustion of the gas, and the large drum in the middle supplies the air employed as the heat-absorbing medium. As the three drums are geared together, the three supplies will always be delivered in the same volumetric proportion, and each will be affected equally by changes in tabular conditions.

The gas enters the calorimeter through a small orifice, and passes into a chamber which is open to the atmosphere through a gauze-protected burner.

The size of the burner is sufficient to prevent any building up of pressure in the chamber from which the gas is drawn. It also serves to maintain an adequate draught upon the gas supply, thus ensuring that changes are rapidly communicated to the record.

The three drums operate in the same manner as an ordinary water-sealed gas meter. The two air drums draw their supply directly from the air above the water seal, which is common to all three drums. The latter are so designed that changes in the water level affect their displacements in the same ratio, and hence the exact water level to within $\frac{1}{10}$ inch is not important.

It is, however, very necessary that the system be level. Two levelling points are provided for the purpose. Surplus water passes over the overflow weir and into the auxiliary water storage tank. Water is transferred from the latter by means of a small chain conveyor to the calorimeter tank, thus maintaining the water-level constant in the latter; there being a constant flow of water over the overflow weir into the auxiliary tank, and back to the main tank by means of the conveyor.

The combustion air is split into primary and secondary air at the outlet of the combustion air drum. The primary air is mixed with the gas in the mixing chamber and conducted to the burner, where the secondary air is admitted.

The products of combustion leave the calorimeter after giving up their heat to the stream of heat-absorbing air from the large drum. The direction of flow of this air is counter to that of the products of combustion, which are thus cooled to within one or two degrees of the temperature of the inlet heat-absorbing air. The passages through which the latter flows are entirely separate from the gas burner, and correspond to the path through which the water flows in water-flow calorimeters.

A polished double-walled tube is fitted round the burner jacket to minimize heat losses, and it is in turn jacketed by the heated air in such a manner as to compensate for any heat losses.

The temperatures of the "inlet heat-absorbing air" and of the "outlet heat-absorbing air" are taken by two electrical resistance thermometers connected with the recorder. The thermometers are composed of nickel wire, and are about 40 ohms resistance.

Nickel wire is employed because its temperature characteristics over a fairly wide range show the same variation as the combined effect of the changes due to the

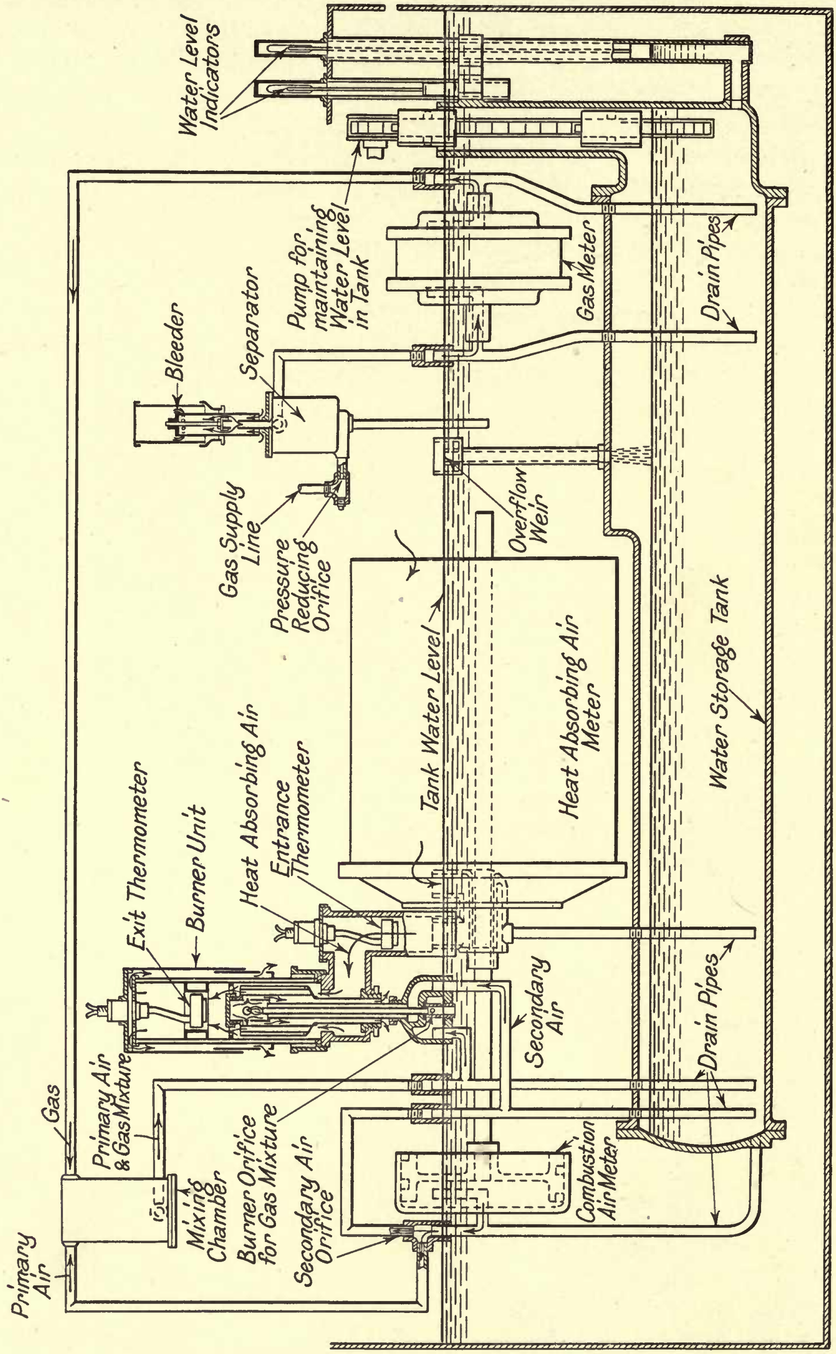


FIG. 106.—DIAGRAM OF THOMAS RECORDING CALORIMETER.

varying content of water vapour in the gas, and to the variation of the specific heat of saturated air with the temperature. The use of this material for the construction of the thermometers therefore compensates automatically for these variations. The calorimeter, apart from the recorder, is shown in fig. 107.

The Recorder.—The two thermometers are connected to the recording mechanism in such a manner that they form two arms of a Wheatstone bridge, two fixed resistances serving as the other arms (see Chapter III. p. 63).

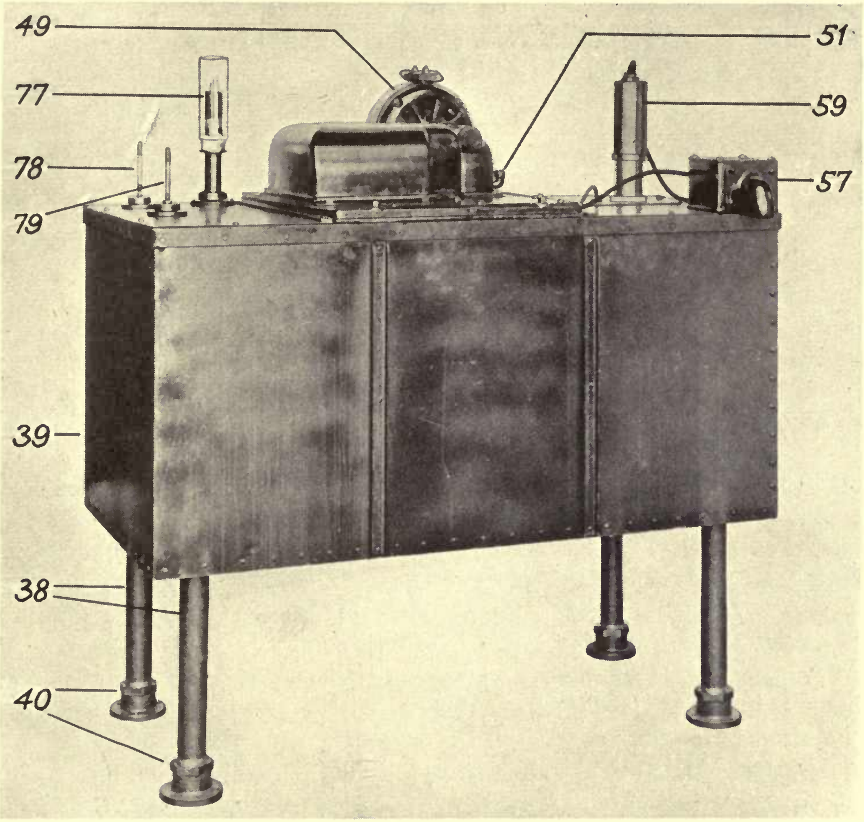


Fig. 107.—Thomas Recording Calorimeter.

Current is supplied to the Wheatstone bridge by a dry battery. If the thermometers are at the same temperature their resistances r and r_1 will be identical, and current will not flow through the galvanometer. If however they are at a different temperature, their resistances will differ and a current will pass through the latter.

The galvanometer needle is clamped at short intervals between contacts, and any deviation of the needle from the zero position, indicating that the system is not balanced, causes the passage of a current through one or the other of two solenoids.

A slide-wire resistance is connected between the two thermometers, and a rider serves as one current feed-point to the Wheatstone bridge. Any movement of this rider shifts some of the slide-wire resistance from one arm of the bridge to the other arm, and thus tends to restore the balance of the bridge.

The position of this rider is controlled by the solenoids which rotate the screw upon which the rider is carried. The passage of a current through either solenoid causes a movement of the rider in such a direction that the system is again in balance, and there is not any flow of current through the galvanometer.

The position of the slide-wire rider depends upon the relative resistances of the two thermometers and is, therefore, a measure of their temperature difference, and hence of the calorific value of the gas.

The position of the rider is recorded upon a chart calibrated to read directly in B.T.U.

The chart is driven regularly by means of an electric motor fitted with a speed governor.

The general arrangement of the calorimeter and recorder is shown diagrammatically in fig. 108, in which a second recorder, actuated by the same calorimeter, is also included.

General Remarks.—The accuracy of the calorimeter is unaffected by variation in the power supply. Such variation will be without effect upon the driving of the drum, as the ratio of the amount of air and gas employed is independent of the speed.

Owing to the employment of electrical thermometers which can be placed at a considerable distance from the recording mechanism, the latter can be placed in any convenient position, and need not be situated on or near the calorimeter itself. A duplicate recorder may also be operated from the one calorimeter if desired.

Precautions for maintaining the Thomas Recording Calorimeter in Working Order.—
1. The lubrication of the small motor generator and grease cups of the reduction gear should be attended to weekly.

2. The condition of the temperature measuring system is checked once a month by obtaining a "cold balance" of the Wheatstone bridge, as follows :—The gas flame in the calorimeter burner is extinguished by stopping the motor, and while the latter is stopped, the mechanical zero balance on the galvanometer is checked. An adjustment is made, if necessary, to bring the needle to a central position. The switch in the recorder case is set to the "balance" position. The motor is started, and sufficient time is allowed for the recorder pen to indicate a steady rate on the chart; and the balance screw is then adjusted, if necessary, to bring the pen to "cold balance" position. About thirty or forty minutes are usually required to obtain a satisfactory cold balance.

3. Once a month, or possibly more often, it may be necessary to clean out the sulphate deposit from the burner.

4. Once in three months all the water should be drained out of the calorimeter tank and, after rinsing out, the latter should be refilled with clean water.

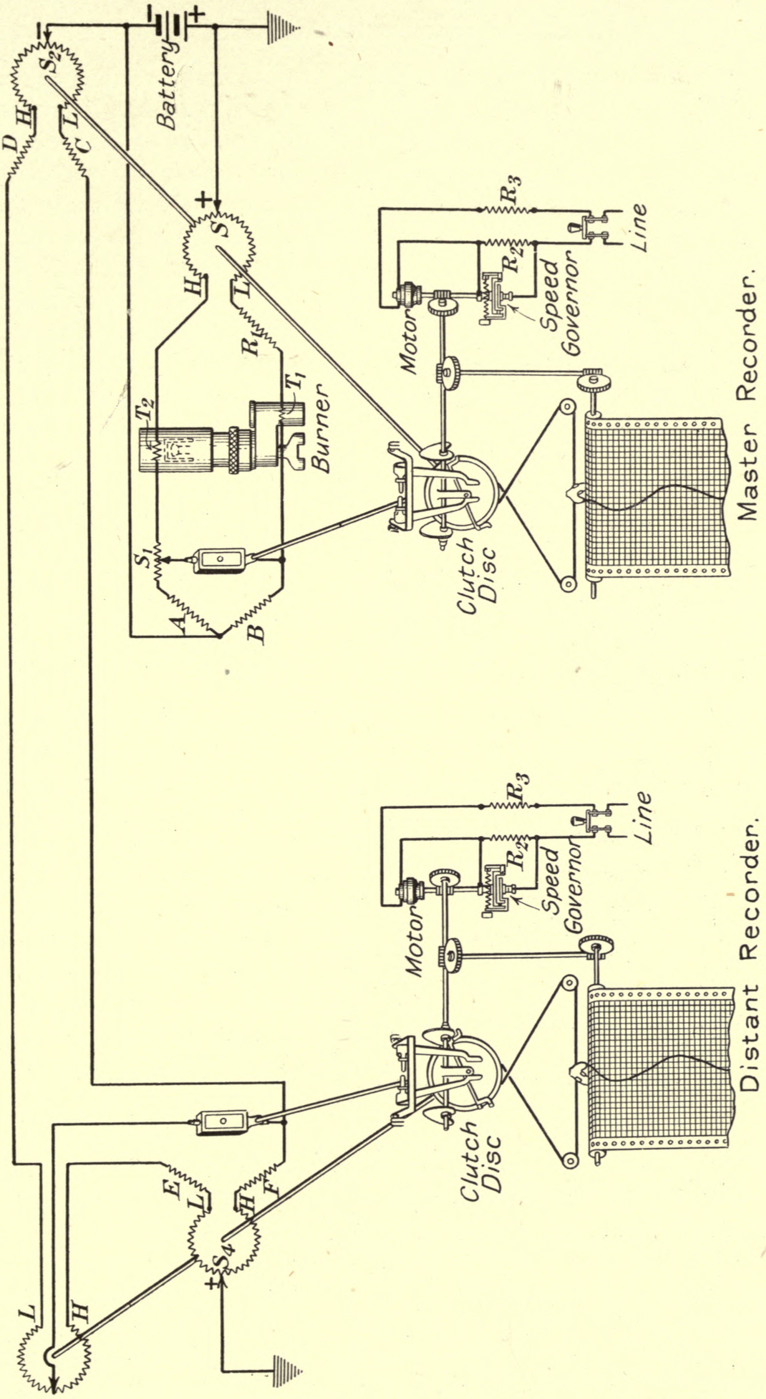


Fig. 108.—Connections for Thomas Recording Calorimeter.

JUNKER RECORDING CALORIMETER

This instrument is noteworthy inasmuch as it was the first recording calorimeter to be produced. The apparatus is designed so that the ratio of the weight of water flowing through the instrument to the volume of gas consumed is maintained constant. There is not, however, any automatic arrangement for correction for variation in tabular number, and hence, presuming the instrument is adjusted to give an accurate record under standard conditions of temperature and pressure, the recorded amount of the calorific value must be adjusted by application of the usual corrections for variation in tabular number.

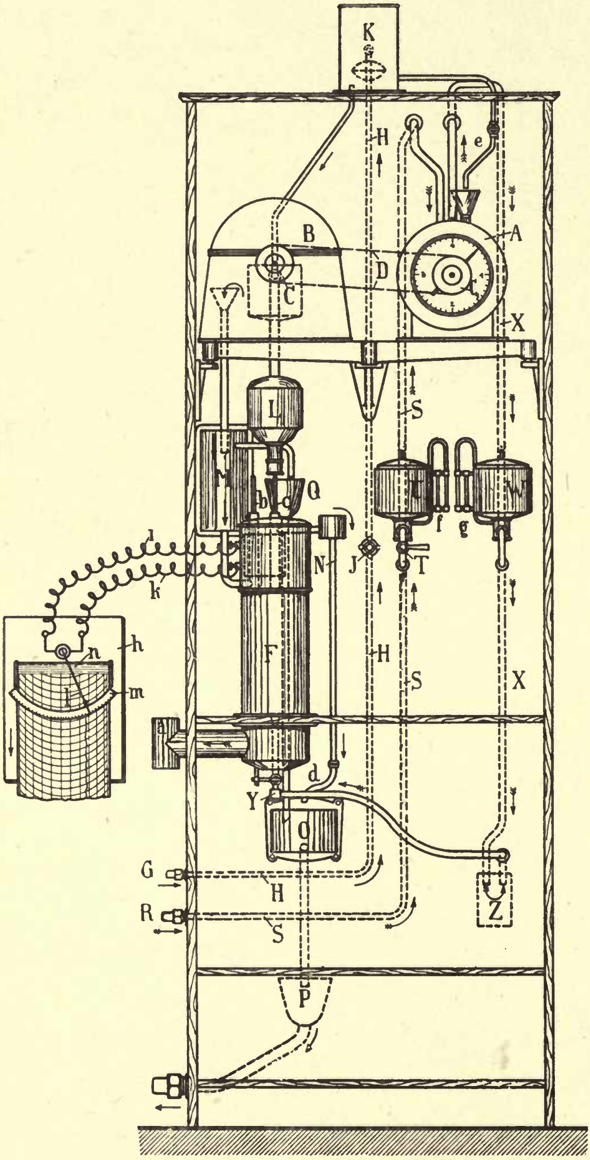


FIG. 109.—DIAGRAM OF JUNKER RECORDING CALORIMETER.

The constancy of the ratio

$$\frac{\text{weight of water flowing through}}{\text{volume of gas consumed}}$$

is ensured by delivering the gas through a wet meter, the drum of which is directly coupled to a special type of water motor which drives the meter, and at the same time allows the passage of a fixed amount of water per revolution, the water flowing through the motor subsequently passing through the inlet of the calorimeter.

Thus each revolution of the wet meter — corresponding to the passage of a fixed volume of gas—is effected by the flow of a fixed amount of water. The volume of gas delivered by the meter is independent of the specific gravity variations, so that (assuming that the water delivery appliance does not vary) the record will always be correct at the particular condition of temperature and pressure for which it is set.

Description of the Apparatus.—The calorimeter comprises a Junker flow calorimeter, as employed for hand determinations of calorific value, fitted with the following adjuncts :—

(*a*) A water motor directly coupled to the gas meter and arranged to deliver a fixed amount of water per revolution.

(*b*) A differential electrical thermometer for measuring the temperature difference between the inlet and the outlet water.

(*c*) Apparatus for recording the temperature measurements which are inscribed on a chart in terms of calorific value.

1. *The Flow of Water through the Calorimeter.*—The water enters at G (fig. 109), and flows through the tube H and a regulating cock to the vessel K. The latter is fitted with a float which regulates the head of water. The water flows from the vessel K to the water motor B and thence to another constant-head overflow vessel L.

The motor B is coupled directly to the wet gasmeter A, through which the gas is delivered, by means of a chain D engaging in tooth wheels C and C, fixed respectively to the water motor and to the wet meter. The water delivered by the motor B flows through a compensating vessel M, which renders the rate of water flow quite uniform.

The water, after leaving the vessel M, enters the body of the calorimeter F, finally leaving it through the tube N, whence it flows to the vessel O, and runs away to waste at P. The surplus water from the vessels M and L runs away to waste through the funnel Q.

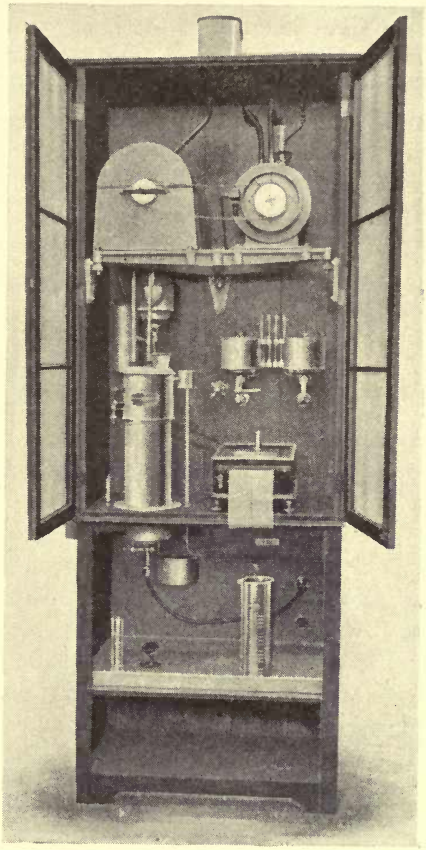


Fig. 110.—Junker Recording Calorimeter.

The calorimeter itself is practically identical with an ordinary Junker calorimeter, and is fitted with inlet-water and outlet-water mercury thermometers *b* and *c*, whereby a determination of calorific value can be made at any time by hand in the usual manner.

2. *The Flow of Gas through the Calorimeter.*—The gas enters the calorimeter at R and passes through the pipe S to the governor U, which is fitted with a pressure gauge.

It proceeds from the outlet of the governor to the wet meter A. After passing through the meter, the gas flows along the tube X and passes through a second governor W, which is also fitted with a gauge. It then flows along the tube X through a water trap Z to the burner Y. The products of combustion and surplus air leave the calorimeter at *a*.

3. *The Recording Mechanism.*—The increase of temperature of the water flowing through the calorimeter is measured by means of a thermo-couple, one junction of which is immersed in the inlet water, and the other being immersed in the outlet water. The E.M.F. so produced is registered on a suspended coil millivoltmeter *h*, the scale of which is graduated to read directly in thermal units. The pointer of the millivoltmeter is caused to touch the chart at intervals and thus to press the latter on to an inked ribbon. The chart is thus marked with a series of dots constituting the record. The chart itself is driven forward by a toothed wheel, driven by clockwork, which engages in perforations along one of its sides.

The complete instrument is shown in fig. 110.

CLASS B

The instruments described in Class A are (with the exception of Junkers calorimeter, which does not automatically correct for variations in tabular number) intended for use as standard calorimeters for recording the calorific value of the finished gas as it leaves the works, and for ensuring that the calorific value is always above the statutory minimum.

These instruments are of necessity elaborate and somewhat delicate in their construction. Recording calorimeters are also of great utility for the actual control of gasmaking. Such calorimeters, intended for works use, should be as simple and robust in construction as possible.

Generally speaking, the appliances to be considered in Class B (in which a portion only of the heat of combustion is imparted to the calorimeter) are intended more especially for works usage, and conform more or less to the specified requirements of simplicity and robustness of construction. Nevertheless the majority of the instruments described are susceptible of a high degree of accuracy, approaching that attainable with the apparatus which have already been described and which are intended for use as standard appliances.

The products of combustion in the case of all the instruments considered in this section leave the calorimeter at such a temperature that the water vapour is not condensed. A portion only of the net calorific value is employed in actuating the instrument.

In the case of the Beasley calorimeter, the ratio of net heat to absorbed heat was the basis of calibration for a number of years, during the period when the controversy regarding the relative values of gross and net calorific value determinations was in progress.

The question which therefore arises, now that calorific value determinations are required in total-heat units, is whether the ratio of gross calorific value to net calorific value is sufficiently constant to enable the ratio of gross heat to absorbed heat to be made the basis of calibration in instruments of this type.

This question has been considered in some detail in the Fifth Report of the Subcommittee of the Gas Investigation Committee of the Institution of Gas Engineers already referred to. The conclusion arrived at is that no error of consequence is introduced in the calorimeter reading with gases down to 450 B.Th.U. gross calorific value, owing to a change in composition giving rise to an alteration in the ratio of gross and net calorific value.

The appliances which are described below all have one feature in common. A portion of the heat of the combustion of the gas is imparted to a column of air which ascends a chimney and which increases the temperature of a portion of the actuating mechanism. In this connection it should be noted that the rate of flow of the heated air column up the chimney depends upon the following formula—

$$v=\sqrt{2ga(t^1-t)h}$$

where v=velocity of draught up the chimney.
g=acceleration due to gravity.
a=coefficient of expansion of air.
t'=mean temperature of the air inside the chimney.
t=temperature of air outside the chimney.
h=height of chimney.

From this it will be seen that the rate of flow does not increase in proportion to the difference of the temperature of the outside air and of the hot air in the chimney, but in proportion to the square root of this difference.

For this reason, when the calorific value of the gas increases, the speed of the air stream past the sensitive element increases, and in greater proportion.

It is therefore evident that, in order that any instrument of this type should have a uniformly divided scale over the whole of its range, it is necessary that some automatic device be provided to compensate for the increased rate of the air stream which, if uncorrected for, would tend to give readings which are subject to a progressive minus error with increase of calorific value.

The methods whereby this correction is automatically applied are described in every case in which the instrument is provided with such automatic compensating device.

Simmance Calorgraph

Simmance's calorgraph, although an instrument in which a portion only of the heat of combustion is absorbed, is nevertheless capable of yielding records of a high degree of accuracy over long periods.

The instrument consists of :—

1. Apparatus for supplying a definite amount of gas, irrespective of variations in specific gravity or external conditions of temperature and pressure, to a burner.

2. A balanced arm carrying at either extremity exactly similar expansible members, one of which is subjected to the stream of air entering the apparatus ; the other member being subjected to the same air stream to which a portion of the heat of combustion of the controlled volume of gas has been subsequently imparted. The

differential expansion of the expansible members produces a displacement of the centre of gravity, thus causing the beam to tilt.

The Flow of Gas through the Instrument.—The gas enters the apparatus through a $\frac{3}{8}$-inch cock A (fig. 111), the inlet pressure being reduced to about 1 inch by the double dry governor B. It then passes up to the gravity governor C.

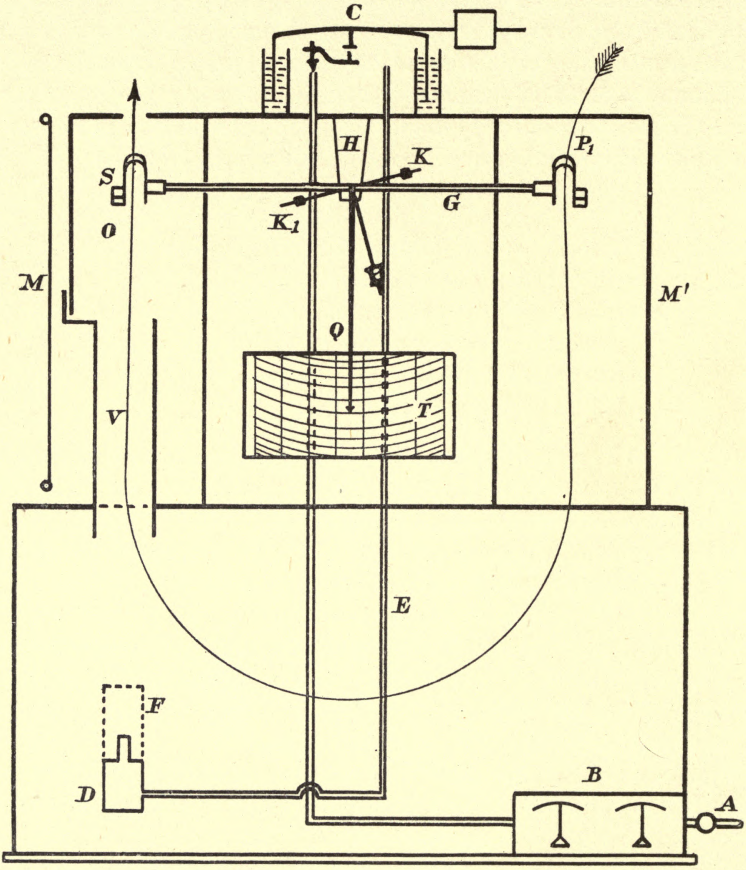


Fig. 111.—Diagram of Simmance Calorgraph.

The latter is exactly the same as already discussed in the description of Simmance's Standard Recording Calorimeter, and by its means the volume of gas supplied to the burner D is maintained constant irrespective of changes of specific gravity and is compensated for changes in tabular number as already explained. The burner D is fitted with a gold nipple, thus forming an incorrodible orifice of constant dimensions. It is also fitted with a copper gauze top held in position by an easily removable cap. The whole burner is surmounted with a perforated copper screen F, the function of which is to maintain the flame quite steady.

The Actuating Mechanism.—The actuating mechanism consists of a balance arm composed of a tube G. This is carried on hardened steel knife edges which engage in hardened steel V notches carried on a bracket H.

The expansible members P and P^1 are carried at the two ends of the balance arm G. The supporting spindle to which the knife edges are fixed also carries a small horizontal rod, to which are attached on either side of the support two movable weights KK^1. These are employed in adjusting the balance so that it is in equilibrium in the required position. The supporting spindle also carries the control weight L and the pen arm Q.

When the equilibrium of the system is disturbed by the differential expansion of the members P and P^1, the balance tilts until equilibrium is restored by the change in position of the centre of gravity of the control weight L relative to the point of support.

In the earlier form of the instrument the expansible members P and P^1 each consisted of six-chamber diaphragms. In this case it was necessary that the two sets of diaphragms were accurately " paired " up, and were similar in every respect. Unless this were the case, temperature and barometric pressure variations would not affect the opposing members equally, and thus the record would be vitiated by the effect of these variations.

In its latest form, the expansible members are composed of bimetallic strips each bent as shown, so that it forms two parallel legs. One leg is attached to the end of the balance arm G, and the other bears a brass weight S.

The bimetallic elements are made from " Thermostatic " metal produced by the British Thomson-Houston Company. This metal is composed of two layers of metallic alloy of widely differing coefficients of expansion by heat. These two layers are permanently united throughout their entire length.

The layer which is on the inside of the bimetallic element is composed of copper alloy, its coefficient of expansion being $9{\cdot}8 \times 10^{-6}$ per degree Fahrenheit. The outside layer consists of nickel steel of nearly negligible expansion (the alloy known as Invar). The coefficient of expansion of this layer is only 4×10^{-7} per degree Fahrenheit—only about one twenty-fifth of that of the inside layer.

Changes in temperature produce a deflexion of the thermostatic metal, the amount of which changes as follows :—

1. It varies inversely as the thickness.
2. It is not affected by changes of width.
3. It varies as the square of the length.
4. It is directly proportional to the temperature change.

The relationship between the deflexion and the temperature change for a particular size of thermostatic metal is shown in fig. 112.

So long as the expansible members PP^1 are at the same temperature, the balance will remain in equilibrium, as both members are precisely similar and equally affected by changes in temperature. Any difference in temperature will cause the weight S, carried by that member which is at the greater temperature, to move farther away from the centre of support of the balance, thus causing the system to assume a new position of equilibrium. The pen, owing to the tilting of the balance beam, moves across the chart T. When the pen is at zero on the chart, the control weight L hangs vertically.

Each of the expansible members P and P^1 is surrounded by a metal screen M and M^1, and in addition, the member on the " hot side " above the burner is enclosed in a mixing chamber O, superimposed upon a tubular chimney V.

Operation of the Instrument.—When the gas is lighted, a stream of air from outside the calorimeter is drawn downwards over the " cold " member to the burner. The stream passes upwards from the burner through the chimney and mixing chamber and out of the instrument.

The " cold " member is maintained at the temperature of the room by the air stream. The " hot " member is at a higher temperature, owing to the fact that the air stream has mixed with the hot products of combustion. The amount of increase in temperature depends upon the calorific value of the gas.

The variation in the rate of flow of the air stream past the hot member is compensated for, as the calorific value increases by its approach nearer to the flame of the burner, owing to the increasing tilt of the beam.

The amount of this approach is adjusted so as to compensate exactly for the increased speed of the air stream. The pointer of the pen on the chart is set to the correct calorific value by a slight adjustment of the gravity weight on the vertical (at zero) rod. The complete instrument is illustrated in fig. 113.

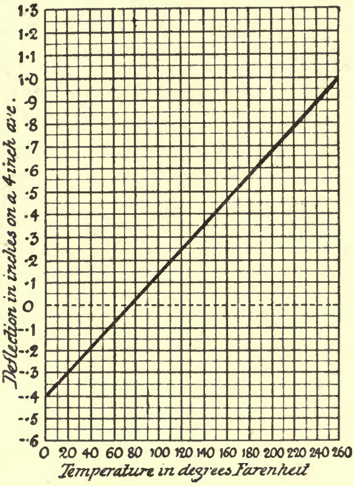


FIG. 112.—DEFLEXION OF THERMOSTATIC METAL.

Precautions required to maintain Simmance's Calorgraph in Working Order.—(*a*) As the relationship between the heat absorbed by the calorgraph and the calorific value is empirical, and depends amongst other causes upon radiation losses from the instrument itself, it is obvious that these losses should be rendered as constant as possible.

The room in which the instrument is situated should therefore be maintained as far as possible at a uniform temperature. This result can be accomplished by means of a luminous flame stove fitted with a simple thermostatic control (see Appendix I.).

(*b*) When the reading of the calorgraph is adjusted by hand tests on a standard water-flow calorimeter, it is essential that the gas under test be of constant quality for a certain time. This calibration is best effected when the record on the chart of the calorgraph is an absolutely straight line.

(*c*) The calorgraph should only be employed with clean gas, free from dirt, condensed moisture or tar; otherwise these particles, suspended in the gas, are liable to clog either the valve of the gravity governor or the burner orifice. Should the gas supply become temporarily dirty, thus fouling the apparatus, or should unusual condensation of moisture occur, the size of the flame will be lessened, and the record will be obviously affected. This condition is quickly remedied by removing the aluminium bell (without turning it upside down, in which case the oil will drain into it) and cleaning the valve by placing a piece of cloth or blotting-paper between the valve and its seating and pressing the valve down gently.

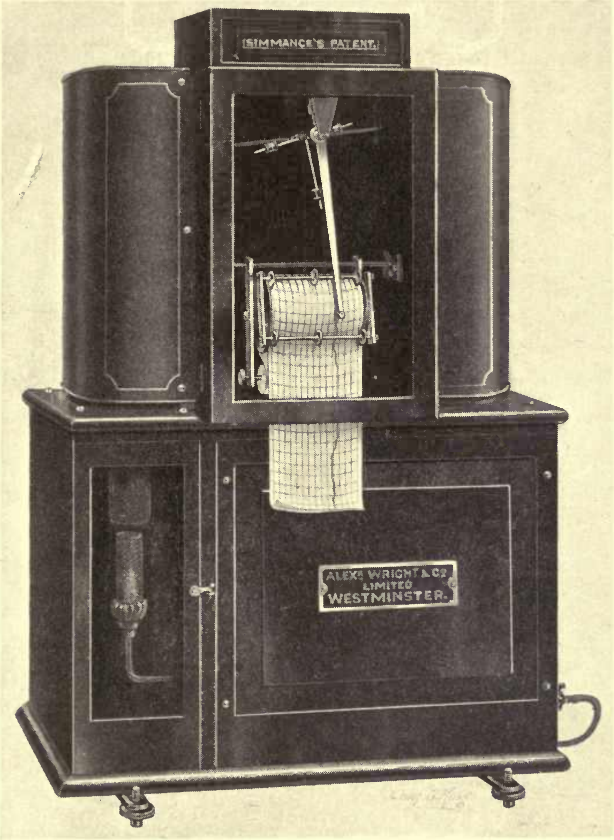


FIG. 113.—SIMMANCE CALORGRAPH.

The orifice of the gold plate below the burner should be cleaned with a piece of soft wood, such as a sharpened match-stick.

In ordinary circumstances, this cleaning should not be often required.

SIMMANCE WORKS' CALORIMETER

This instrument is in many respects very similar to the calorgraph, and differs from the latter chiefly with respect to the operating mechanism, which is more robust than the tilting balance beam of the calorgraph.

The calorimeter consists of :—

1. Apparatus for supplying a definite amount of gas, irrespective of variations in specific gravity or of external conditions of temperature and pressure.

2. A movable arm, the motion of which is due to the difference between the expansions of two opposing bimetallic elements. One of the elements is exposed to the cold incoming air, and the other to the same air stream after it has been heated by mingling with the products of combustion.

The Flow of Gas through the Instrument.—The gas enters the calorimeter at A (fig. 114), and its pressure is reduced to about 1 inch by the double dry governor BB^1.

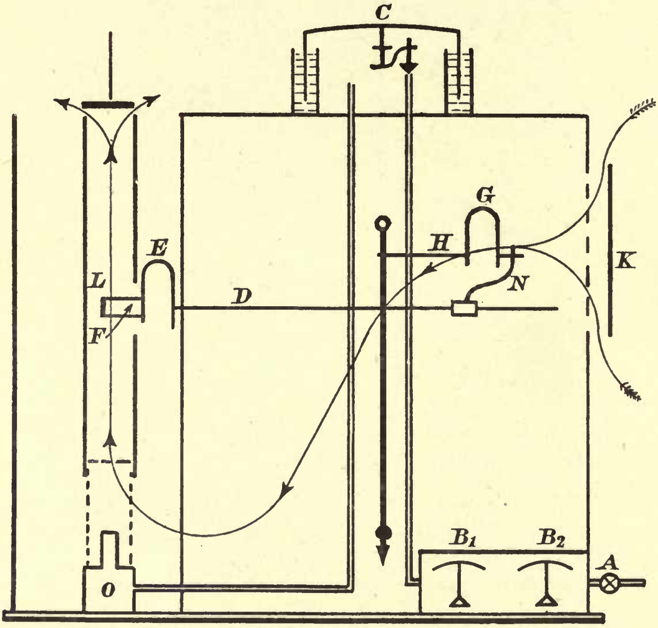


Fig. 114.—Diagram of Simmance Works' Calorimeter.

It then passes to a gravity governor C which is exactly the same as that used in the calorgraph. The gas passes from the gravity governor to the burner O, which is also the same as employed in the calorgraph. The consumption of gas is small, being only 1 cubic foot per hour.

The Actuating Mechanism.—The mechanism is fixed, instead of being movable as a whole, as in the case of the calorgraph. It consists of a rod D, to one end of which is attached an expansible bimetallic element E shaped as already described. A copper rod F is firmly fixed to one end of the bimetallic element E, and is heated by the stream of air passing over the burner. Heat is conducted through the rod F to the bimetallic element E and causes it to expand. As one limb of the element E is fixed, this expansion is communicated to the rod D, which thus moves in a direction parallel to its length. The motion of the rod D is communicated, by means of a coupling N, to the bimetallic element G, which is also fixed by one limb, and is in turn connected to the pen mechanism by a link H. Any expansion of the bimetallic element G occurs in a direction opposite to the expansion of the " hot " element E.

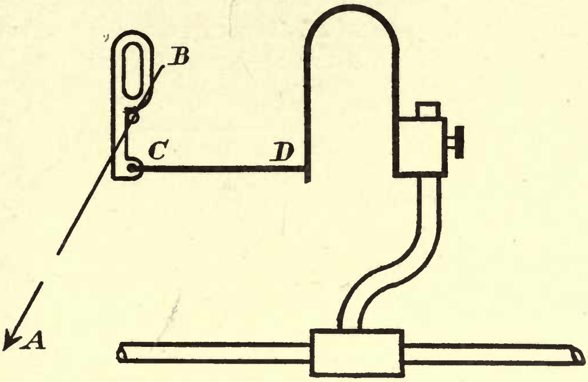


Fig. 115.—Linking Mechanism: Simmance Works' Calorimeter.

Operation of the Instrument.—On lighting the gas, a stream of air from the room enters the calorimeter through a gauze screen, which is shielded from draughts by an external shield K. The air stream passes in turn over the " cold " expansible element G, past the burner, up the chimney L, and over the copper rod F, finally passing out of the instrument at the top of the chimney.

As the bimetallic elements E and G expand in opposite directions, the difference between their expansions, constituting the movement of the rod D, will directly depend upon the increase in temperature of the rod F, which is a function of the calorific value of the gas. Barometric changes are of course without effect upon the bimetallic elements.

The increased rate of air-flow past the hot element E, due to increase in calorific value, is compensated for by the use of a novel type of linking in the pointer mechanism.

This is illustrated diagrammatically in fig. 115.

The pen arm AB is moved by linking CD connected to the moving rod, which is actuated by the differential expansion of the two elements.

The link CD moves in a horizontal direction, and the resultant movement of the pen arm AB is along the arc of a circle.

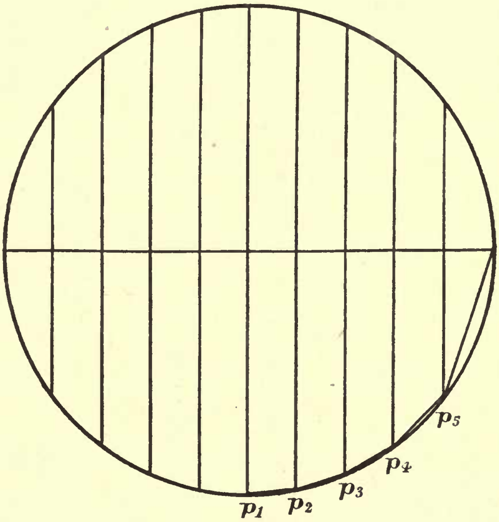


Fig. 116.—Theory of Linking Mechanism.

Suppose a circle is described (fig. 116), and vertical equidistant chords are drawn therein, then the distance between two successively parallel chords, which is always the same, will represent equal increments of the movement in a horizontal direction of the link CD. The pen arm, as it is displaced more and more from its vertical position AB, will, for equal amounts of horizontal movement as represented by the distance between the vertical chords, move through progressively larger distances, proportionally to the distance between the points of intersection and the vertical chords of the circumference of the circle, p_1, p_2, q_1, q_2, r_1, r_2, etc.

These distances become progressively greater as the displacement of pen arm AB from the vertical position increases. The increase in the movement of the pen with successive equal increments of horizontal movement is shown graphically on the curve (fig. 117).

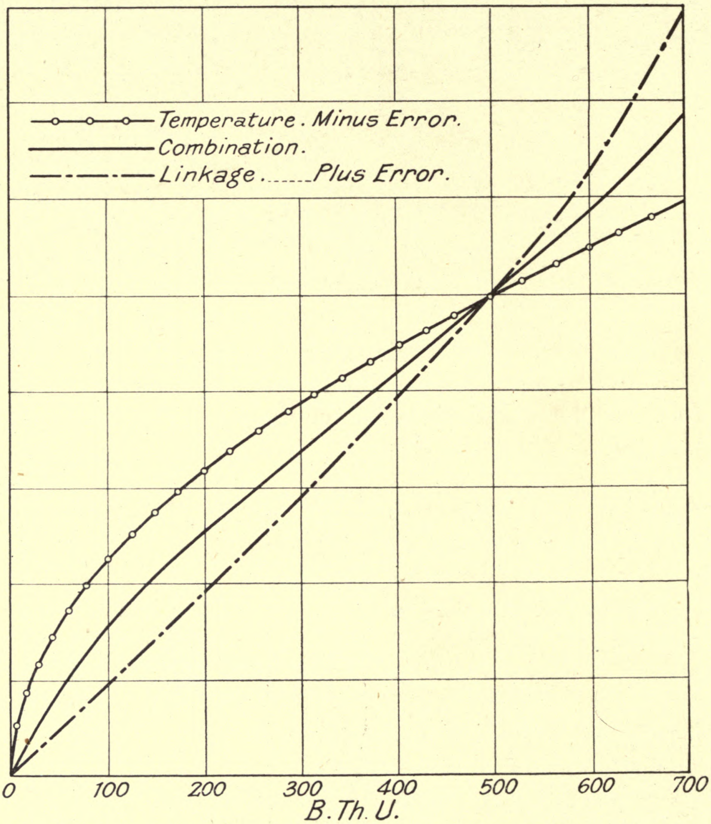


FIG. 117.—CORRECTION OF VARIABLE AIR FLOW BY SPECIAL LINKAGE MECHANISM.

The " temperature " curve shows the relative linear expansion of the hot member with calorific value—this expansion being progressively smaller as the heating value rises, due to increased induction of air as explained above.

The linkage curve shows the progressively increasing angular movement of the pen arm, as the link is displaced from its zero point. The combination of these two variables from a linear scale compensate for one another and give the middle curve, which between 200 and 600 B.Th.U. is a straight line, and hence corresponds to an equal scale.

By suitable variation of the zero position of the link, and consequent displacement and modification of the linkage curve, the scale of equality can be made coincident with any range of calorific values.

The exact adjustment of the stroke for a given calorific value is effected by a damper at the top of the outlet chimney L. The complete instrument is shown in fig. 118.

Attention to the same precautions, as were detailed in the description of the calorgraph, will enhance the accuracy of the record. When the instrument has once been lighted up and adjusted it should not require any further attention (apart from changing the chart and refilling the pen) for long periods.

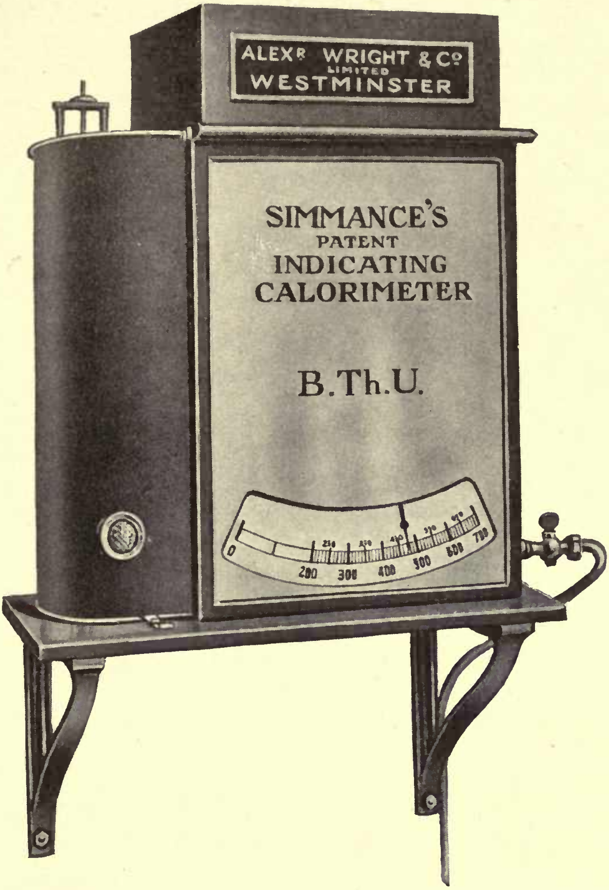


Fig. 118.—Simmance Works' Calorimeter.

Beasley Recording Calorimeter

This instrument is well known, and has been in use for a number of years. The calorimeter comprises :—

1. A wet meter, the revolution of which is controlled by a pendulum escapement, through which the gas is delivered to the burner.
2. A special type of differential recording thermometer, actuated by a portion of the heat of combustion of the gas.
3. The recording mechanism and chart.

1. *The Escapement Meter.*—The gas enters the calorimeter through a double dry governor situated on the top of the escapement meter, whereby the pressure at the inlet of the meter is maintained constant at about $\frac{15}{10}$ths water gauge. If the inlet pressure is too great (more than $\frac{30}{10}$ths), since the free revolution of the drum is prevented by the pendulum escapement, the water-line may be depressed on the inlet side of the meter, with a consequent increase in its capacity per revolution. The gas passes from the outlet of the governor to the escapement meter, which consists of a wet meter, the drum of which has a capacity of 0·033 cubic feet per revolution. The

spindle of the drum is connected by a coil spring to a pendulum escapement, which is arranged to permit the drum to make one revolution per minute. The meter therefore passes gas at the rate of 2 cubic feet per hour, *measured under the prevailing conditions of temperature and pressure,* and this rate is unaffected by specific gravity conditions.

Tests made by the Research Sub-committee of the Institution of Gas Engineers showed that gases of widely differing specific gravities passed through the escapement meter at identical rates.

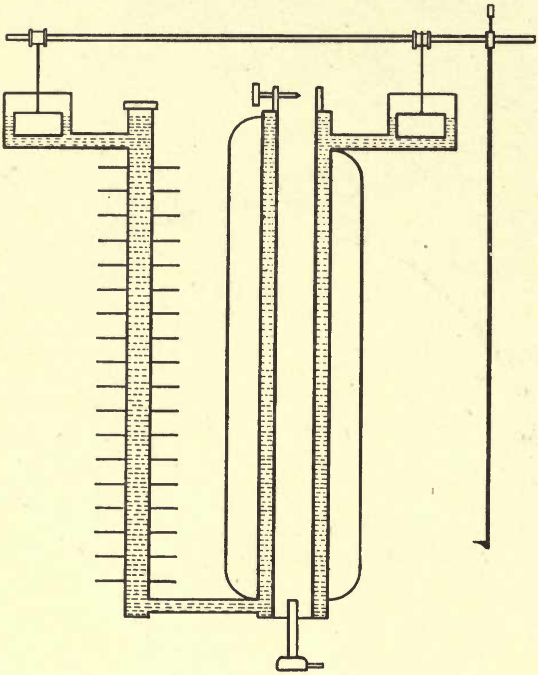


FIG. 119.—"U" TUBE: BEASLEY RECORDING CALORIMETER.

The water-line of the meter is adjusted by bringing the water up to a glass pointer in a sight box. During this process the gas is shut off from the meter, and the inlet is placed at atmospheric pressure by means of a small cock provided for the purpose. The gas passes from the outlet of the meter to the burner, which is situated within the inner tube of the "hot limb" of the thermometer (*q.v.*).

The air supply to the burner is controlled by a delicate adjustment, and the flame is left with a small luminous tip which can be viewed in a mirror provided for this purpose.

2. *The Differential Recording Thermometer.*—This consists essentially of a U tube containing oil. A portion of the heat of combustion is imparted to the oil contained in one limb of the U tube, the oil in the other limb being maintained at atmospheric temperature. The density of the oil in the hot limb is reduced, and hence the free surfaces of the oil in the two limbs are no longer at the same level.

The "hot limb" of the U tube consists of a double tube (the inner one being 2¼ inch diameter, see fig. 119). The outer casing of the double tube is fitted with radiators. The annular space between the two tubes is filled with oil. The "cold limb" B is a single tube fitted with radiators whereby it is maintained at atmospheric temperature.. The hot and cold limbs are placed vertically, and are connected together at the bottom.

The tops of the two limbs are connected by horizontal pipes to two circular tanks. When the oil in the hot limb is heated it expands and flows into the tank to which it is connected. This expansion and flow into the tank causes a loss of head, so that at the same time there is fall in the level of the oil in the tank connected to the cold limb. Hence when the calorimeter is at work there is always a difference in the level of oil in the two tanks which is proportional to the heat supplied, and hence to the calorific value of the gas burnt.

The difference between the oil levels in the two tanks is measured by means of sinkers suspended in each tank. These sinkers are attached to pulleys rigidly connected to a spindle. As the sinkers are suspended from opposite sides of these two pulleys, the rise of one sinker and the fall of the other sinker rotates the spindle in the same direction. The amount of rotation is a measure of the difference in level, and hence of the calorific value.

The majority of the heat transference to the oil is effected through the medium of the hot products and surplus air passing up the interior of the hot limb, and very little is due to radiation.

The reading obtained on the calorimeter is adjusted by the regulation of the draught up the hot limb. The latter is surmounted by a cap provided with a circular opening 1 inch in diameter, into which a $\frac{1}{4}$ inch screw projects. By advancing or withdrawing this screw, the volume of air passing up the hot limb can be regulated so that the correct calorific value is inscribed by the pen on the chart. The screw adjustment is very sensitive and a movement of one turn, or $\frac{1}{20}$th of an inch, causes a variation in the value recorded on the chart of approximately 10 B.Th.U's.

(3) *The Recording Mechanism and Chart.*—A tape chart is employed, and is graduated from 300 to 700 B.Th.U's. The division of the chart is not uniform, and the scale becomes more compressed in the region of the higher calorific values. This irregularly divided scale is necessitated by the variation in the speed of the draught with different calorific values, which as already stated, requires to be specially compensated for, if a uniformly divided scale is required.

The chart is not provided with a zero, which is, however, immaterial as a brass scale is fitted to the instrument for correctly placing the chart, and this scale is provided with a zero mark upon an extension.

The chart is driven forward by a toothed wheel, the chart passing between this wheel and a leather roller which is pressed towards the toothed wheel by a spring.

In some cases the time ruling on various batches of charts may vary slightly, and to compensate for this, the spindle of the toothed wheel is made hollow. It can be expanded or contracted by the action of a screw so as to make the time reading on the chart agree with that indicated on the dial of the clock provided on the instrument. The recording pen arm is firmly attached to the spindle (rotated by the motion of the floats). The pen itself is attached by a hinge to the bottom of the pen arm, and so balanced that it always maintains contact with the chart. The complete instrument is shown in fig. 120.

Precautions necessary for maintaining Beasley's Recording Calorimeter in Working Order.—(*a*) The water-line of the meter should be adjusted as follows :—

With the water-line slightly too low, the drum is given at least one complete revolution, finishing with the drum in a position midway between two oscillation points. The latter are four points, at which there is a rather marked oscillation of the water-level due to the unsealing of the compartment of the drum. Water is then run in very slowly through the cock below the thermometer, using a rubber tube and funnel, until the water surface just touches the pointer. The contact can be determined very accurately by the apparent distortion of printed matter reflected in the surface of the water. During this process the cock at the meter inlet is open to the atmosphere, and the pendulum is swinging freely.

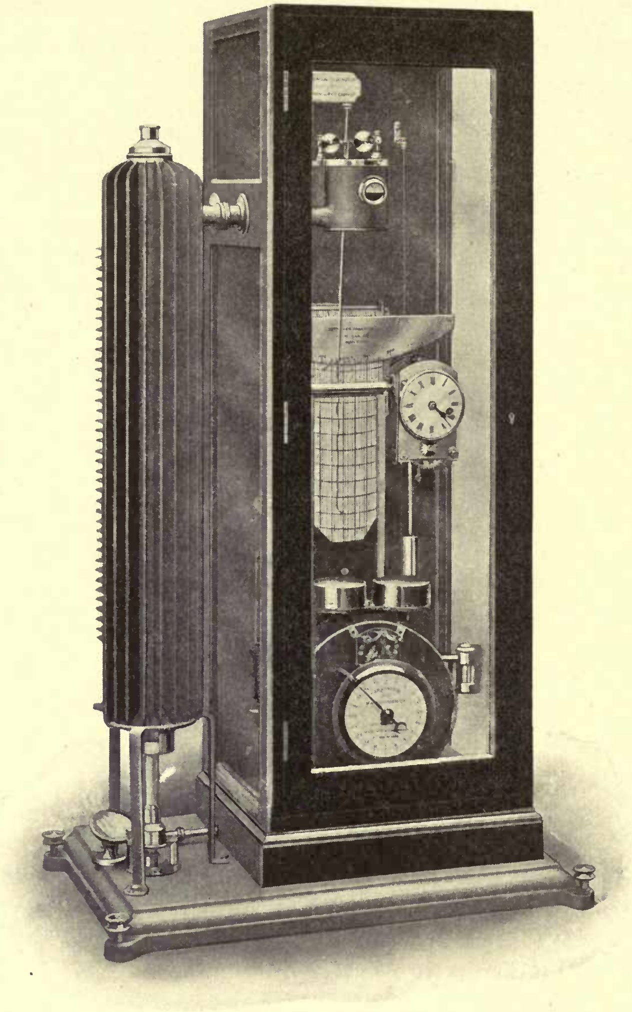


Fig. 120.—Beasley Recording Calorimeter.

(*b*) The water-line of the meter drops gradually owing to the gas entering being often only partly saturated. For this reason it is necessary to readjust the water-line at frequent intervals.

(*c*) When the instrument has been in use for a few weeks, the inside of the hot limb, the cap at the top and the adjusting screw become covered with a deposit which has the effect of reducing the draught up the hot limb and thus increasing the recorded value for the same quality of gas As the flame is practically non-luminous, the deposit is not soot, and as a matter of fact, has been found to be chiefly composed of inorganic matter—probably dust carried up with the ascending air current. The cap should therefore be removed and cleaned thoroughly every fortnight. The interior of the hot tube should also be cleaned out at the same time.

(*d*) The recorder should be set up in a position free from draughts or direct radiation from the sun or other source.

(*e*) When the recorder is first started, at least an hour must elapse before steady readings are obtained.

Beasley's recording calorimeter was reported upon in the Fifth Report of the Research Sub-committee of the Gas Investigation Committee of the Institution of Gas Engineers.

The following summary of the conclusions arrived at is abstracted therefrom :—

" 1. The advantages of the Beasley Recorder are :—

" (1) Comparative simplicity of construction and operation.
" (2) Absence of complication because no water supply is required.
" (3) Ready response to changes in gas quality.
" (4) The gas rate is not dependent upon the quality of gas supplied to the recorder.

" 2. Against this must be set certain disadvantages.

" (1) The record is liable to change with alteration in atmospheric temperature and pressure, and no attempt is made to compensate for these.
" (2) There is no convenient means of setting or checking the chart, except by reference to an independent water-flow calorimeter.
" (3) The instrument is sensitive to draughts.

" 3. The instrument may be set to read gross or net C.V., and no error of consequence will be introduced in the reading with gases down to 450 B.Th.U.'s gross, owing to change in composition giving rise to a different ratio of gross and net C.V.

" 4. Daily water-lining is essential. In our tests there was a drop in the water-line of the meter, due chiefly to evaporation, causing the meter to increase in capacity by approximating 1 per cent. per day.

" 5. Periodical cleaning of the chimney and cap of the hot limb is necessary, since the accumulated dust in these parts reduce the flow of air through the chimney.

" 6. When steps have been taken to allow for or overcome errors due to evaporation in the meter and draughts, the recorded C.V. agrees with the values obtained with the Junkers' and Boys' Calorimeters (the results of the latter not being reduced to 60° F. and 30 inches barometer) within plus or minus 10 B.Th.U.

" Sufficient evidence has not been obtained to account for this difference.

" 7. This recorder is in our opinion a useful instrument for the control of gas manufacture, but from some errors to which it is liable, unsuitable for official purposes."

THE SIGMA B.TH.U. INDICATOR

The Sigma B.Th.U. Indicator is the name given to an indicating calorimeter devised by Stewart. This instrument is also of the hot-chimney type, and comprises two main portions :—

(1) Apparatus for controlling the volume of gas burnt so that a constant volume, referred to standard conditions, is supplied to the burner, irrespective of changes in specific gravity or of variation in tabular number conditions.

(2) A special type of differential thermometer actuated by a portion of the heat of combustion of the controlled volume of gas.

(1) *The Gas-flow Regulator.* — The gas enters the pressure governor (fig. 121) at the top by means of the inlet pipe. It leaves the governor and passes through a down-flow tube to an orifice. The pressure at the latter is proportional to the difference in weight of two similar columns of gas and air respectively. This is the principle employed by Simmance in his gravity governor (see p. 113), and is the condition necessary for regulating the discharge of gas through the orifice in such a manner that the volume is corrected for tabular number and is independent of specific gravity variations.

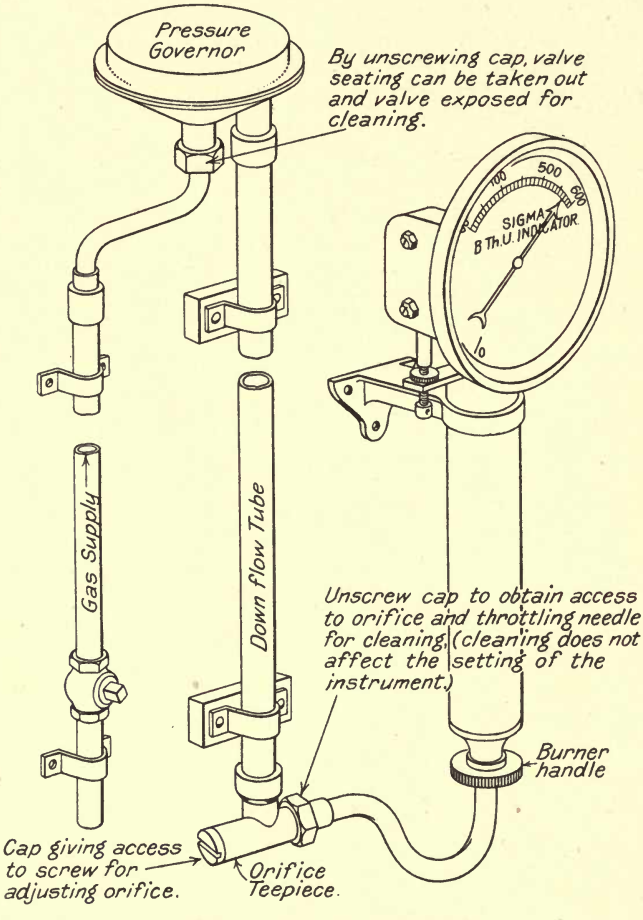


FIG. 121.—DIAGRAM OF SIGMA CALORIMETER.

The theory of a governor of this type was explained fully in the discussion on Simmance's Gravity Governor (*q.v.*).

(2) *The Differential Thermometer.*—The gas is burned inside an arrangement of concentric tubes R, S, T, the upper ends of which are shown in fig. 122.

The products of combustion, mingling with the surplus air, pass up through the central tube T and escape to air through a hollow casting P. The two tubes S and T, owing to their different situation relatively to the flame, and to their different diameters, attain different temperatures, and therefore expand by different amounts. As these two tubes are rigidly connected together at their lower ends, their upper ends, and therefore also the castings Q and P, to which they are respectively fixed, move relatively to one another by an amount dependent on the heat developed by the burning gas. This motion provides the means whereby the calorific value of the gas is measured.

It should be particularly noted that this motion arises entirely from the *different* temperatures which these two tubes acquire from the flame. As the tubes are both made of the same material, any general rise of the room temperature will cause both tubes to expand equally, and will therefore not affect the reading. (This is independent of the temperature compensation effected by the gas flow regulator which concerns the effect of temperature on the gas itself.)

The casting P (fig. 122), is rigidly fixed to the bottom of the case G, and therefore the arm J, which is a projection from the casting Q, will move the plunger H, with which it is connected by the zero adjusting screw K, in a vertical direction. The parts B, C, D, E, and F form a lever system, the special features of which are that it transmits the motion of the plunger H to the pointer N, while very greatly magnifying it. This is effected in the following manner:—The ring B is rigidly attached to the case G, while the second ring C is attached to the ends of the guide springs A and to the plunger H, the other ends of these springs A being fixed to the case by the pillars L.

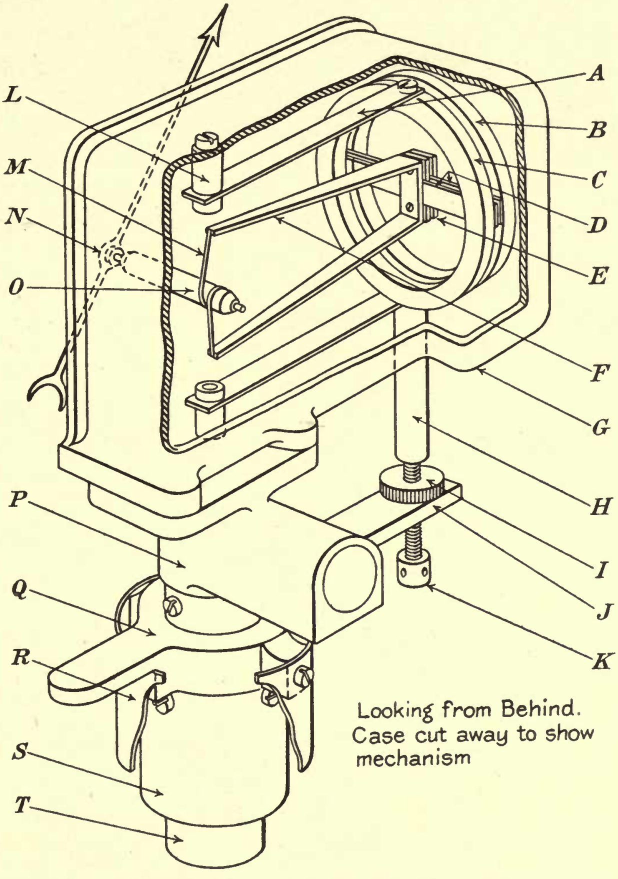


FIG. 122.—DIFFERENTIAL THERMOMETER: SIGMA CALORIMETER.

The ring C is therefore able to move vertically by the flexion of the guide springs A, but not in any other direction.

Stretched across and firmly attached to each of rings B and C is one of the thin, flat springs D. These springs are clamped together and to the fork F, midway along their length, by the clamp E. The springs D are very rigid edgewise—that is vertically—but, being thin, they can twist easily. If, therefore, the ring C is made to move vertically by means of the plunger H while B is held by the case, the springs D act as " torsional pivots " on the fork F, causing it to tilt. Attached to the end of this fork is the metallic driving-band M, which is wrapped round the pointer spindle O, and turns it in the same manner as a belt turns a pulley. The torsion springs D can be put very close together, in proportion to the distance between them and the spindle O, and a very great magnification can thus be obtained without back-lash. In the actual instrument the magnification is about 600—*i.e.* the end of the pointer moves through a distance 600 times as great as the relative expansion of the tubes S and T.

A third tube R surrounds the expansion tubes S and T. This tube carries the burner at its lower end, and also protects the flame and inner tubes from draughts. The supply of air for the flame enters at the top of this tube through the annular space between it and the casting Q, passes downwards to the flame and upwards through the centre tube T.

The Sigma calorimeter has only been made in the form of an indicating instrument, but the author has been informed that a recorder, working upon identical principles, will shortly be produced.

Precautions required in using the Sigma Calorimeter.—(*a*) The instrument should be protected from air currents and direct radiation.

(*b*) When the instrument has been in use for a few hours the gas should be shut off and the apparatus allowed to cool down completely. This will require one or two hours. If necessary, the zero of the instrument should be readjusted as it varies a little when the apparatus is first used. The zero should only be adjusted when the instrument is quite cold and should be checked once a week. It may be caused to vary a little through vibration.

(*c*) The orifice at the base of the downflow tube should be removed from the T-piece in which it is mounted and cleaned with a soft brush and a little benzene when necessary. The needle valve and its seating in the pressure governor should also be cleaned in the same manner.

SIMMANCE AUTO-CONTROL CALORIMETER

This apparatus is designed to control automatically the proportions of two gases of different calorific values in order to produce a gas of a desired calorific value by such mixture. If " A " is a gas of higher calorific value than is desired, and " B " of a lower quality, a combination of the two in proper proportions will naturally produce a gas which is a mean between the two. Therefore " A " gas must be of a constantly higher value than the desired mixture, although it may vary in both pressure and quality, and " B " must be a gas of a constantly lower quality than the desired mixture, although it may also vary in its pressure and calorific value.

The auto-control is actuated by a special adjunct to the Standard Recording

Calorimeter (described on p. 108 *et seq.*) which is influenced by the mixed gas, and causes an increase of pressure and subsequent larger supply of the rich gas until the mixture has attained the figure of calorific value desired, when the pressure of the rich gas is lessened, or may be arranged to shut off entirely at will.

The variation in the supply of the rich gas is effected by means of a specially constructed water-seal valve, being an adaptation of the ordinary district or retort-house governor (see fig. 123).

The valve is suspended from the bell B sealed in the water tank C. When the bell B is not weighted at all, the valve closes the orifice and shuts off the supply of gas. The degree to which the valve is opened is controlled by weighting the bell B by means of a variable water load contained in the chamber D on the roof of the bell.

The inlet water pipe E, which should not be less than 1 inch diameter, leading to the water chamber D, is bent over and is immersed in the water-loading chamber to such a depth that, when the bell has risen to its highest point, the end of the pipe will not touch the bottom of the chamber, and when the bell is at its lowest point, the tube must still have its end submerged in the water. The tube thus acts as a syphon pipe and serves for unloading the chamber.

A large overflow, not less than 1 inch diameter, is fixed at F in the side of the water chamber, so that the water cannot fill up too much, but flows away freely, as it will continue to run into the water chamber as long as the poorness of the mixture makes it necessary to keep the bell fully loaded.

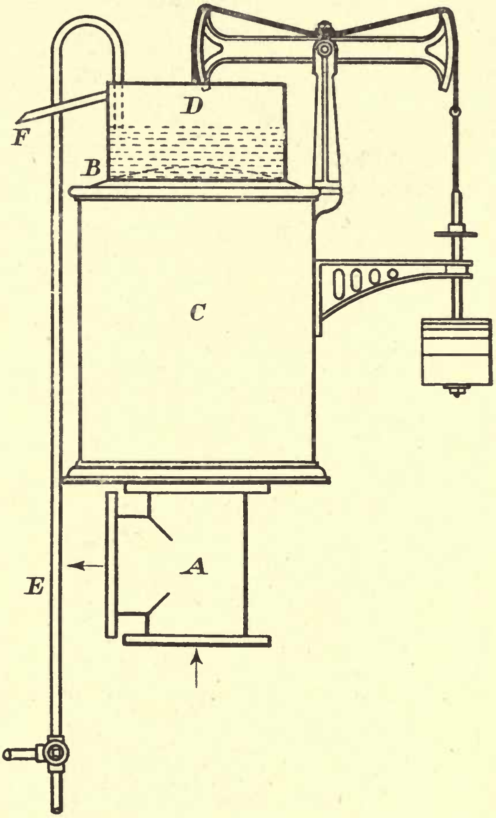


Fig. 123.—Governor used with Simmance Auto-control Calorimeter.

Water is admitted to this chamber or discharged from it according to the position of the pen on the auto-control calorimeter, which is worked by the mixed gas. This is effected in the following manner :—

Auto-control Apparatus.—The recording pen (fig. 124) is fitted with an electric contact which is capable of very fine adjustment, so that contact is made and broken by the influence of a change of one or two B.Th.U.'s in the quality of the gas. When the contact is made, current flows through a magnet, which attracts an arm, thus deflecting a pendent nozzle from its position which is normally vertical. This nozzle delivers the water flowing from the calorimeter, and when contact is broken and the nozzle is hanging vertically, this water flows into the trough which feeds one of the hanging buckets. Similarly, when contact is made, the nozzle is diverted and the water flows into the other part of the trough and feeds the bucket on the other side. The buckets exert a tangential pull upon the grooved wheel, thus causing it to revolve in one direction or another according to which bucket is filled by the water.

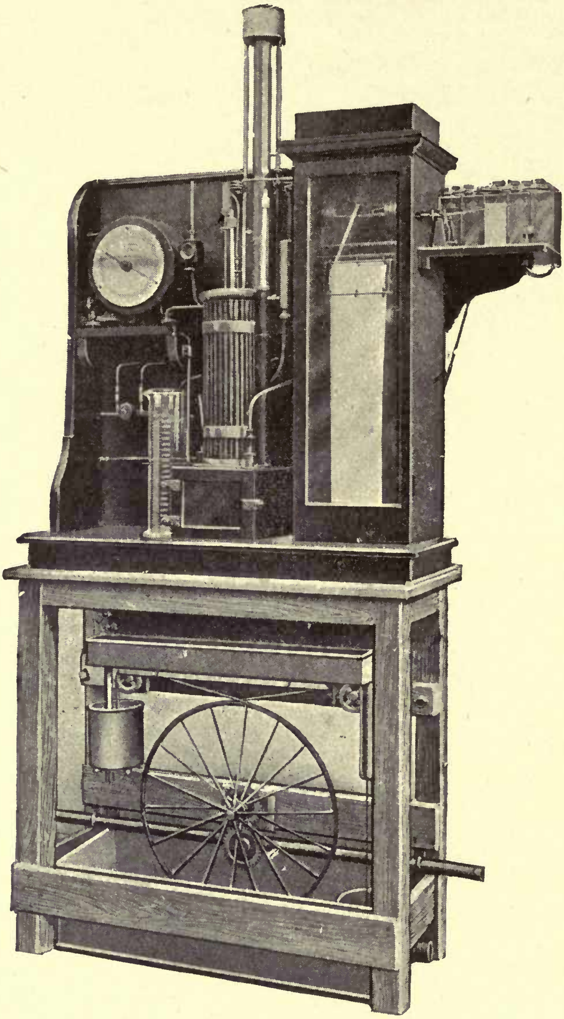


FIG. 124.—SIMMANCE AUTO-CONTROL CALORIMETER.

The spindle of the wheel is geared to the cock of the main-water supply. A connection, not less than 1 inch, is made from this cock to the pipe which effects the water loading of the governor, and according as either one or other of the two buckets is filled, so the water is either turned on into the water chamber on the roof of the governor bell or is syphoned therefrom.

The water from the buckets and also from the governor is discharged into a waste tank.

Remarks upon the Operation of the Auto-control.—The constancy of the calorific value of the mixed gas will depend upon the rapidity with which the governor can be loaded and unloaded.

It is obvious that the regularity of make of the two gases to be mixed will have a considerable effect upon the rapidity with which this loading and unloading of the governor can be effected, and the resultant quality regulated. If the rich gas is of a constant quality or nearly so, and is supplied at a constant pressure to the governor, then it would be possible to weigh down the bell to a point which leaves the auto-control very little to do. This is presuming that the poor gas is also comparatively regular; but so long as the richer gas is above the desired quality, and the poor gas is not too low in quality, then the action will be rapid. It must, however, be noted that supposing the rich gas is of 700 B.T.U.'s, the poor gas, say, 130 B.T.U.'s, and the desired mixture is to be say 300 B.T.U.'s, then the entry of the rich gas in large quantities will have an immediate effect; but if we suppose that the poor gas sinks to 90 B.T.U.'s and the rich gas to 350 B.T.U.'s, then it may be that, although the richer gas governor is weighted down to its fullest extent, and all the gas passed that is possible, yet, as there are no means of cutting off the supply of the poor 90 B.T.U. gas, it is possible that the resultant mixture can never arrive at the 300 B.T.U. standard.

It is, of course, necessary that the two gases are thoroughly mixed before they enter the calorimeter.

The following summary epitomizes in tabular form the salient features of the various instruments described in the context.

RECORDING CALORIMETERS

Calorimeter.	Type.	Gas Control.		Control of Cooling Medium.	Method of Recording Temperature Difference.	Remarks.
		(*a*) For Specific Gravity.	(*b*) For Tabular Number.			
Simmance Standard.	Water flow; heat totally absorbed in calorimeter.	Special type of gravity governor.	Effected by the gravity governor.	Water used and passed through a fixed gold nipple. Automatic head of water self-adjusting to variations in resistance of calorimeter to water flow.	Two identical aneroid chambers working in opposition on a rod; the movement is transmitted to the pen by amplifying levers.	Hand tests can be made at any time without disturbing the record.
Boys . . .	Water flow; heat totally absorbed in calorimeter.	Gas delivered by special meter, speed of which is controlled by a pendulum.	Speed of meter controlled in proportion to tabular number by special gear which is varied automatically according to T. N. variations.	Water measured out by operation of tilting buckets, and resulting flow rendered uniform by flow through small holes.	Two elastic chambers filled with amyl alcohol. Differential expansion transmitted through a system of magnifying levers.	Records percentage deviation from "declared value," and integrates the total deviation.
Fairweather .	Water flow; heat totally absorbed in calorimeter.	Wet meter controlled by pendulum and escapement.	Effected by automatic variation of rate of water flow.	Fixed head of water (apart from alterations purposely effected to correct for tabular number).	Two identical aneroid chambers working in opposition on a rod.	Hand tests can be made at any time without disturbing the record.
Thomas . .	Air-flow; heat totally absorbed in calorimeter.	Gas delivered through wet meter, coupled directly to air-flow meter.	Effected by use of air as cooling medium instead of water.	Air for cooling, taking place of water, is delivered by a driven wet meter.	Electrical resistance thermometers with automatic adjustment of Wheatstone bridge to a state of balance.	Records can be produced at any distance from the calorimeter.
Junker . .	Water flow; heat totally absorbed in calorimeter.	Gas delivered through wet meter, coupled to water-flow meter.	None.	Water delivered through meter coupled to gas meter.	Thermo-couple and millivoltmeter.	Hand tests can be made at any time without disturbing the record.

Simmance Calorgraph.	Hot chimney.	Special type of gravity governor.	Effected by the gravity governor.	Approach of "hot member" of recording thermometer to flame with increased draught in chimney.	Two similar thermostatic elements carried at each end of a balance beam, tilting of which is caused by displacement of centre of gravity owing to expansion of "hot member."	
Simmance Works' Calorimeter.	Hot chimney.	Special type of gravity governor.	Effected by the gravity governor.	Use of special link between bar and pen arm, which corrects for an increased draught in chimney.	Two similar thermostatic elements working in opposition along a bar, the movement of which is transmitted to the pen by amplifying levers.	
Beasley . .	Hot chimney.	Wet meter controlled by pendulum and escapement.	None.	Compensated for by irregularly divided scale.	The difference in level in the two arms of a U-tube containing oil, one arm being heated, is transmitted to the pen through sinkers partly immersed in each limb of the U-tube.	
Sigma.	Hot chimney.	Governor fitted with down-flow tube to the burner.	Effected by down-flow tube from governor to burner.		The differential expansion between two concentric metallic tubes, both heated by the products of combustion, is transmitted by amplifying levers to the pointer.	

CHAPTER VII

SELECTIVE GAS ANALYSERS

There are numerous reactions and processes in which either one or more of the reacting substances or a product of the reaction is a gas. It is frequently the case that the attainment of the maximum efficiency of the reaction depends upon the amount of the gaseous reacting material or of the gaseous product being maintained within certain limits.

Automatic instruments for analysing and recording the amount of a particular constituent of a gaseous mixture may be termed "selective recording gas analysers," and such appliances are of a considerable utility in gasworks.

Carbon dioxide was the first gas to be analysed and recorded automatically, and the great utility of the carbon dioxide recorder lies in the resultant fuel-saving which is effected by its use, as explained fully in Chapter I. This aspect is of far greater importance to-day than ever before, owing to the greatly enhanced cost of fuel.

The accuracy of the analyses effected by a modern carbon dioxide recorder is very considerable, and the results obtained agree very closely indeed with hand determinations carried out with all the refinements necessary to attain a result of the highest degree of accuracy. The following table, showing the results of tests carried out by the National Physical Laboratory on two instruments of well-known makes, clearly shows this :—

Instrument A.			Instrument B.		
Vacuum.	Hand Test Average.	Recorder Chart Average.	Vacuum.	Hand Test Average.	Recorder Chart Average.
Inch.	Per cent.	Per cent.	Inch.	Per cent.	Per cent.
0·75	4·99	4·91	0·5	5·68	5·29
	9·09	8·98		10·07	9·70
	15·88	15·39			
	18·77	17·83			

Carbon dioxide recorders are of three main types :—

I. Volumetric recorders, in which the carbon dioxide contained in a fixed volume is absorbed chemically, and the consequent reduction in volume is recorded as a percentage.

II. Diffusion recorders, in which the carbon dioxide is absorbed chemically after diffusion through a porous pot, thus producing a pressure difference between the interior and the exterior of the porous pot. This pressure difference is recorded and is a function of the amount of carbon dioxide.

III. Electrical carbon dioxide recorder. In this instrument the variation in the electrical conductivity of the gaseous mixture, which is a function of the percentage of carbon dioxide, is recorded.

I. VOLUMETRIC CARBON DIOXIDE RECORDERS

The first practical carbon dioxide recorder, due to Arndt, was a volumetric recorder and was operated by the vacuum in the chimney. It was intended only for use in conjunction with boiler settings, as from its design it could only be employed for the analysis of the gases under a vacuum. It could not, for example, be employed in any installation where, according to modern practice, a system of balanced draught is employed. It was also, as will be gathered from the description, very bulky and cumbersome. In spite of its obvious drawbacks, the instrument was of real utility and opened out a new field. A short description of the appliance is therefore included as a matter of historical interest.

Arndt Carbon Dioxide Recorder

The complete appliance is shown in fig. 125.

The motor which operates the mechanism consists of a large balanced bell A which rises and falls in a tank containing water, covered with layer of oil to prevent evaporation. The bell is connected to the chimney or flue by a standpipe which rises up the centre of the tank. The bell A is connected by a cord passing over a pulley D to a bottle E. It is balanced so that it will just rise when communication with the chimney is closed. When, however, the bell is connected to the chimney, the draught in the latter causes the bell to sink. The motion of the bell has to be reversed at intervals, and this reversal is effected by means of the lever F, which is actuated in the following way :—As the bell A rises it turns the pulley D, and in so doing brings one of the pins G against the lever F and forces the latter over, the lever, when it reaches the vertical position, falling to the right by its own weight. The action causes the valve H to open communication between the bell and the chimney. The bell A then descends, and the opposite pin on the pulley forces the lever F back to the left, thereby through the valve H, closing communication between the bell A and the chimney and opening it to the atmosphere, when the bell A again descends and the cycle recommences.

The motion thus imparted to the pulley D is employed to actuate two pumps. These pumps are similar in action to the motor pump A, and consist of bells rising and falling in water tanks fitted with standpipes. They are shown in detail in fig. 126. The motion of the pulley D is also employed in raising and lowering the bottle E. The latter is connected to the measuring vessel L by a rubber tube M, and is filled with a solution of glycerine in water. When the bottle E rises the liquid in the vessel L rises, and when it reaches a certain fixed point, the gas inlet tube K is closed. An inner tube is contained in L, and is connected to atmosphere by a pipe. When the liquid reaches the bottom end of the inner tube, exactly 100 cubic centimetres of flue gases are contained in the vessel L. These flue gases are drawn into the apparatus from the chimney through the tubes JJ by means of the pumps II. They then pass by way of the tube K to the vessel L. (The bottle E and the tubes JJ were filled with glycerine solution in the original apparatus. This solution was supposed to have less solvent action than pure water upon carbon dioxide. The use of glycerine solution in carbon dioxide recorders is, however, unnecessary.)

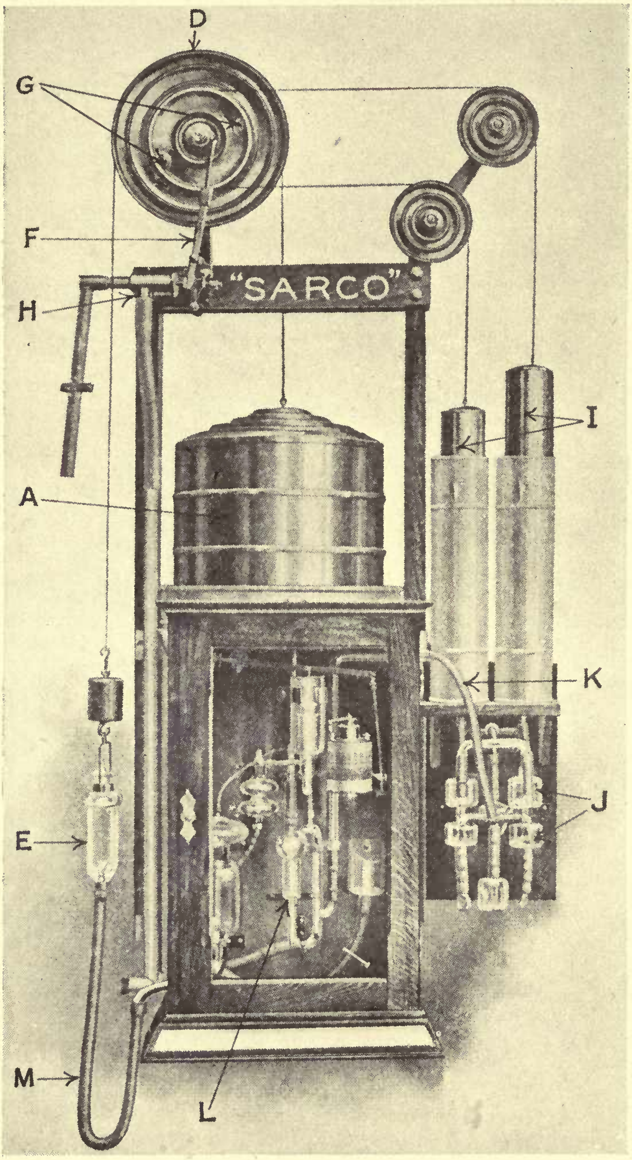


Fig. 125.—Arndt Carbon Dioxide Recorder.

As the bottle E rises further, the gases in the vessel L are gradually forced through a tube into a vessel, which contains a solution of caustic potash. When the liquid in L reaches a fixed mark, the whole of the 100 cubic centimetres of gas have been forced over into the potash vessel. The motor A reverses at this point, this operation being effected automatically by the action of the two studs GG on the lever F as already explained. The valve H is also opened automatically when the bottle E is at its highest point—*i.e.* when the liquid reaches the fixed mark in L.

The carbon dioxide in the flue gases is absorbed by the potash solution. The pressure of the residual gases displaces the potash in the potash vessel and forces it up a tube into an air vessel. When the potash reaches the bottom of another tube which is open to the atmosphere, a certain quantity of air is confined in the space above. When the potash has risen to the bottom of this tube it has driven 60 c.c. of air at atmospheric pressure out of this tube; but on the potash rising further, the air in the upper part of the air vessel is compressed, thereby raising a balanced bell contained in a tank sealed with glycerine solution. An inner tube, closed at its lower end,

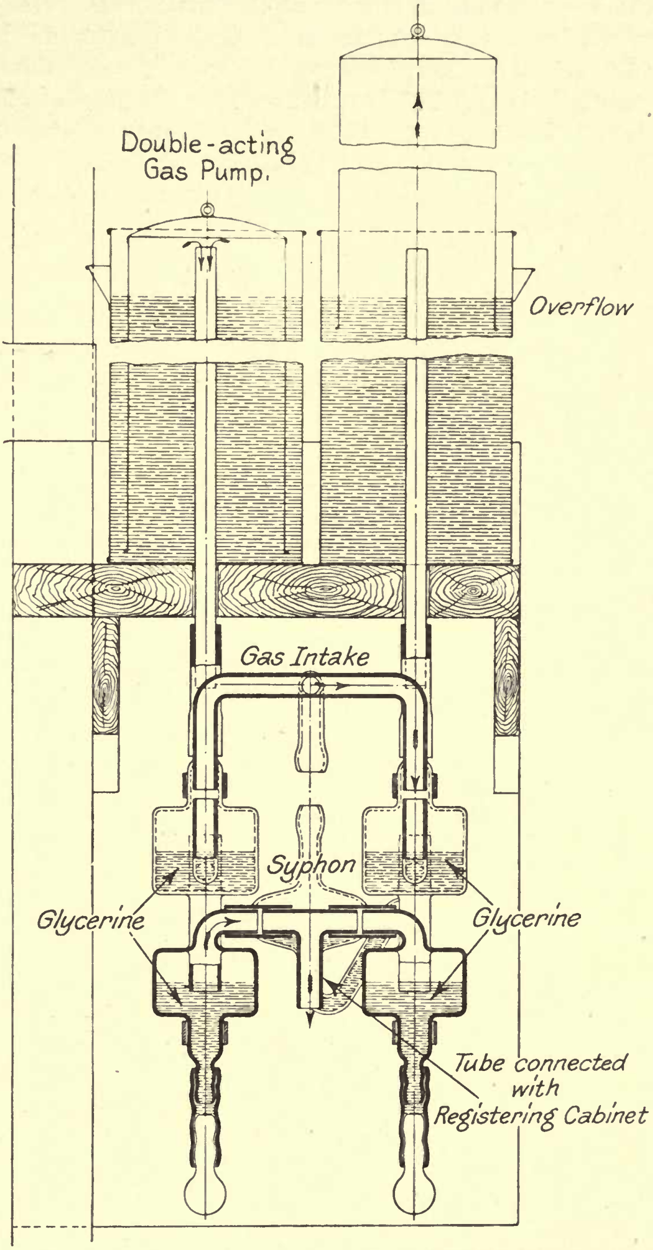


FIG. 126.—PUMPS FOR ARNDT CARBON DIOXIDE RECORDER.

is contained in the balanced bell. In order to raise the latter to the point where the lower end of the tube which it contains touches the rod actuating the recording mechanism, 20 c.c. of air are required, and the remaining 20 cc. (making up, together with the 60 c.c. which were exhausted to air, the total 100 c.c.) serve to raise the registering lever. This lever carries a pen working on a chart. The latter is calibrated from 1 to 20 per cent. For every 1 per cent. of carbon dioxide absorbed 1 c.c. of air less is driven into the balanced bell, and the registering lever rises 1 per cent. less on the chart. Hence if there is not any carbon dioxide present the pen rises to the top of the chart.

Simmance Carbon Dioxide Recorder

The next advance in the construction of automatic gas analysers was in the introduction by Simmance of a small flow of water as the motive power. In the earlier types of his instrument this flow was employed to move a float which, rising and falling in a tank which emptied at intervals by a syphon pipe, actuated a pump which inspired the flue gas into the apparatus. The water flow was also employed to work a filter pump whereby a constant draught was maintained on the supply pipe to the analyser, and the freshness of the sample analysed was thereby ensured. The gas was distributed to the various parts of the appliance by means of an automatic cock operated by the water flow. The latest form of the instrument is operated by a series of water seals maintained at their correct levels by means of a continuous flow of water.

The apparatus consists of the following parts :—

1. A gas-extracting chamber G (fig. 127), working in conjunction with a syphon tank E which periodically extracts a large sample of gas from which a smaller definite volume is measured off and delivered to a caustic potash tank.
2. A potash tank N, fitted with inlet and outlets and filling plug.
3. A small gas-holder with rising bell O and scale of 100 parts for remeasuring the sample after absorption of the carbon dioxide.
4. A rotating clock movement for carrying the chart and pen mechanism for recording the result of each analysis.
5. A water cistern and injector A for drawing the gas up to the recorder, and " tell-tale " gas chamber C for showing the condition of the piping.

The operation of the recorder is as follows :—

The water stream flows through the injector A, thereby causing a continuous stream of gas to be drawn from the pipe B connected to the flue. This stream of gas enters the tell-tale chamber at the bottom of the pipe C and is seen as a constant stream of bubbles passing through the water in this chamber. The water then flows to the tank E, which is fitted with a syphon pipe F, whereby the tank is emptied as soon as it becomes filled. The syphon discharges the water more rapidly than it flows into the tank E, and hence the latter is periodically filled and emptied. A metal bell G stands in the syphon tank E and is fitted with an inlet pipe H, which communicates with the flue pipe by a non-return liquid seal J. The bell G is also fitted with a pipe which communicates with the air through another liquid seal L.

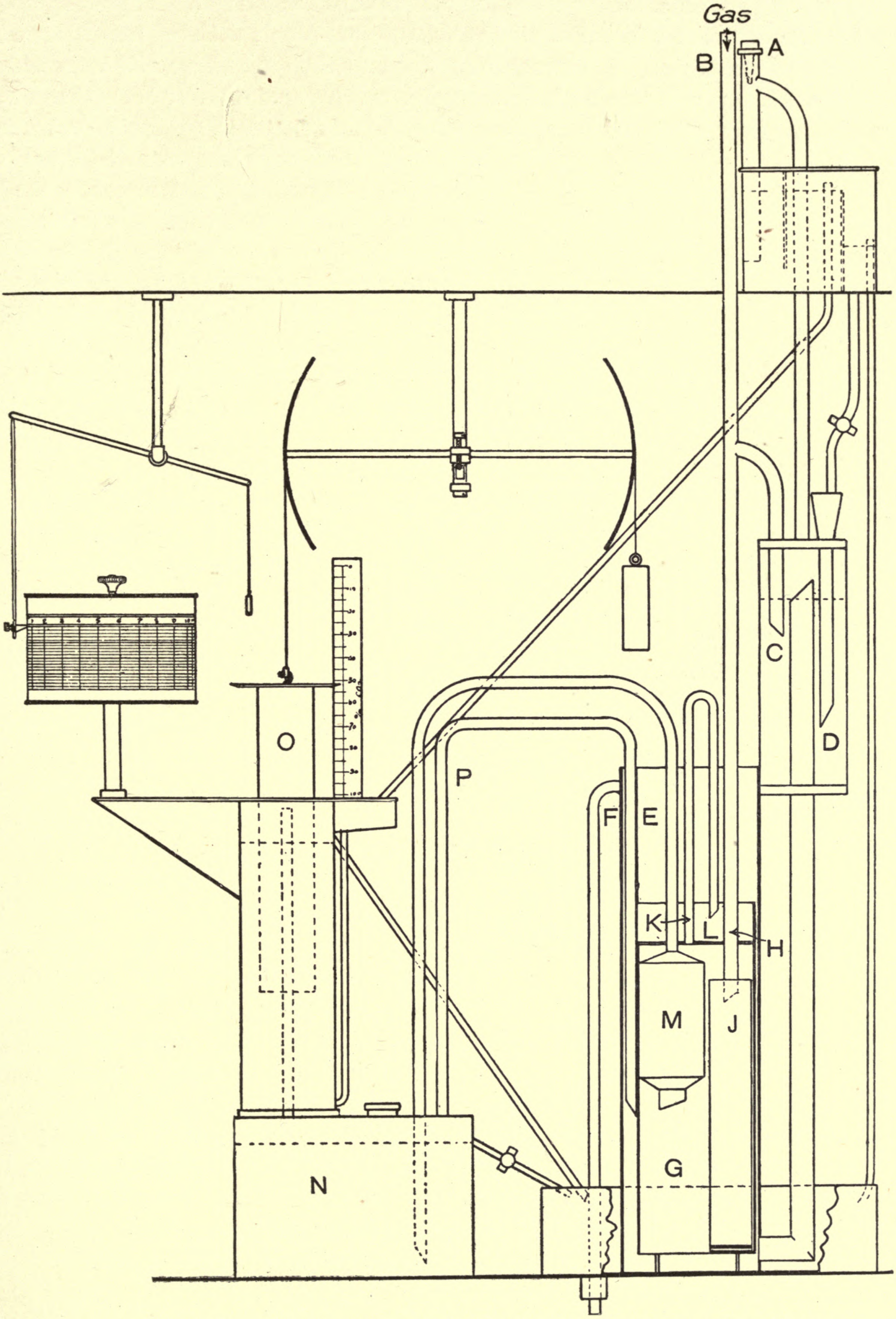


FIG. 127.—DIAGRAM OF SIMMANCE CARBON DIOXIDE RECORDER.

A smaller gas chamber M is contained within the bell G. This chamber is open at the bottom, and an outlet pipe at the top connects it with the tank N containing potash solution. As the surrounding water in the syphon tank E falls, during the period whilst the water tank is emptying by the operation of the syphon F, a sample of gas from the continuous stream flowing through the flue pipe is drawn into the bell G through the seal J. When the tank has emptied and it commences to refill by the influx of water, as this water rises, so the bulk of the sample is driven out to air through the outlet seal L. A small fixed volume is trapped off by the rise of the water in the chamber M, and as the water level continues to rise this portion is driven through the potash solution in N and the unabsorbed portion (or rather a volume of residual gas exactly equal to the volume of the unabsorbed portion) flows into the balanced bell O, which therefore rises to a height which depends upon the volume of the unabsorbed portion. At the same moment as the chamber M is sealed, the vent pipe from the potash vessel N is also sealed by the rise of water-level.

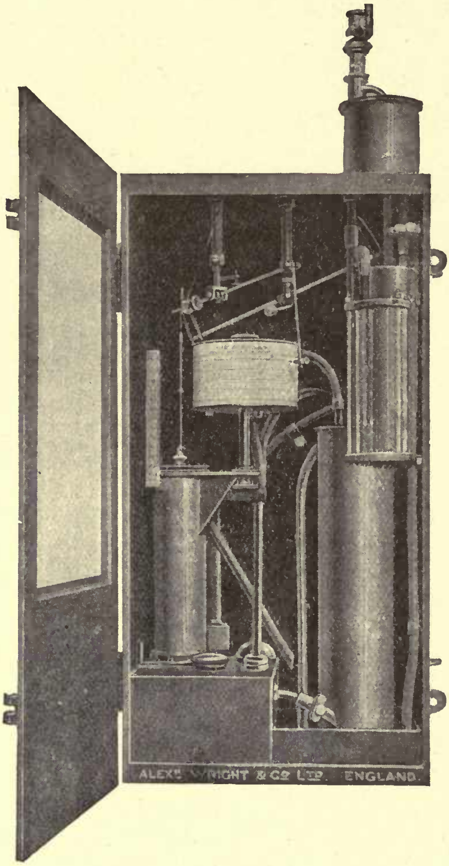


FIG. 128.—SIMMANCE CARBON DIOXIDE RECORDER.

The quantity of gas trapped off in the chamber M is just sufficient to raise the moving bell O over 100 divisions of the scale if there is no absorption in passing through the potash solution—*i.e.* if carbon dioxide is not present. If a sample of gas containing carbon dioxide is trapped off in M, the volume passing through the potash tank is lessened owing to the absorption of this carbon dioxide, and the bell O will therefore not rise so high. The total movement of the bell, which is of uniform cross-section, is divided into 100 parts, and hence the height to which it rises is a direct indication of the percentage of carbon dioxide in the sample.

The height to which the bell rises is recorded on a chart by means of a simple dropping-arm mechanism described fully in Chapter II. For ordinary running one analysis is effected about every three minutes, and the ends of the pen markings form a continuous curve showing the variation in the amount of carbon dioxide.

When the syphon discharges the water in the tank E, a fresh charge of gas is drawn in through B, and the residue of the previous sample, contained in the bell O, is exhausted through the pipe P, the end of which is unsealed as the water-level falls. The bell O is balanced so that it just sinks when P is opened to the atmosphere. The action of the instrument therefore goes on quite automatically so long as the flow of water is maintained.

The rate at which the analyses are effected depends upon the rate at which the water flows into the tank E, and the number of analyses per hour can be regulated as described by adjustment of this rate of flow.

The water seals are maintained at their working height by the flow of water. Should the flue pipe become choked, air instead will be drawn into the tell-tale chamber through the pipe D (which is sealed at a greater depth than the orifice of the pipe C). An indication of the stoppage is thus afforded.

The water in tank in which the bell O rises is constantly renewed by an auxiliary flow through the inlet and outflow pipes shown in the diagram. The collection and first measurement of the gas, and its measurement after analysis, are both effected at the same temperature by this means.

The salient features of the instrument are :—

(i.) A very small volume of gas is actually employed for each analysis, and forms a portion of a much larger representative sample. The consumption of potash is therefore low, and at the same time changes are recorded immediately they occur.

(ii.) All water-levels are maintained automatically.

(iii.) The apparatus is constructed of metal throughout.

The complete apparatus is shown in fig. 128.

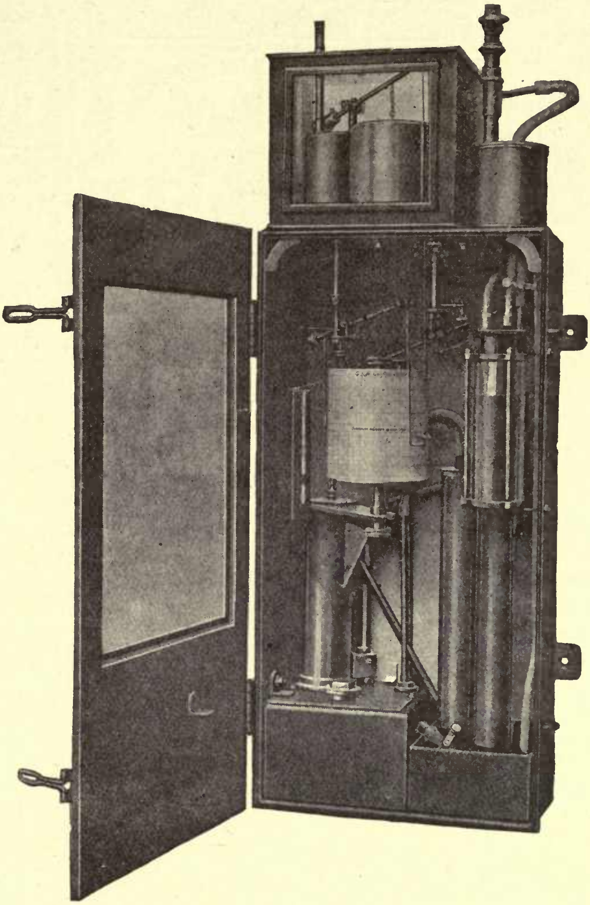


Fig. 129.—Simmance Combined Carbon Dioxide and Draught Recorder.

Simmance's carbon dioxide recorder is frequently fitted with a draught recorder as described on p. 46, Chapter III. The records of draught and of carbon dioxide are inscribed on the same chart. A combined instrument of this nature is illustrated in fig. 129.

The only attention required to maintain the apparatus in working order is the renewal of the potash solution and the change of charts and refilling of the pen.

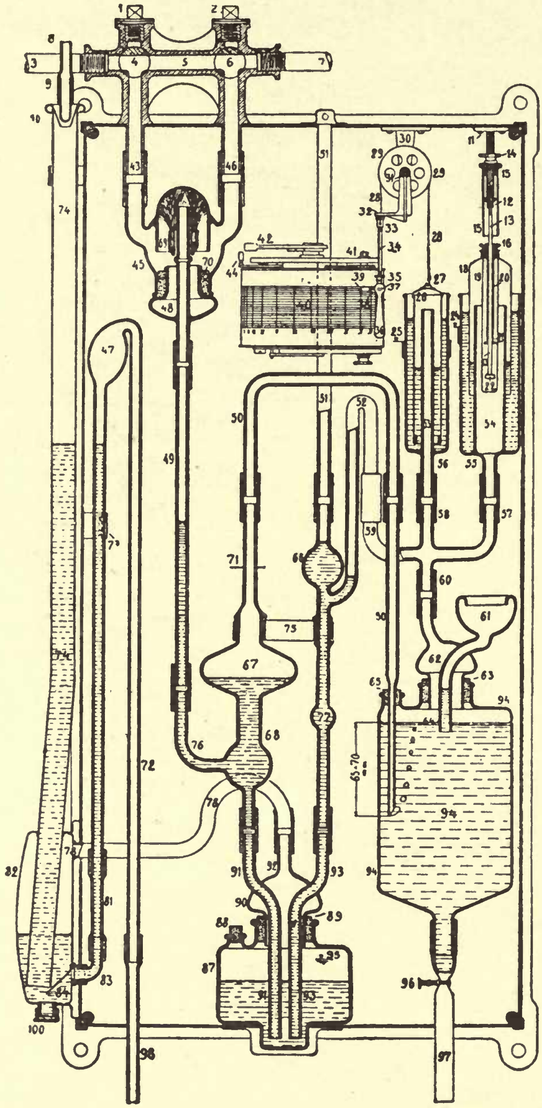


Fig. 130.—Diagram of Sarco Carbon Dioxide Recorder.

The same form of Simmance carbon dioxide recorder is quite suitable for registering the carbon dioxide in water gas. When required for this purpose it is advantageous to employ a chart which is more openly divided, and which reads up to 10 per cent. only.

The instrument is usually constructed for use with a liquid absorbent, but by a small modification, the latter can be replaced by a solid absorbent in form of small granules of specially prepared material, should it be desirable to avoid the use of a liquid absorbent.

Sarco Carbon Dioxide Recorder

The Sarco instrument is a modern development of a design of carbon dioxide recorder, of which Arndt's original apparatus, described above, was the prototype. The adoption of a small flow of water to actuate the mechanism and the development of other modifications have resulted in the production of an instrument which is much more compact and reliable than in its original form.

The *modus operandi* of the instrument will be gathered by reference to the diagram in fig. 130, and the complete instrument is shown in fig. 131.

The water operating the instrument flows through tube 74 into the power vessel 82, compressing the air above the water-level, and this pressure is transmitted to vessel 87 through tube 78. The pressure thus brought to bear on the surface of the liquid with which vessel 87 is filled (to mark 95) sends this upwards through tubes

91 and 93. Thence it passes up into vessels 68, 67, 77, and 66, and into tubes 49, 51 and 52. It rises until it reaches the zero mark 71, which will be found on the narrow neck of vessel 67.

At the moment it reaches this mark the power water, which, simultaneously with rising in vessel 74, has also travelled upwards in syphon 72, will have reached the top of this syphon, which then commences to operate, and a much larger quantity of water is disposed of than flows in through injector 9, so that the power vessels 74 and 82 are rapidly emptied. As the pressure on vessel 87 is thus released the liquids return from their respective tubes into this vessel.

Assuming tube 49 to be in connection with a supply of flue gas, a sample of this is drawn in from the continuous stream which passes through 43, 45 and 46, as the liquid recedes in 49, by the partial vacuum which is created by the falling of the liquid.

As soon as the flow in the syphon stops, vessel 82 begins to fill again, and the liquids in tubes 91 and 93 rise afresh. The gas in 67 and 68 is now forced up into tube 50, and caused to bubble right through a solution of caustic potash (specific gravity 1·27) with which vessel 94 is filled (to point 64 marked on the outside). In this process any carbon dioxide that may be contained in the gas is quickly absorbed by the potash. As the gas has to pass through the potash, the absorption is rapid and complete.

The remaining portion of the sample collects in 62 and passes up through 60 into tubes 57 and 58. (It cannot pass out at 59, as this outlet is sealed by the liquid in 52.)

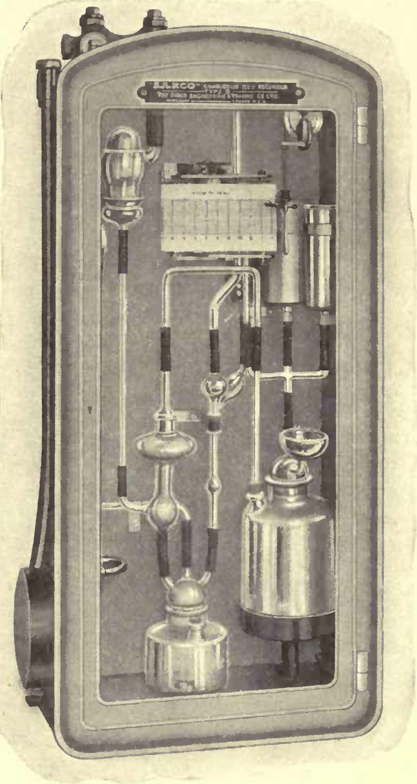


Fig. 131.—Sarco Carbon Dioxide Recorder.

The gas now passes under the two floats 18 and 26, whereof the former is constructed larger and lighter, and will therefore be raised first.

By turning the thumbscrews 14 and 15, the stroke of this float is adjusted until just 20 per cent. of the whole of the sample remains to raise float 26 when there is not any absorption in the vessel 94, as would be the case if air is passed through the recorder. This float has attached to it a pen 36, which is caused to travel downwards on the chart as the float rises.

If there were no carbon dioxide in the gas, there would not be any absorption by the potash in 94, and the whole of the 20 per cent. would reach the float 26. Thus the pen would travel the whole depth of the chart from the 20 per cent. line at the top to the zero line at the bottom. In actual working, any carbon dioxide contained in the sample would be absorbed by the potash, a correspondingly less quantity would reach float 26, and the pen would not travel right down to the bottom of the chart, but would stop on the line which denoted the percentage of carbon dioxide in the sample.

Thus any carbon dioxide absorbed will be indicated by a shorter travel of the pen—the actual percentage being given by the line on which the pen stops.

On the return stroke of the liquid, the gas is pushed out from under floats 18 and 26, through tubes 57 and 58, and into tubes 59 and 52. From here it passes out into 66 (as soon as the liquid has fallen below the outlet of tube 52) and through tube 51.

It will be seen that the gas, when analysed, leaves the recorder by a set of tubes entirely separated from those through which the samples are obtained, so that there is no possibility of mixing the old with the new samples.

II. INSTRUMENTS OPERATED BY DIFFUSION

Webster Carbon Dioxide Recorder

This apparatus may be regarded as a development of the well-known carbon dioxide indicator, in which the air contained in a chamber fitted with a porous diaphragm diffuses out into atmosphere containing carbon dioxide more rapidly than the latter diffuses in, owing to the greater density of carbon dioxide. The diminution of pressure thus occasioned is registered by an aneroid gauge, graduated to read directly in percentages of carbon dioxide.

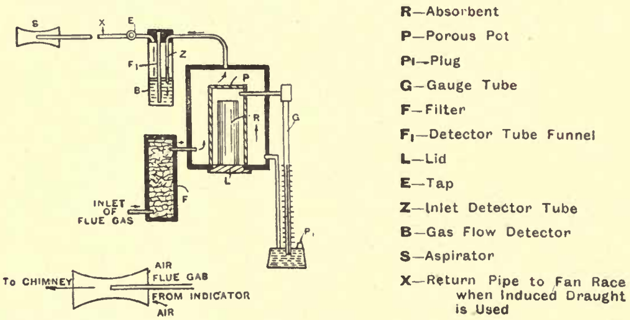


Fig. 132.—Diagram of Webster Carbon Dioxide Recorder.

The operation of the instrument is shown diagrammatically in fig. 132.

The flue gas is drawn through the apparatus by the aspirator S, which is connected to the chimney, and is operated by the draught therein. So long as there is a vacuum of at least $\frac{3}{4}$ inch water at the base of the chimney the aspirator will function adequately. The gas enters the instrument through a filter F (*vide infra*), and after being freed therein from suspended solid particles, it flows into a chamber in which a porous pot P is contained. The gas leaves this chamber and passes through a bottle B containing water, which serves as a tell-tale, so that the flow of gas through the apparatus is under observation, and any stoppage in the connecting pipes will be indicated by a partial or complete cessation of the flow of bubbles. The gas then passes through the cock E, which serves to control its rate of flow, to the aspirator S.

The porous pot P contains an absorbent cartridge R, which is filled with a material which absorbs carbon dioxide rapidly (*q.v.*). As the gas flows over the pot P it diffuses into the interior, and the carbon dioxide which it contains is removed by the absorbent. A difference of pressure is thus set up between the interior and the exterior of the porous pot P, and the amount of this difference will depend upon the volume of gas absorbed from the interior —*i.e.* upon the percentage of carbon dioxide. This measurement of differential pressure is indicated in the diagrammatic sketch by a simple water gauge. In the recording instrument the pressure difference is recorded by a differential pressure gauge of the aneroid diaphragm type connected to the interior and exterior of the pot P respectively. The recorder is illustrated in fig. 133.

The absorbent cartridge R is renewed every twenty-four hours, and is withdrawn by removal of the lid L. About ten minutes are required, after the insertion of a new absorbent cartridge, before the instrument again gives a correct reading.

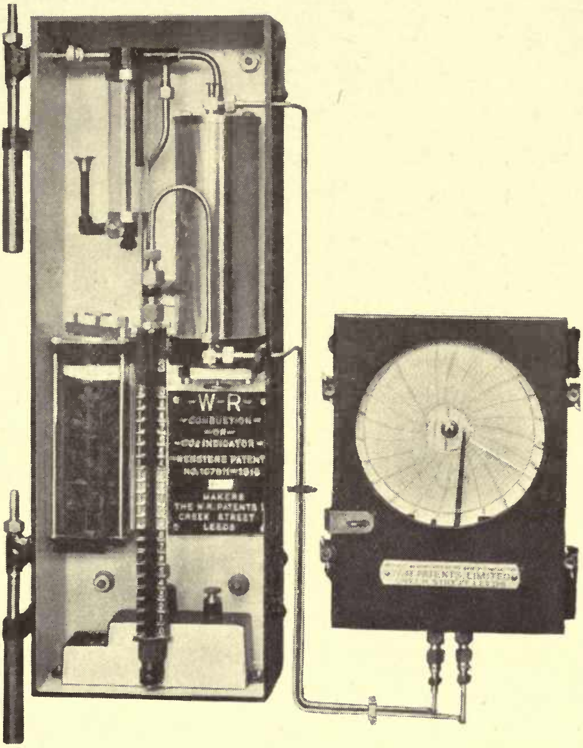


FIG. 133.—WEBSTER CARBON DIOXIDE RECORDER.

CARBON DIOXIDE RECORDER FOR WATER GAS

Owing to the fact that Webster's recorder is operated by the diffusion of the gaseous mixture through a porous pot, the form of the instrument employed for flue-gas analysis is unsuitable for use with water gas, owing to the presence of a considerable quantity of hydrogen in the latter. This gas would diffuse so rapidly through the porous diaphragm that the pressure difference set up by the absorption of the carbon dioxide from the interior of the porous pot would be largely or completely nullified. For this reason a special instrument is employed for the analysis of carbon dioxide in water gas. The presence of hydrogen does not cause any trouble or error in the case of the purely volumetric recorders of the types already described.

The operation of the water gas carbon dioxide recorder will be gathered by reference to fig. 134.

A continuous sample of blue or carburetted water gas passes by its own pressure through the cock E into two similar chambers containing inverted porous pots P and P_1, which are mounted in such a way as to be perfectly airtight. Removable lids L and L_1 are fitted to these porous vessels, the right-hand one of which contains a dry cartridge R for absorbing carbon dioxide. The cartridge in the left-hand pot is merely a dummy, inserted to maintain the respective volumes of the two pots approximately equal. The gas, the flow of which is shown by arrows, after passing continuously through the chambers containing the porous pots, burns at the outlet with the flame F. The insides of the two porous pots are connected to the two sides of a recording differential pressure gauge, which will thus indicate the difference between the pressures prevailing in their interiors. On the passage of water gas through the apparatus, carbon dioxide will be continuously absorbed in the right-hand pot, and the greater the proportion of carbon dioxide the larger is the resulting differential pressure which is occasioned by the removal of the carbon dioxide. The recording differential gauge is graduated to read directly in percentages of carbon dioxide.

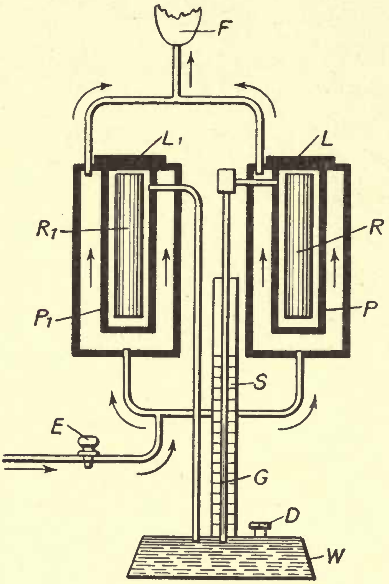


Fig. 134.—Diagram of Webster's Water-gas Carbon Dioxide Recorder.

Absorbents for Carbon Dioxide

Volumetric and diffusion recorders must be provided with a suitable absorbent for effecting the removal of carbon dioxide from the gaseous mixture undergoing analysis. The absorbents employed must conform to certain requirements in order to perform this function satisfactorily.

(i.) The *reactivity* of the absorbent must be high—*i.e.* the carbon dioxide must be rapidly absorbed even when the analyses are performed very frequently, so that the removal of the carbon dioxide is always complete.

(ii.) The *capacity* of the absorbent should be as high as possible—*i.e.* the amount of carbon dioxide which is effectively absorbed by the expenditure of a certain amount of reagent should be a maximum. In certain cases the frequency with which the charges require renewal is of greater moment than their actual cost, and in this case the capacity of the absorbent is referred to its chemical activity per unit weight or volume rather than to its prime cost.

(iii.) It is also essential that the products resulting from the absorption of carbon dioxide should not be of such a nature as to prove detrimental to the continued operation of the instrument. For example, it is important that any tubes immersed in the absorbent should remain clear and should not become stopped up.

(iv.) A useful addition to the absorbent consists in some self-indicating method of showing at a glance the proportion of the reagent which is still available for use, so that the absorbent is always changed in time, but, on the other hand, unnecessary waste is prevented.

A solution of caustic potash in water of specific gravity about 1·25 (1 lb. of potash dissolved in about 1 lb. water) is the absorbent most generally used in carbon dioxide recorders. This conforms to the first three of the above-mentioned requirements, but does not permit of any indication of the state of exhaustion of a charge of absorbent. For this reason, and owing to the dispersion of the absorbent into a liquid form (whereby it is uniformly exhausted), it is undesirable to employ a charge for more than about two-thirds to three-fourths of its theoretical absorptive capacity.

Caustic soda has a higher absorptive capacity—weight for weight—than caustic potash, and it is also cheaper. It cannot, however, be successfully employed instead of the latter, as the sodium carbonate crystals formed by the absorption of the carbon dioxide would soon choke up the inlet tube which is immersed in the absorbent.

The ordinary soda-lime granules, obtainable from all chemical dealers, can be employed as an absorbent. The varieties obtainable are, however, very inefficient chemically—*i.e.* they lose their capacity for the complete removal of carbon dioxide from a gaseous mixture when only about 20 per cent. of their theoretical absorptive capacity has been exhausted.

The author has developed a dry absorbent for use in carbon dioxide recorders which conforms to all the requirements postulated above. The preparation is made in the form of fine granules about 14–18 mesh, and is composed of slaked lime, caustic soda and ferric hydroxide. The product is very reactive, and its capacity is also very large. The absorbent is contained in a tall glass cylinder, and as it becomes exhausted a coloured line—due to the dehydration of the absorbent by the heat of combination—moves up the tube. It is thus possible to see exactly how much absorbent remains unexhausted. In this manner the charge can be employed until over 80 per cent. of its theoretical absorptive capacity has been exhausted.

III. THE CAMBRIDGE ELECTRICAL CARBON DIOXIDE RECORDER FOR FLUE GASES

The electrical carbon dioxide recorder depends upon the variation of the thermal conductivity of a mixture of gases with its composition. If one component only of the gaseous mixture is variable, and if the thermal conductivity of this component differs from that corresponding to the other principal constituents of the mixture, it is possible to determine the amount of the variable component by measurements of thermal conductivity. The method was first developed by Shakespear for testing the purity of gases used in aeronautics, and for the determination of the permeability of airship and balloon fabrics. It has been adapted to the construction of carbon dioxide recorders suitable for flue-gas analysis.

The thermal conductivity method has obvious limitations and cannot, generally speaking, be applied to the analysis of complex mixtures of several variable constituents. When, however, the percentages of all other gases except the one to be measured are small, and the gas to be measured can readily be absorbed without affecting the other constituents, a double-flow method is employed, in which the thermal conductivities are compared before and after the absorption of the constituent in question.

The effect of water vapour in the gaseous mixture can always be compensated for automatically. This may be effected either by drying the gas or preferably by saturating it completely.

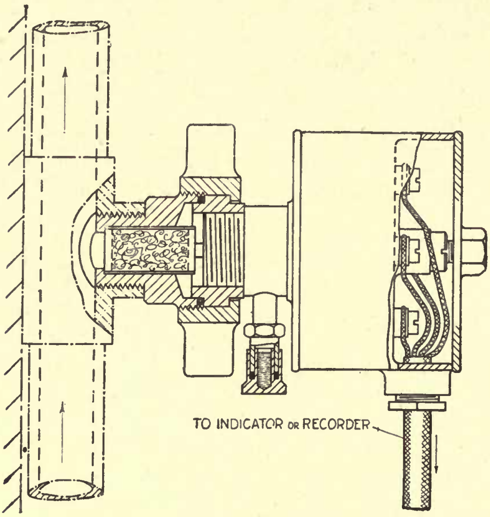


Fig. 135.—Cambridge Electrical Carbon Dioxide Recorder Head.

The carbon dioxide meter in which the conductivity determinations are effected is shown diagrammatically in fig. 135.

Identical spirals of platinum wire are enclosed in brass cells which are contained in a copper block. Each of these spirals forms one arm of a Wheatstone bridge circuit (see Chapter IV, p. 63). If an electric current be allowed to flow in this circuit, the two spirals will become heated and will lose heat to the walls of the cells. If the two cells contain gases of different thermal conductivities, the spirals will cool at different rates; one will therefore be maintained at a higher temperature than the other.

This temperature difference will give rise to an inequality in the resistance of the two spirals, owing to the variation of the resistance of the platinum spiral with the temperature (see Chapter IV, p. 62). The bridge will therefore become unbalanced and the galvanometer pointer will be deflected. The extent of the deflexion will depend on the difference in the temperature, and hence on the conductivity of the gases in the two cells.

The arrangement is therefore very similar to the resistance thermometer outfits employing the deflexion method of recording the results (*q.v.*).

In the case of the carbon dioxide meter the flue gas to be analysed is caused to flow past one of the cells, and any changes in its composition are communicated to the cell contents by diffusion within a minute. The other cell is filled with air, which is kept saturated by water in a tube connected to the cell, to counteract the effect of water vapour, as the flue gases are always saturated. The difference between the thermal conductivities of oxygen and carbon dioxide (which replaces more or less the oxygen in the flue gases) causes an unbalancing of the bridge as described, and the resultant deflexion of the galvanometer will depend only upon the amount of carbon dioxide in the flue gases. The deflexion is therefore recorded on a chart scaled to register percentages of carbon dioxide.

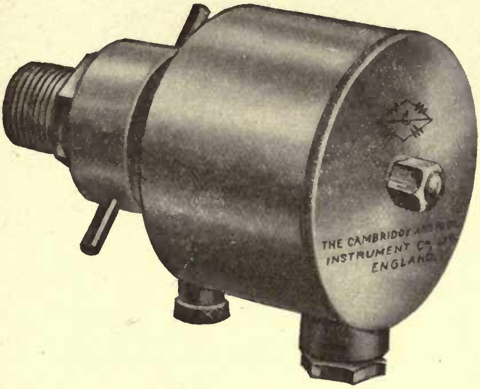


FIG. 136.—CAMBRIDGE ELECTRICAL CARBON DIOXIDE RECORDER.

Two manganin coils, constituting the other two arms of the bridge, are also contained in the carbon dioxide meter, which is shown complete in fig. 136.

Four-way leads are taken from the carbon dioxide meter to the recording galvanometer, which is situated in any convenient place. The spare leads are compensating leads for the elimination of any temperature effects. The connections are shown diagrammatically in fig. 137.

The electrical carbon dioxide recorder lends itself to the installation of multiple-point outfits connected to one or more indicating and recording galvanometers in precisely the same manner as already described in the case of multiple-point resistance thermometer outfits (see Chapter IV, p. 67). The recording galvanometer employed is a double-pivoted instrument of robust type, and by the use of a double-thread recorder with one or two galvanometers either two or four records can be obtained on the chart, as previously described (see Chapter IV, p. 65).

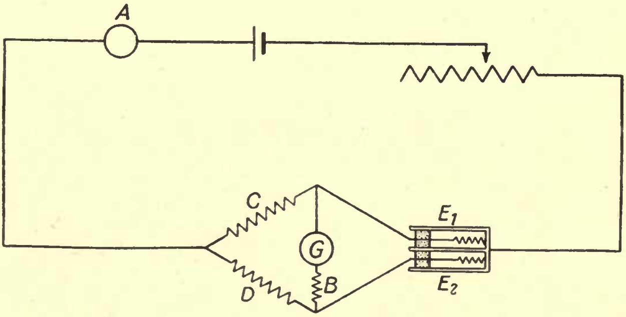


FIG. 137.—CONNECTIONS FOR ELECTRICAL CARBON DIOXIDE RECORDER.

The electrical carbon-dioxide recorder is operated by a battery, a two-volt accumulator being required for each carbon dioxide meter. Any change in the voltage of the battery must be compensated for by adjustment of a variable resistance. An ammeter is therefore provided to register the current in the Wheatstone bridge circuit, which must be maintained constant at 120 milliamperes. The variable resistance is adjusted in accordance with the reading on the ammeter. If the current will not equal 120 milliamperes the battery requires recharging.

The pipe line and its accessories are shown in fig. 138.

The flue gas is drawn through a soot filter (*vide infra*) by means of a water aspirator provided with a gauge indicating the pull. The carbon dioxide meter is attached to the pipe so that the flue gas flows past it, the changes being rapidly communicated by diffusion, as stated above. The reading of the electrical carbon dioxide meter is independent of the rate of gas flow.

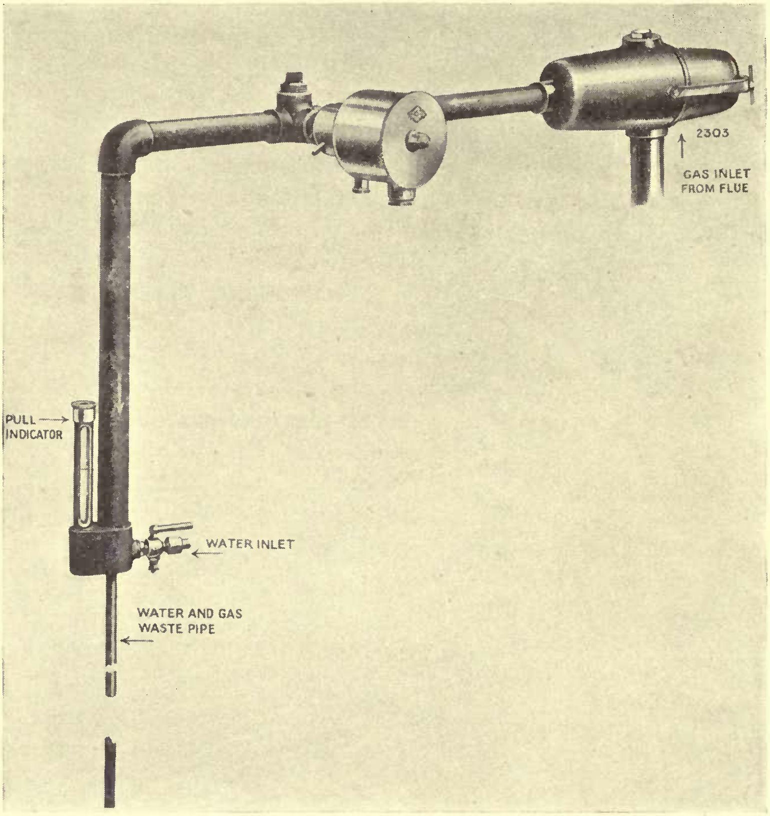


Fig. 138.—Pipe Line for Electrical Carbon Dioxide Recorder.

GENERAL REMARKS UPON THE USE OF CARBON DIOXIDE RECORDERS

(i.) The method of connecting a recorder to the various boilers as required is a matter of some importance. The pipe must be large enough to transmit changes in composition very rapidly, and should be as free as possible from bends and constructions of any kind. A very convenient method of connecting the various boilers to their recorders is employed in conjunction with Simmance's carbon-dioxide recorder.

A pipe *a* (fig. 139) is run along the range of boilers, and opposite to each boiler a ⊥-piece is left. A small iron oil cup *b* is screwed on to each of the ⊥-pieces, and a cap is dropped over the inner tube. A little lubricating oil is poured into the cup, thus sealing it. A length of iron barrel is inserted into each flue, and on the end of each of these pipes an oil cup is screwed, the cup being provided with a cap and sealed with oil. This arrangement affords a means of making connection from any boiler to the pipe *a*. When it is desired to test a boiler, the cap (of the oil cup corresponding to this boiler) is removed, and a filter (*vide infra*) is inserted in its place.

A short length of pipe *e* (fig. 140), is attached to the cover of the filter. This is attached to an elbow and cover *f* arranged to reach the oil cup *b* on the pipe *a*, and it is inserted in this oil cup after the cap is removed. In this manner an unrestricted connection of the full bore of the pipe is made and can be removed in a moment to clean the filter or, if required, can be moved together with the filter to the next boiler should it be desired to change over. One set of filter fittings will thus be adequate for a whole range of boilers, and each boiler requires two oil cups and caps.

The pipes inserted into the flues should be 1 inch in diameter and should be cleaned once a fortnight. The remainder of the piping is subsequent to the filter and will not become stopped up. A ½-inch pipe is adequate for the pipe *a*.

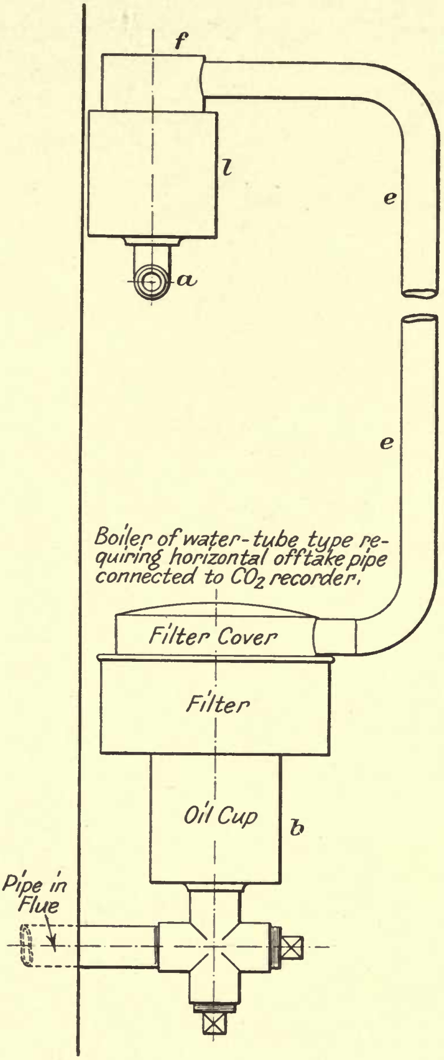


Fig. 139.—Connections for Carbon Dioxide Recorder.

(ii.) Flue gases are, of course, always laden with particles of dust and soot which would tend to choke up the instruments and destroy the accuracy of the records. Before proceeding to the instrument the gases must therefore be passed through a suitable filter to remove the deleterious suspended matter. Either wood wool, cotton wool or glass wool may be employed as the principal filtering media, and it is frequently advisable to insert a preliminary layer of fine charcoal or pumice granules, which will remove the coarser suspended matter and prolong the life of finer filtering media employed.

A convenient form of filter-box is shown in fig. 141.

The filter is oil sealed, and is intended for use with the hydraulic seal method of connecting the recorder to the boiler, described above.

(iii.) The water supply to carbon dioxide recorders, operated by a flow of water, should be passed through a copper-gauze filter—about 90 mesh. This will remove any large suspended particles and prevent any possibility of the aspirator becoming choked up.

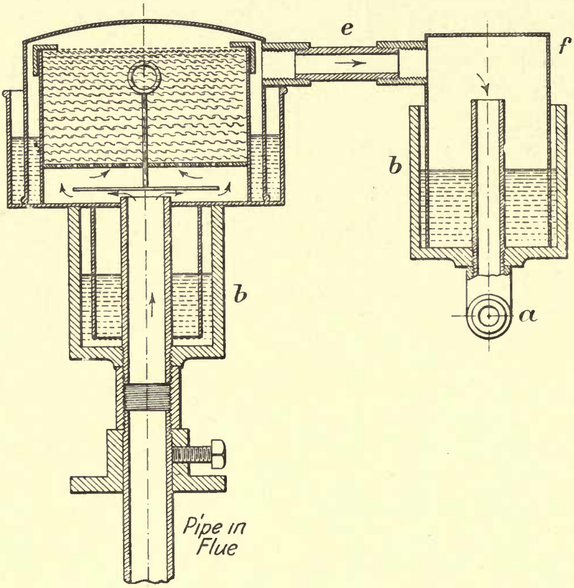


FIG. 140.—CONNECTIONS FOR CARBON DIOXIDE RECORDER.

CARBON MONOXIDE RECORDER

The practical realization of an automatic carbon monoxide recorder has been a matter of some difficulty — due to the nature of the gas itself. It is a comparatively simple matter to construct an automatic gas analyser to record the amount of an easily absorbable gas such as carbon dioxide, sulphur dioxide, chlorine, etc. The electrical method of measuring the thermal conductivity can also be employed for certain purposes. In the case of carbon monoxide, however, its physical and chemical properties impose limitations upon the design of an automatic recorder which militate against the successful usage of either volumetric or thermal conductivity methods.

So far as a volumetric arrangement is concerned, the known absorbent for carbon monoxide is cuprous chloride, in either acid or ammoniacal solution. It is quite impracticable to employ such a solution in the construction of a recorder for carbon monoxide for a variety of reasons, of which the following are the most cogent :—

(i.) The absorbent combines with oxygen and will remove this gas together with the carbon monoxide.

(ii.) The absorption is slow and, generally speaking, imperfect. When the solution is quite fresh the absorption may be fairly complete ; but as the solution becomes used, the absorption becomes less and less complete until at last a stage is reached in which more carbon monoxide may be evolved from the solution than it absorbs, and it may actually increase the amount of this gas in the sample to be analysed—instead of completely removing it. This difficulty is familiar to most operators who are accustomed to performing hand gas analyses, including the determination of carbon monoxide.

(iii.) The solution is relatively expensive.

The thermal conductivity method for automatically recording the amount of a constituent cannot be employed for recording carbon monoxide, as the thermal conductivity of this gas is practically the same as that of nitrogen and oxygen.

The author has devised a carbon monoxide recorder in which the difficulties enumerated above are overcome in the following manner.

The carbon monoxide in the gaseous mixture is selectively oxidized to an equal volume of carbon dioxide, and the amount of the latter is recorded on a suitable form of carbon dioxide recorder. It will be evident that in cases where the gaseous mixture contains carbon dioxide in variable amount, the percentage of carbon monoxide cannot be deduced from such a record, as the value of the latter will be the total of two amounts of carbon dioxide—one originally present as such in the gas, and the other produced by selective oxidization of the carbon monoxide—both of these amounts being independently variable.

If, however, the amount of carbon dioxide is fairly small and nearly constant, the recorder can be arranged to give the percentage of carbon monoxide with great accuracy.

An instance of such a condition is afforded by the finished output of a gasworks. In this case the sum of percentages of carbon dioxide and unsaturated hydrocarbons in the product of any particular works is nearly constant and will not, as a general rule, fluctuate by more than ±1·5 per cent. on either side of a mean value. A suitable mean value can therefore be selected for the sum of the percentages of carbon dioxide and unsaturated hydrocarbons for any particular works. The gas supplied to the recorder is passed through an absorbent for removing the carbon dioxide and then through the selective oxidization tube, wherein the carbon monoxide is completely and rapidly oxidized to carbon dioxide, and the unsaturated hydrocarbons are absorbed but are not oxidized.

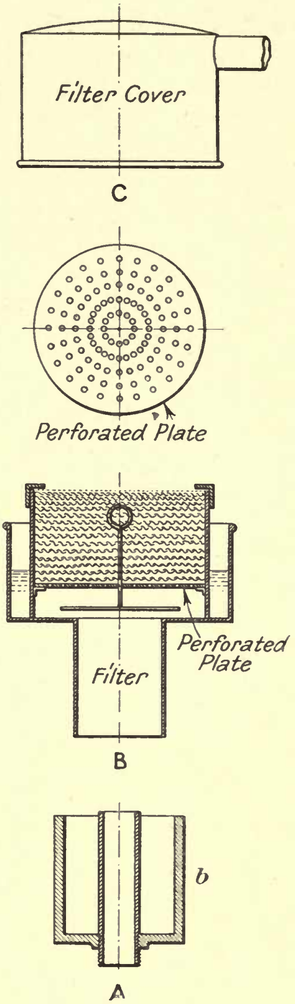


FIG. 141.—FILTER-BOX FOR CARBON DIOXIDE RECORDER.

If therefore the fixed mean sum of the percentages of carbon dioxide and unsaturated hydrocarbons be assumed to be x, then the gas selectively oxidized, corresponding to 100 of the original gas, is $100-x$. As, however, the recorder deals with this volume of $100-x$ as its original sample in the first measurement, the volume of carbon dioxide (*i.e.* of carbon monoxide) absorbed in the recorder will be recorded as a percentage of the volume $100-x$. The ratio of the lengths of the dropping arm to the pen arm (*vide infra*) is therefore adjusted so as automatically to reduce the movement of the pen in the ratio $\frac{100-x}{100}$ so that the record will be correct in terms of percentages of the original gas before any absorption of carbon dioxide or unsaturated hydrocarbons has been effected.

The assumption of a fixed mean value x per cent. for the sum of the carbon dioxide and unsaturated hydrocarbons would appear to imply that the record of carbon monoxide can only be accurate if these percentages are in actual fact x. Theoretically of course, this statement is correct, but as a matter of actual practice it can readily be shown that the maximum probable error of, say, 2 per cent. in the value of x will not occasion any appreciable error in the record of carbon monoxide. This can perhaps be shown most clearly by an actual example.

Suppose $x = 6$ per cent.
True CO $=15$ per cent.
Actual sum of $CO_2 + C_nH_{2n} = 8$ per cent.

15 parts CO absorbed from 94 parts of gaseous mixture are recorded as 15 per cent.

15 parts CO absorbed from 92 parts of gaseous mixture will therefore be recorded as $\frac{94}{92} \times 15$ per cent. $=15{\cdot}3$ per cent.

When the fact is taken into consideration that a hand analysis made on an improved Orsat apparatus for carbon monoxide on a sample containing 15 per cent. of this gas is quite likely to be erroneous by 0·5 per cent., it will be seen that the probable accuracy of the recorder is actually considerably greater than the probable accuracy of the hand analysis. A deviation of as much as 2 per cent. from the mean value is most unusual, and as a matter of experience it has been found that a carbon monoxide recorder, working on finished gas with a percentage of carbon monoxide varying from about 12 per cent. to 20 per cent., never showed the slightest variation from an accurate hand analysis.

Description of Recorder.—The gas is first passed through either a suitable vessel containing caustic solution, or if preferred, it is caused to traverse a glass tube containing the special dry absorbent granules for carbon dioxide, referred to above. The gas then proceeds to the selective oxidation tube. This consists of a glass tube about 2½ inches in diameter filled for ⅞th of its length with granules composed of iodine pentoxide and fuming sulphuric acid. If the proportion of sulphur trioxide in the latter is suitably adjusted, these granules effect the immediate and complete oxidation of all the carbon monoxide in coal gas or in mixed coal and carburetted water gas, without oxidizing any of the other constitutents. The unsaturated hydrocarbons are removed by absorption, but are not oxidized, and for this reason the amount of unsaturated hydrocarbons present must be considered in the assumed percentage x, as explained above. Iodine is set free by the oxidation reaction, but nearly all of it remains *in situ* in the granules. A small amount of iodine escapes as vapour, and this is completely removed by granules composed of highly activated charcoal, with which the last ⅛th of the oxidation tube is filled.

The iodine liberated is of considerable value, and is easily recoverable. The value of the iodine thus obtainable reduces the cost of oxidizing material required for the recorder very considerably.

After passing through the selective oxidation tube, the gas proceeds to a Simmance carbon dioxide recorder similar, except in two respects, to the instrument described above.

(i.) The ratio of the lengths of the drop arm to the pen arm is adjusted to compensate for the value of "x."

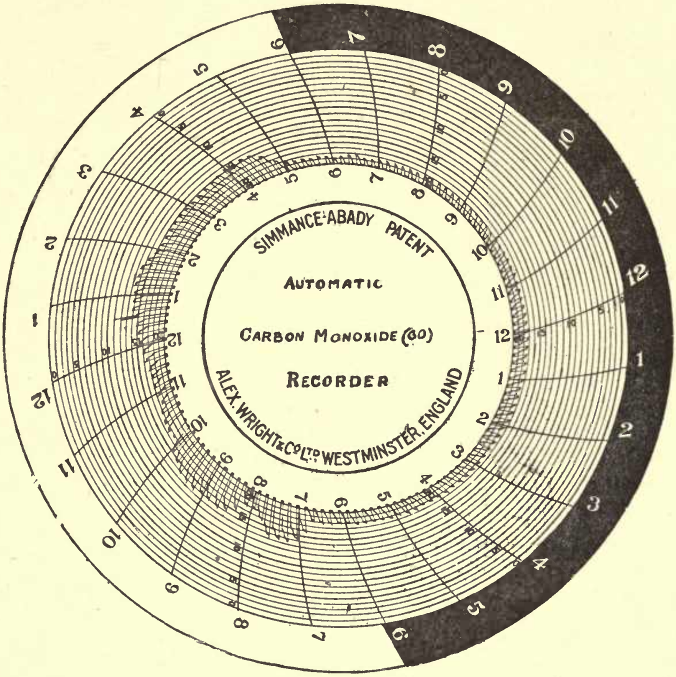


Fig. 142.—Record from Carbon Monoxide Recorder.

(ii.) The rate of inflow of the water is reduced so that the number of analyses per hour is reduced to about 6. If desired, however, this rate can be increased to about 20 analyses per hour without loss of accuracy.

An example of a record made with this instrument is shown in fig. 142, and the instrument itself is illustrated in fig. 143.

Combined Carbon Monoxide and Carbon Dioxide Recorder

In cases such, for example, as the analysis of water gas or producer gas, in which both carbon monoxide and carbon dioxide are subject to variation within comparatively wide limits, the simple carbon monoxide recorder described cannot be employed.

It is necessary in such cases to employ a combined carbon monoxide and carbon dioxide recorder.

The arrangement of the combined recorder is shown in fig. 144.

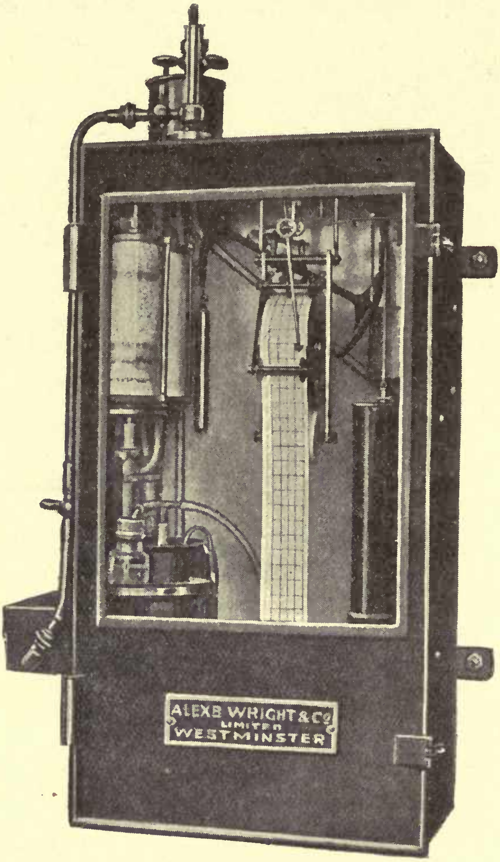


Fig. 143.—Simmance and Levy Carbon Monoxide Recorder.

Two separate streams of gas are supplied to the instrument. The stream entering at A at the right-hand side is drawn into the apparatus by the operation of the syphon tank B, and is measured off and discharged through the potash tank C into the recording bell D, the amount of carbon dioxide contained in the gas being inscribed by the dropping pen E on the right-hand side of the chart F.

The other stream of gas enters the instrument at G on the left-hand side, and then passes through the oxidation tube H. It is then aspirated into the syphon tank I, is measured off and discharged through the potash tank K into the recording bell L.

The total carbon dioxide absorbed in the latter, which is the sum of the percentages of carbon monoxide and carbon dioxide, is inscribed by the dropping pen M on the left-hand side of the chart F.

This record may be made with a different coloured ink to the record of the carbon dioxide alone. The influx of water is arranged so as to fill the two syphon tanks at identical rates, and thus the carbon dioxide and carbon monoxide plus carbon dioxide records are made simultaneously. The value of the former subtracted from the latter gives the percentage of carbon monoxide.

It is evident that in this instrument no calibration for "x" is necessary, and the two records obtained will always be absolutely correct, provided the gaseous mixture analysed does not contain any unsaturated hydrocarbons. This is the case with producer gas and blue water gas.

If employed on carburetted water gas, the necessary calibration to allow for the small percentage of unsaturated hydrocarbons present (which are removed by absorption in the oxidation tube) must be applied to the pen M, in the manner already described.

Sulphuretted hydrogen Recorder.—Sulphuretted hydrogen is invariably present as an undesirable impurity, the complete elimination of which is required. The sulphuretted hydrogen recorder, devised by Edwards, is designed not to give a register of the amount of sulphuretted hydrogen present, but rather to obtain a record showing the complete absence of this impurity from the purified gas both before and after storage in the holder.

When the apparatus is employed to control the working of the purifiers, positive indications of the presence of sulphuretted hydrogen will be obtained in certain circumstances. In these cases, a rough estimate of the amount of sulphuretted hydrogen present can be arrived at by a visual estimation based on the appearance of the record.

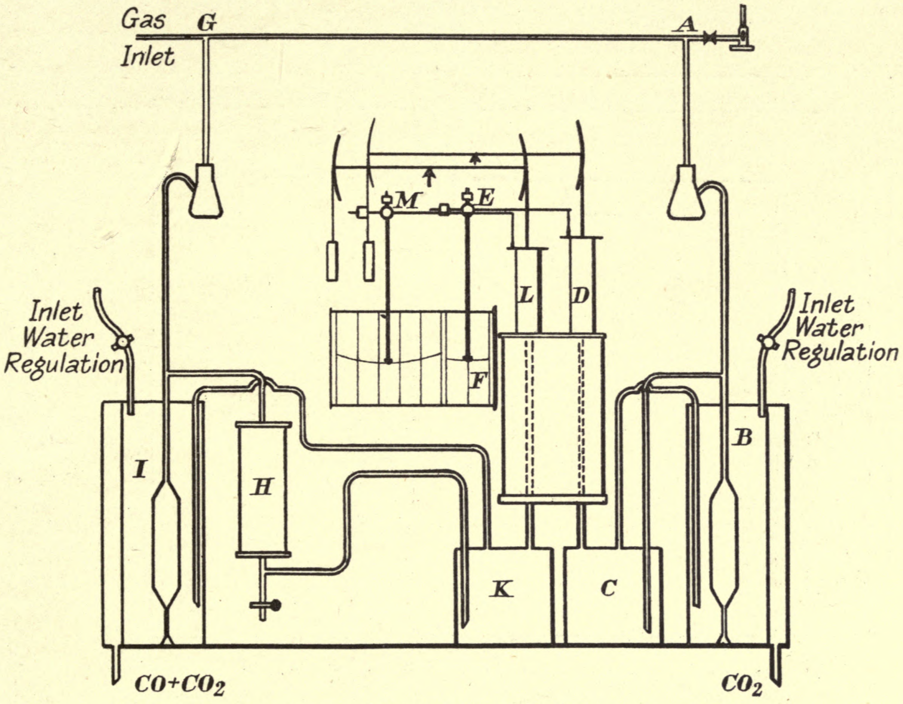


FIG. 144.—SIMMANCE AND LEVY COMBINED CARBON MONOXIDE AND CARBON DIOXIDE RECORDER.

Description of the Recorder.—The recorder is of very simple design, and consists of an arrangement for causing the localized application of a jet of the gas to be tested to a portion of the surface of a special chart. The latter has the usual time spacing ruled on it, and is impregnated with lead acetate. The absence of sulphuretted hydrogen is recorded by the continued freedom of the chart from discoloration at the line of impact of the gas jet. Any trace of this impurity will be recorded as a brown or black line on the chart, and the amount present can be roughly gauged by the depth of colour of the stained line.

The jet of gas to be tested comes from the lower end of a jet A (fig. 145), of small bore, and impinges directly and intimately upon the prepared surface of the chart B fixed to the circumference of the recording drum L. The surface of the paper is disposed so as to be slightly below the jet orifice but not in actual contact with the latter. After impinging upon the chart B, the gas stream ascends an outer glass

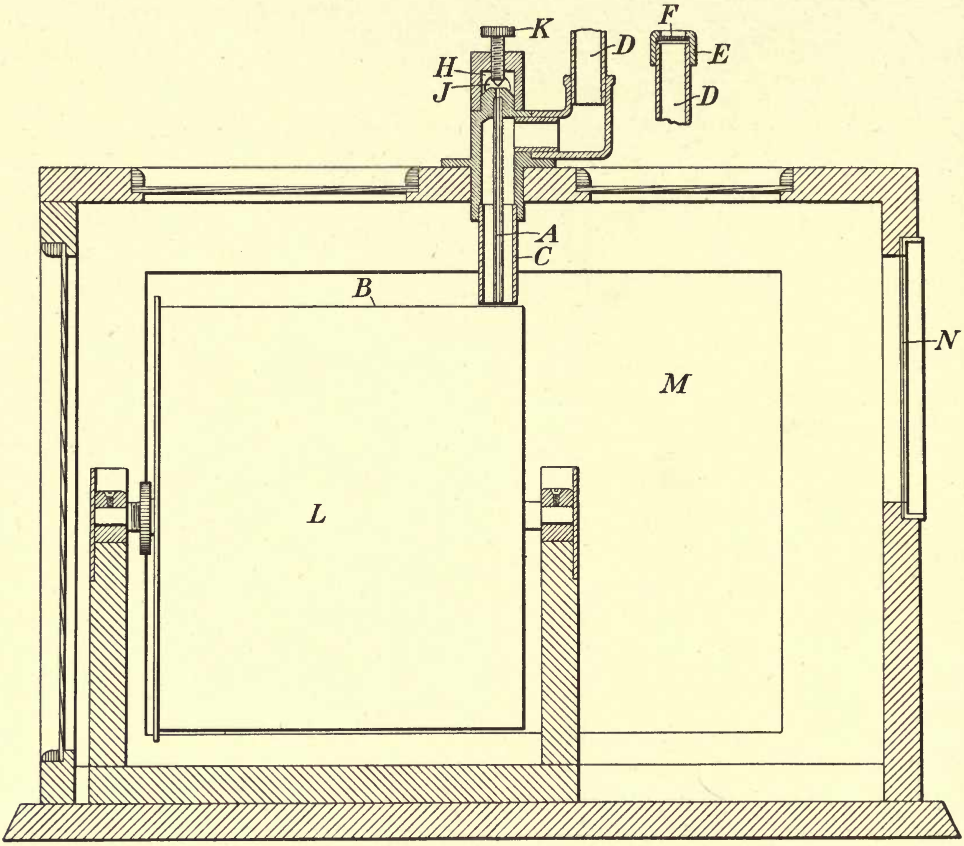


Fig. 145.—Edwards Sulphuretted Hydrogen Recorder.

tube C, which surrounds the lower portion of the jet pipe, and then passes into an upright suction tube D, surmounted by a cap E carrying a wire gauge F where the gas is burnt with a non-luminous flame.

The length of the suction tube D is so adjusted that the ascending column of light gas draws air through the space between the paper B and the jet-surround tube C, and so prevents escape of gas at this point, whilst the end of the jet-surround tube C is so shaped that the action of the gas is localized upon the paper.

A constant flow of the gas to be tested is maintained through an inlet pipe, then through a chamber H, and is finally led away to a pilot light by way of an outlet pipe J. The volume of the jet of gas impinging upon the paper B is regulated by a needle valve, fitted in the inlet chamber H, to give the desired sensitiveness (say 0·3 feet of gas per hour).

The prepared chart B is enclosed within an airtight glazed chamber M, provision being made for the ingress of air by way of a circular aperture N, covered by porous paper impregnated with lead acetate.

A better arrangement would be to cause the incoming air to be drawn through a small cylinder containing highly activated charcoal granules. The freedom of the air from any trace of sulphuretted hydrogen could thus be ensured for a long period, the charcoal being changed every few months as a measure of precaution.

A number of jets may be disposed side by side if required. For example, five jets may be employed and coupled to the main inlet and the four outlets of a set of four purifying boxes, the records serving as a check upon the working, particularly where the backward rotation system is in use.

CHAPTER VIII

VOLUME RECORDERS

THE instruments described in the present chapter are constructed to record the rates of flow, of either gases or liquids, at any given period. In addition to this, means are usually provided for obtaining the total amount of material which has passed through the meter during any given period.

The ordinary wet station meter, provided with a train of counting wheels, is the prototype of this class of apparatus, but this instrument does not yield a continuous record—it merely gives a reading of the total amount of gas which has passed through it since the counting train was last set.

The modern types of meters—whether for liquids or for gases—are almost invariably constructed to give a continuous record of the variation of the rate of flow, which is inscribed upon a chart as usual. The amount of the total flow during any period can be obtained from this record by integration by means of a suitable planimeter. In most cases, however, the instruments are also provided with a train of counting wheels whereby the flow is integrated, and the total passage of liquid or gas is read off on the dials.

Volume recorders for use in gasworks are required for registering three different classes of flow :—

A. Gas meters.
B. Steam meters.
C. Liquid flow meters.

A. GAS METERS

Modern gas metering devices are characterized by three important features which are not displayed by the old type of wet station meter.

(*a*) They are far more compact.

(*b*) The recorder can, in most types, be situated at a distance from the actual metering point.

(*c*) A continuous record of the rate of flow is obtained as well as an integration of the total amount of gas passed.

The most important types of gas meters are :—

1. Meters operated by the use of various devices for producing a differential

pressure. The amount of the differential pressure so produced is a function of the flow, and is recorded on a chart calibrated in terms of flow.

2. Rotary meters, in which the gas flow causes the rotation of specially designed devices. The number of revolutions is a function of the flow and is recorded.

3. The electrical station meter, in which the electrical energy required to maintain a certain temperature difference in the gas stream flowing between two selected points is measured. The energy required is a function of the flow, and is recorded in terms of the latter.

1. METERS OPERATED BY THE PRODUCTION OF A DIFFERENTIAL PRESSURE.

Meters of this type consist of two distinct portions :—

(*a*) The apparatus for producing the differential pressure.

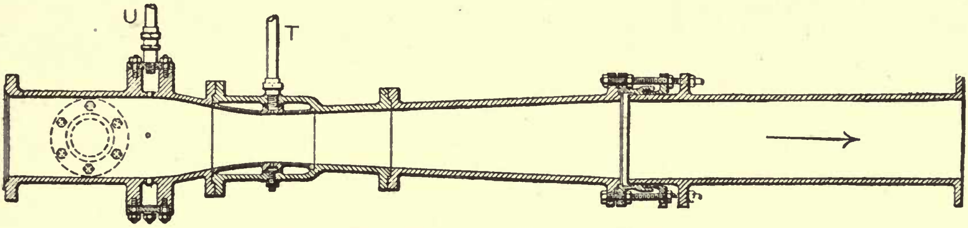


FIG. 146.—DIAGRAM OF VENTURI TUBE.

(*b*) The apparatus for recording the differential pressure produced by (*a*), and for integrating the total flow.

(*a*) *Apparatus for Producing the Differential Pressure.*—This invariably consists of some form of restricting orifice which is interposed in the stream of gas to be measured. The pressure difference thus produced may be that existing at certain specified distances on either side of the orifice, or it may be measured between the full diameter of the main and the orifice itself.

A number of types of differential pressure-producing apparatus are employed in the various designs of Kent gas meters, chief amongst which are :—

(1) *The Venturi Tube.*—This is the oldest and most widely employed form of restricting orifice. It consists of a gradually converging upstream cone, a short parallel throat section, and a very gradually diverging downstream section (see fig. 146).

The operation of a Venturi tube is illustrated diagrammatically in figs. 147 and 148, in which, for the sake of clearness, the tube is represented as filled with liquid.

As the flow passes through a pipe of diminishing area, it loses the pressure which it exerts laterally as it gains in velocity. The pressure at the throat is therefore less than the pressure in the full diameter of the tube. The major portion of the pressure loss at the throat is recovered during the passage of the gas through the downstream cone, a small proportion being lost due to friction.

The maximum pressure difference, or Venturi head, required to operate the

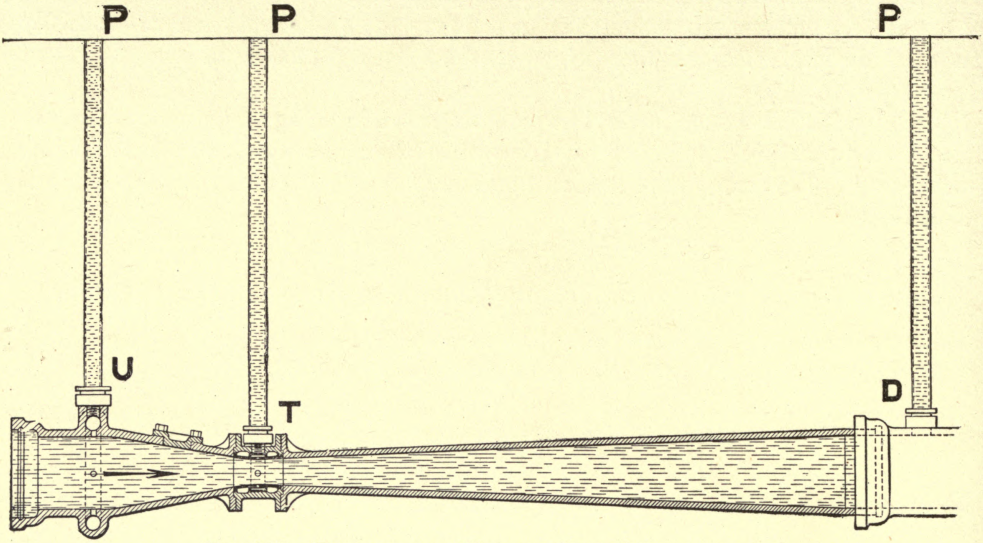


Fig. 147.—Operation of Venturi Tube (liquid at rest).

recording and integrating instruments is 2-inch water gauge. The loss of pressure during the passage of the gas through a standard Venturi tube is $\frac{1}{4}$ inch water gauge

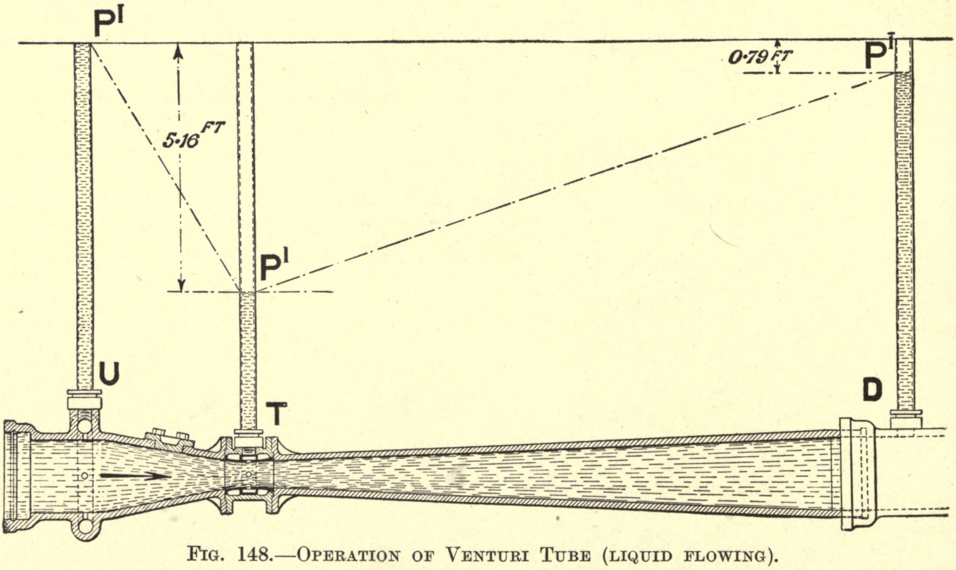


Fig. 148.—Operation of Venturi Tube (liquid flowing).

when the Venturi head is 2 inches. The difference of pressure transmitted to the recorder is that which occurs between the full diameter of the main and the parallel portion of the throat section.

Venturi tubes are constructed of very widely varying dimensions according to the volume of flow which is passed through the tube. The Venturi tube itself forms part of the main through which the substance to be metered is passed. The function of the gradually tapering downstream cone is to enable a large proportion of the pressure difference to be recovered, so that the loss of pressure due to the insertion of the tube is reduced to a minimum.

If a Venturi tube be employed for measuring dirty gas, its accuracy may be impaired by the deposition of foreign matter upon the throat section. This difficulty is obviated by the provision of a heater for the throat section. This is employed during the colder months of the year and maintains the walls at a slightly higher temperature than that of the gas passing through. The condensation of tarry matter or naphthalene is entirely prevented thereby. This difficulty is seldom experienced in the case of town gas.

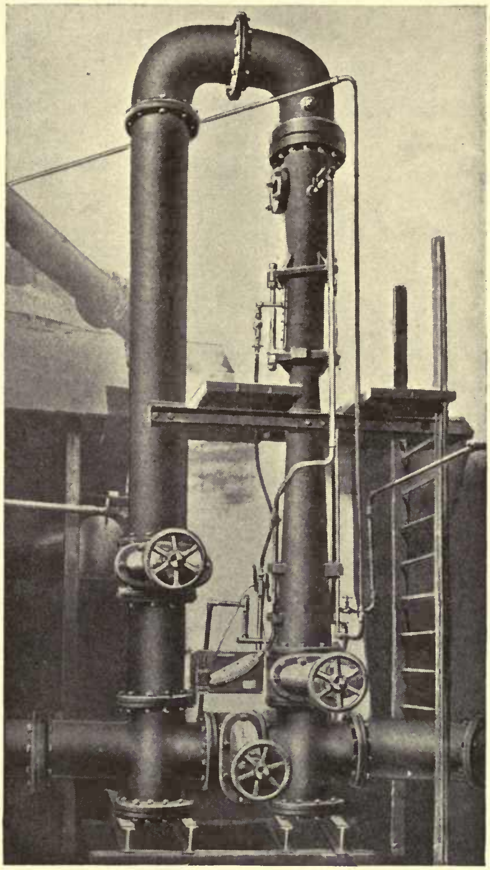


FIG. 149.—VENTURI TUBE MOUNTED VERTICALLY.

The Venturi tube is provided with a by-pass, and the throat section is arranged so that it can quickly be removed. In order to facilitate the inspection and cleaning of the latter, the Venturi tube may be installed vertically (see fig. 149), or it can be installed horizontally (see fig. 150). The former requires less space and there is less tendency towards the production of deposit on the throat section.

(2) *The "Orivent" Tube.*—This tube (fig. 151) is a modified form of Venturi tube, specially suitable for large mains about 2 feet in diameter where the gas is fairly clean and where the great length of the Venturi tube would be inadmissible. It can be installed horizontally or vertically. The pressure loss with this type of orifice is greater than is the case with a Venturi tube.

(3) *The "Y" Type Orifice* (fig. 152).—This consists of a modified butterfly valve which can be clamped at one of four predetermined amounts of opening, for each one of which the coefficient of discharge has been found by calibration.

Each of these four positions of the valve is so designed that it will pass twice the amount of gas at the same maximum differential pressure as it will when set in the next lower position. In this way it is possible with an instrument, which is only itself accurate down to one-eighth of the maximum flow, to obtain readings which are accurate down to $\frac{1}{8}\times\frac{1}{2}\times\frac{1}{2}\times\frac{1}{2}\times\frac{1}{2}=\frac{1}{128}$th of the maximum flow for which the orifice can be designed.

The position of the sector to which the orifice is attached has to be altered by hand in order to obtain the total range of flow measurement. The orifice is therefore unsuitable for use in cases where the flow varies without warning over a large range.

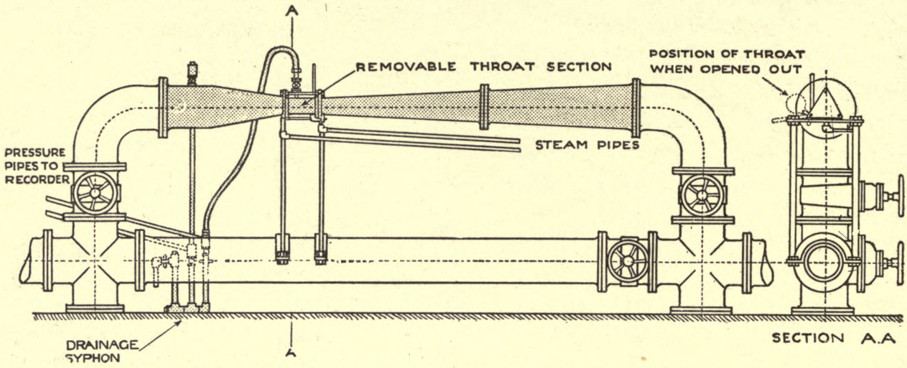


FIG. 150.—VENTURI TUBE MOUNTED HORIZONTALLY.

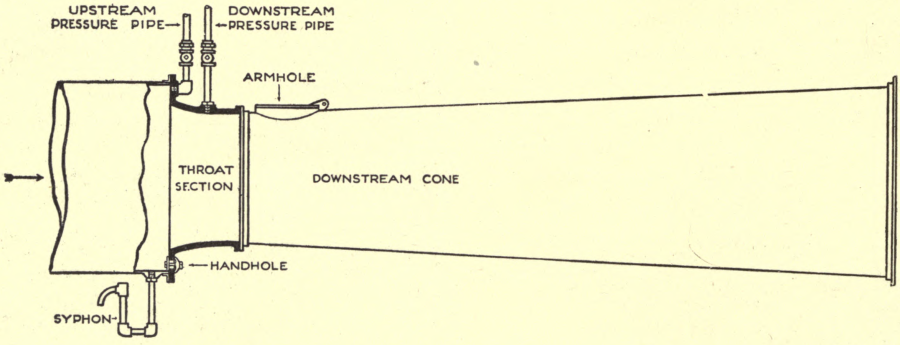


FIG. 151.—ORIVENT TUBE.

(*b*) *The Apparatus for recording the Differential Pressure in Terms of Flow and for integrating the Total Flow.*—The recorder employed in Kent gas meters, whereby the differential pressure is measured and the total flow integrated, is shown diagrammatically in fig. 153.

The gaseous discharge in cubic feet per minute through a Venturi tube is given by the formula—

$$D_1=K_1\sqrt{\frac{(p_1-p_2)T_1}{sp_2}},$$

where T_1=absolute temperature.

p_1=absolute pressure at the Venturi upstream.

p_2=absolute pressure at the Venturi throat.

s =specific gravity of the gas referred to air.

K_1=constant.

(1) *Recording Apparatus.*—The instrument comprises a water-sealed bell A (fig. 153), the throat pressure acting upon the inside of the bell and the upstream pressure upon the outside. The motion of this bell, which is proportional to p_1-p_2 (the Venturi head), is transmitted by a system of levers to the pen C, which inscribes the rate of flow upon a square-root chart.

The record of the rate of flow thus obtained is only correct for a gas of a particular density, but its general utility is unimpaired by this source of error. Specific gravity variation would, however, seriously affect the value of the total flow registered on the integrating apparatus. For this reason means are afforded for automatic correction of the reading as described below.

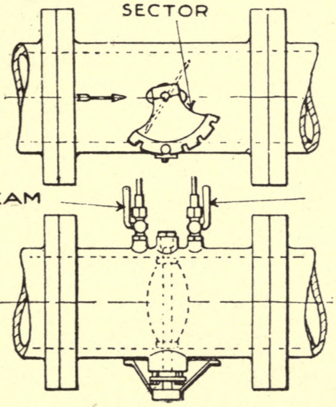


FIG. 152.—Y-TYPE ORIFICE TUBE.

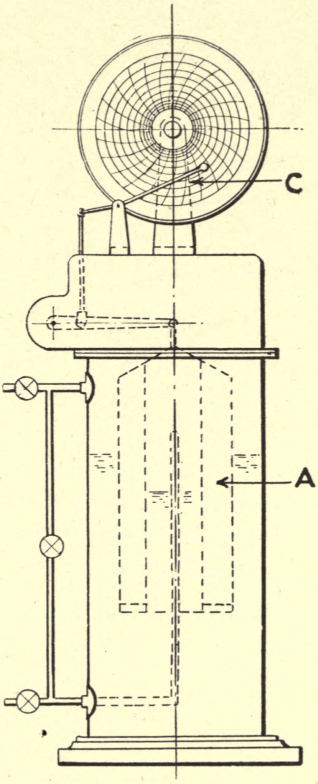


FIG. 153.—DIAGRAM OF KENT VENTURI RECORDER.

(2) *Integrating Apparatus.* — The motion of the bell is transmitted to the integrating mechanism by a connecting rod R (fig. 154). The integrator, which is shown diagrammatically in fig. 154, consists of a cam C which is caused to rotate, and an arm A carrying a spherical contact-piece S which is raised or lowered by the connecting rod R—its motion thus depending upon the differential pressure measured by the bell. The spindle carrying the cam C also bears a toothed wheel W, which drives the counter-wheel T through the wheel X and the pinion Y. When the contact-piece S is out of contact with the surface of the cam, the rocking frame F,

which carries the wheel X and the pinion Y, moves forward until it reaches the stop B, being pulled by the spring C so that the wheel X engages with the wheel W and transmits its motion to the counter train T through the pinion Y. When the cam moves round so that the contact-piece S is pushed back by it, the wheel is thrown out of gear with the wheel W, and the counter ceases to register. By suitably shaping the cam, any desired amount may be added to the counter reading during each revolution of the cam for any specified position of the arm A.

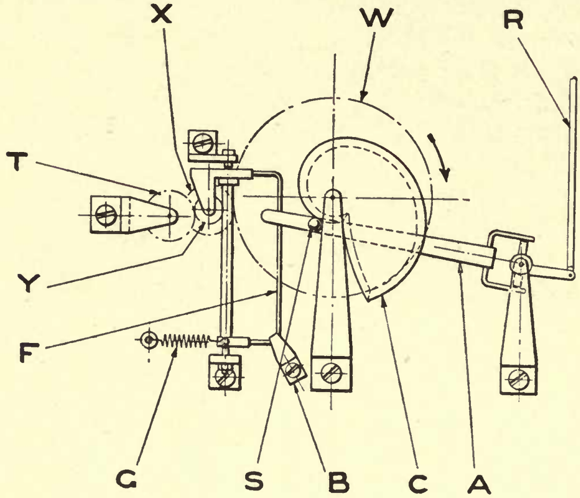


Fig. 154.—Diagram of Integrating Mechanism of Kent Venturi Recorder.

Correction for Specific Gravity.—If the gas be passed through a Venturi tube at constant pressure, inspection of the formula for the discharge shows that the variables are

$$p_1 - p_2$$

$$s$$

and $$T_1$$

(T_1 may be regarded as a constant for all practical purposes).

In order that the reading may be correct, it is therefore necessary to compensate automatically for changes in the specific gravity of the gas. This correction is effected in the following manner. If the cam C were rotated at a uniform speed, the rate of registration for a given flow in the main would be proportional to the square root of the specific gravity of the gas passing, and as already mentioned, the reading would only be correct for gas of a particular specific gravity. The correction for the variation in the specific gravity of the gas is obtained by making the speed of rotation of the cam C depend upon the specific gravity of the gas by driving it by means of a small wet gas meter W (fig. 155), which is continuously rotated by gas escaping from the main through a small orifice to the atmosphere, the pressure across this orifice being maintained constant by a sensitive regulating valve RV. The rate of flow of the gas through the small orifice, across which the difference of pressure is maintained constant, is inversely proportional to the square root of the specific gravity of the gas, and hence the variation in the speed of the wet meter gives exactly the compensation required, and the counter registers the actual volume passed.

The regulating valve RV is compensated for changes of level of the liquid seal by the displacer H, and for variations in the inclination of the balance arm by the weight I. The valve maintains the pressure across the orifice and corrects to within ±0·002 inch of water.

The counting mechanism is driven by the wet meter.

Further information on the operation of Venturi meters is given in papers by J. L. Hodgson on "The Commercial Metering of Air, Gas and Steam," *Proc. Inst. C.E.*, vol. cciv., and "The Metering of Air and Gas by Means of the Venturi Tube," *Trans. Inst. of Mining Engineers*, vol. lxii. pp. 208–220.

The recording and integrating apparatus can be situated at any distance up to about 300 feet from the actual metering point. Connection between the recorder and the Venturi tube or other orifice is effected by tubing $\frac{1}{2}$ inch to $\frac{3}{4}$ inch diameter, which must be carefully laid to avoid pressure losses due to sharp bends, etc., and collection of moisture.

General Remarks upon the Use of Kent's Station Meter.—(i.) The principal source of trouble is the formation of a deposit upon the throat of the Venturi tube. The amount of deposit will naturally vary with the nature of the gas flow which is measured. When metering town gas, no deposit whatsoever should occur, and an examination of the throat once every six months is quite sufficient.

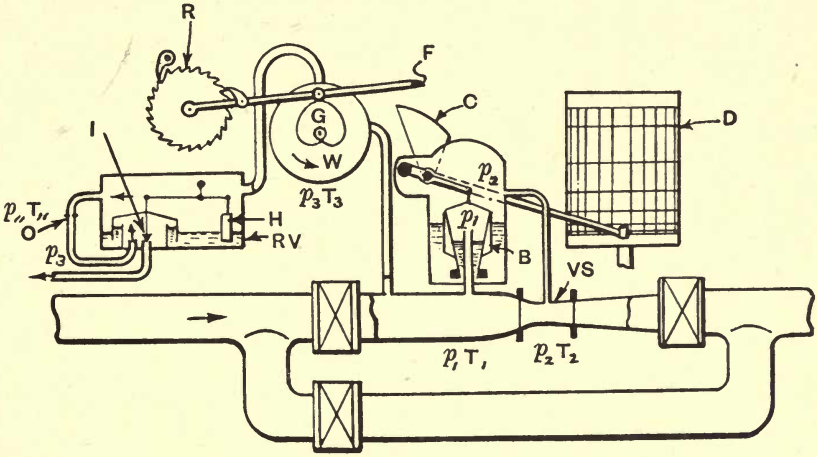


Fig. 155.—Diagram of Compensation for Specific Gravity in Kent Venturi Recorder.

(ii.) In some cases where dirty gas is measured, it is impossible entirely to prevent the formation of deposit upon the throat of the Venturi tube. The throat section is made easily removable, and can thus readily be inspected and cleaned. In the case of the Orivent tube the throat section is not removable, but hand holes are provided for cleaning.

(iii.) If it be desired at any subsequent date after the Venturi tube has been installed to increase the maximum flow measured, this is accomplished by fitting a new throat section to the Venturi tube and installing a new change wheel in the counter train of the recorder; provided that this was arranged for when the tube and recorder were originally installed.

Thorp Diagrammatic Meter

This instrument is of a different type, and is designed to give a continuous record of the rate of gas flow, the record obtained being uncorrected for specific gravity variations.

The construction of the meter is shown in fig. 156. It consists essentially of a conical tube T situated in an outer casing as shown. A circular disc H is contained in the conical tube and is free to move in a vertical direction. The inlet gas stream flows past the disc H, which rises or falls; its position at any time being determined by the volume of gas passing. A vertical rod V is attached to the moving disc H, and carries a pen E whereby the chart is inscribed.

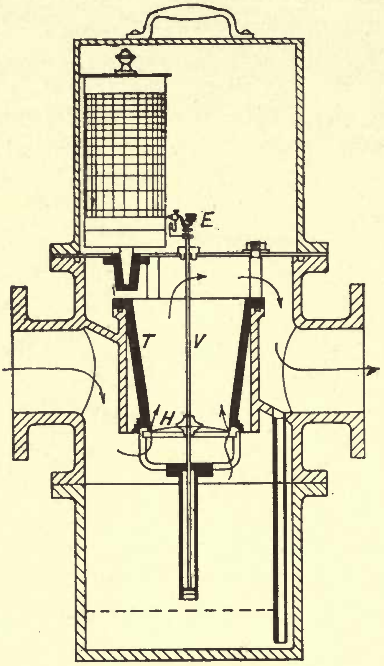


Fig. 156.—Section of Thorp Diagrammatic Meter.

The chart is irregularly divided, and its ruling depends upon the specific gravity of the gas.

Electro Gas Flow Meter

The Electro Gas Flow Meter comprises apparatus for the production of a differential pressure, the square root of which is proportional to the gaseous discharge, as already explained.

The differential pressure produced is measured electrically, and the complete apparatus comprises an indicator, a recorder showing the variation in the discharge over a period of twenty-four hours, and an integrator which shows the total flow over any given period.

The differential pressure is produced by the insertion of an orifice plate $\frac{1}{32}$ inch in thickness between two flanges in the gas main. The upstream and downstream pressures are communicated by short lengths of $\frac{3}{8}$-inch piping to a rising bell in the metering device. The principle upon which the apparatus is actuated is shown diagrammatically in fig. 157.

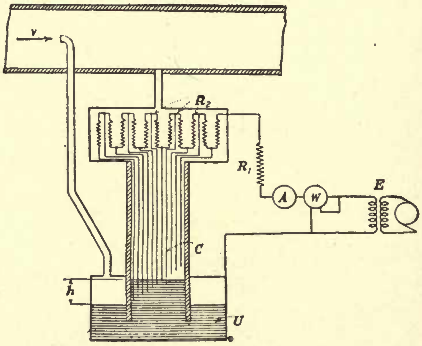


Fig. 157.—Diagram of Operation of Electro Gas Flow Meter.

The upstream and downstream pressures are communicated to the two limbs of a mercury gauge U. The mercury forms part of an electrical circuit and makes contact on the low-pressure side with a number of contact rods C; the precise number of which are connected depends upon the level of the mercury—*i.e.* upon the amount of the differential pressure produced by the liquid or gaseous flow to be measured. The electrical circuit also comprises a fixed resistance R_1, which is connected in series with the variable resistance R_2 (actuated by the mercury level), a constant source of electromotive force E, an ammeter A, and a wattmeter W. The current flowing therefore depends upon the differential pressure and hence upon the rate of discharge. In addition, the total flow over a given period will be proportional to the product of the current and the time, or (as the voltage is constant) to the watt-hours consumed. The resistances are so proportioned that the ammeters, both indicating and recording, register the gaseous discharge in cubic feet, and the total flow is read directly on the dials of the wattmeter. The results shown upon these instruments are correct for a certain specific gravity, and corrections must be applied for any variations from the value assumed for this function.

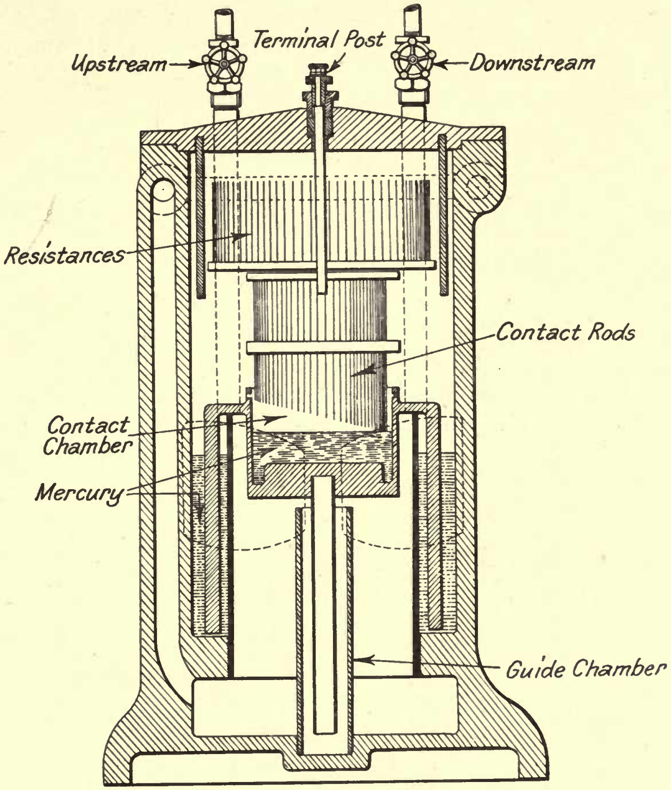


Fig. 158.—Section of Meter Body of Electro Gas Flow Meter.

The meter body is shown in section in fig. 158. The top of the rising bell already referred to forms the contact chamber containing mercury. The bell itself rises and falls in oil; as the differential pressure, in the case of a gas meter, is insufficient to actuate a mercury gauge, and a considerable vertical movement of the mercury in the contact chamber is thus obtained. The surface of the mercury is covered with a layer of oil to prevent sparking when the circuit is made or broken.

The instrument panel on which the indicator, recorder, and integrator are situated can be placed in any convenient position.

2. ROTARY METERS

THORP ROTARY METER

This instrument comprises :—1. A large anemometer which rotates in the gas stream. This anemometer is so designed that the number of revolutions which it makes is directly proportional to the amount of gas passing, over a considerable range of flow.

2. Counting mechanism for registering the total flow of gas through the meter.

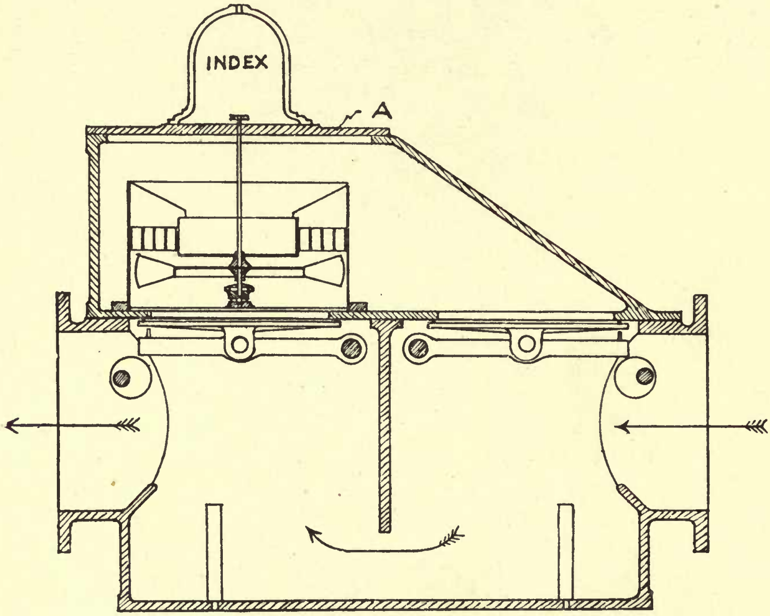


FIG. 159.—SECTION OF THORP ROTARY METER (BY-PASS OPEN).

The meter is made in several different types to suit various requirements. A simple arrangement, in which a meter and by-pass are combined in one casing, is shown in figs. 159 and 160. In fig. 159 the meter is out of action and the gas stream is by-passed so that the mechanism can be examined and cleaned if required. Fig. 160 shows the meter in action. The direction of the gas stream is indicated by arrows in each figure.

KENT TURBINE METER

The Kent Turbine Gas Meter is intended for use in cases where the cost of a more expensive type of metering device would render the use of the latter inadmissible. It can only be employed if the moving parts are not liable to be seriously deranged by deposit.

It comprises :—(1) A moving portion—a rotor—which is inserted in the gas flow, and is caused to rotate continuously by the flow of gas.

(2) An orifice through which the gas, causing the movement of the rotor, is delivered.

(3) Counting mechanism for registering the number of rotations of the rotor.

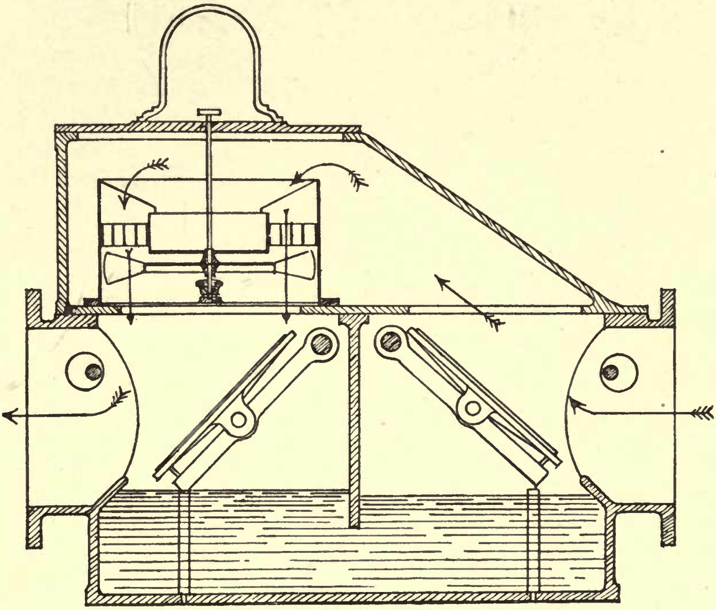


Fig. 160.—Section of Thorp Rotary Meter (By-pass Closed).

The operation of the turbine meter is empirical. The size and disposition of the various parts are adjusted so that the number of revolutions of the rotor is directly proportional to the flow of gas over a certain range. The meter measures the actual volume of gas under the prevailing conditions. The readings must therefore be

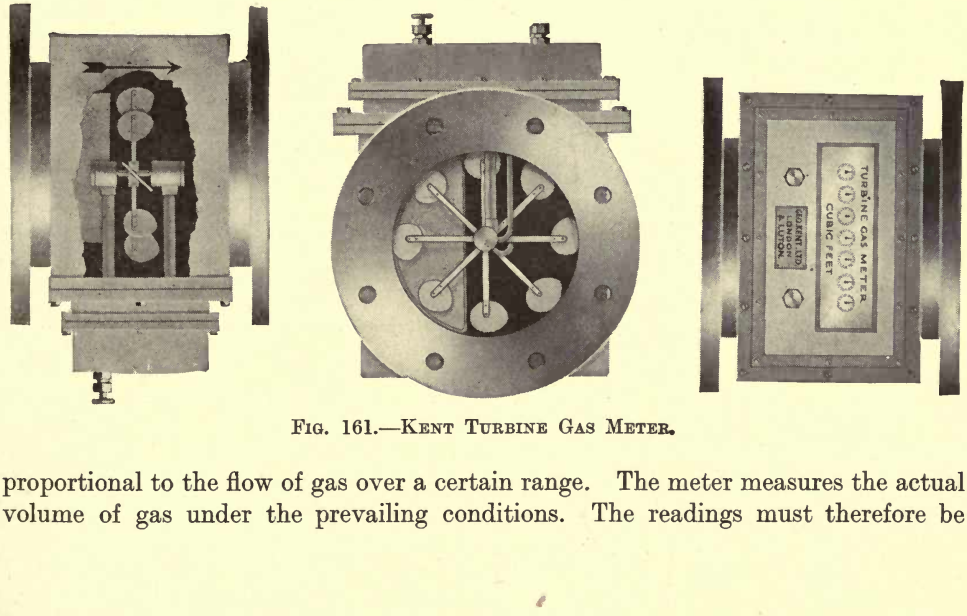


Fig. 161.—Kent Turbine Gas Meter.

corrected for changes in temperature and barometric pressure. The gas flowing through the meter must be supplied at the pressure for which the instrument was calibrated and this pressure must be maintained constant, or the necessary correction made.

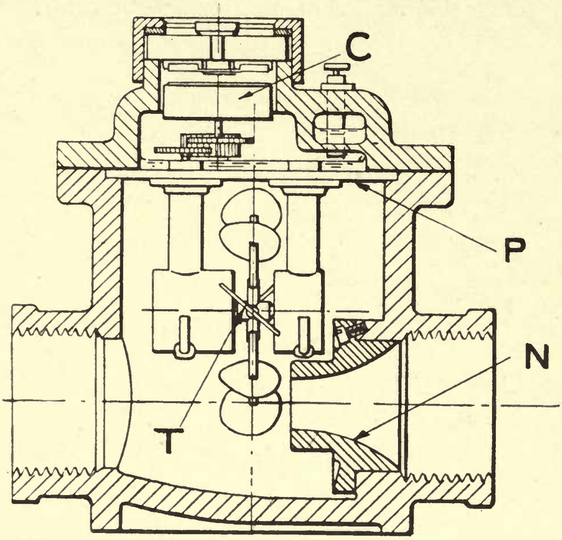


Fig. 162.—Section of Kent Turbine Gas Meter.

(1) *The Rotor.*—This consists of a number of blades carried on arms mounted upon a central hub. It is essential, in a turbine gas meter, that the bearings be as free from friction as possible, and furthermore, they must not wear or increase in friction during use. The rotor is carried on anti-friction wheels, which are continually bathed in oil. The housings of the bearings are placed out of the direct flow of the gas in order to reduce the liability to the deposition of tar upon them.

(2) *The Orifice.*—The orifice or nozzle through which the gas is discharged on to the rotor must not clog up, as in this case the meter will read fast.

A single jet is employed, as in this case the periphery of the jet surface for a given jet area is reduced to a minimum, and hence the error caused by a given thickness of deposit is likewise a minimum.

(3) *The Counting Mechanism.*—The number of revolutions of the rotor are registered upon a train of counting wheels, the dials reading in cubic feet. Three views of the meter are shown in fig. 161, and a sectional diagram in fig. 162.

3. Thomas Electrical Gas Meter

Gas measurements are effected by the Thomas Electrical Gas Meter, which was developed in America, in an entirely novel manner.

The amount of heat required to raise the temperature of a certain quantity of coal gas, or coal and carburetted water gas, through a given temperature difference is practically constant, and is independent of :—

(i.) The actual volume occupied by the gas (within normal limits of volume changes).

(ii.) The pressure of the gas.

(iii.) The temperature of the gas.

(iv.) The specific gravity of the gas.

(v.) Variations of composition met with in gasworks practice.

If therefore a stream of gas flows past two specified points and heat is supplied to this stream so as to raise the temperature of the gas stream through a certain fixed value, the amount of heat required to effect this temperature rise will depend solely upon the rate of gas flow and upon its humidity. Furthermore, the rate of gas flow, as deduced from the amount of energy required to raise its temperature through the given interval, will not be the actual flow under the prevailing conditions of measurement, but will be automatically corrected to the standard conditions for which the instrument is calibrated—actually 60° F. and 30 inches pressure. This is so because each unit quantity—say, 1 cubic foot measured at 60° F. and 30 inches pressure—contains the same amount of matter at whatever temperature and pressure it is measured, and therefore requires the same amount of energy to raise its temperature through any given interval.

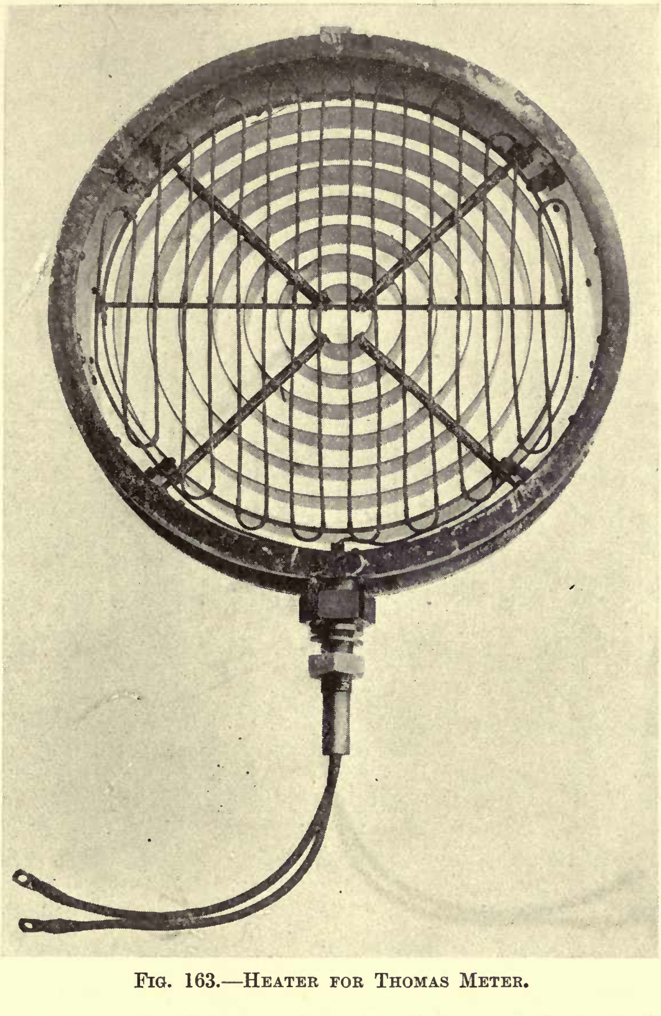


Fig. 163.—Heater for Thomas Meter.

The operation of the Thomas meter is based upon these facts, of which advantage is taken to obtain the flow measurements in the following manner.

The instrument comprises :—

(1) An electrical heater which serves to raise the temperature of the gas exactly two degrees Fahrenheit during its flow through the meter.

Fig. 164.—Thermometer for Thomas Meter.

(2) Electrical resistance thermometers situated on the entrance and exit sides of the electrical heater. These serve to indicate the rise in temperature of the gas and to operate the regulator (3).

(3) A regulator which is operated by the resistance thermometers, and which varies the current flowing through the heat in accordance with the rate of gas flow, so

that the heat supplied to the gas stream is exactly the amount required to raise its temperature 2° F.

(4) A temperature difference coil for automatically correcting for varying water-vapour content in the gas.

(5) A housing, in which (1), (2), (3), and (4) are installed.

(6) A wattmeter, which integrates the total electrical energy consumed by the heater in raising the temperature of the gas flow 2° F.

(7) A recording wattmeter, which inscribes the rate of flow upon a chart.

Description of Instrument.—(1) *The Electrical Heater.*—The heater unit is shown in fig. 163. It consists of special coils of resistance wire wound backwards and forwards inside an insulating drum. The two terminals are brought outside through a gastight connection.

(2) *The Resistance Thermometers.*—Each of the resistance thermometers consists of a nickel wire encased in a flexible tube and wound backwards and forwards over a circular frame. The flexible tube is covered with lead and sealed so that the nickel wire is entirely protected from any corrosive action. One of the thermometer units is shown in fig. 164

(3) *The Regulator.* — The two thermometers are arranged to form two arms of a Wheatstone bridge (see p. 63), the other two arms being fixed resistances. The bridge is balanced when the exit thermometer is exactly 2° F. warmer than the inlet thermometer. In these circumstances there will not be any flow of current through the galvanometer connected across the bridge. If, however, this temperature difference of 2° F. is disturbed, the ratio of the resistances of the thermometers will alter, the balance will be destroyed, and a current of more or less magnitude will flow through the galvanometer, thus causing a deflexion of the pointer.

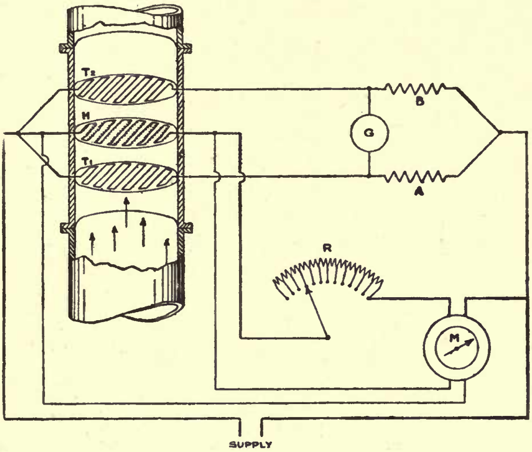


FIG. 165.—DIAGRAM OF ARRANGEMENT OF THOMAS METER.

The general disposition of the heaters, thermometers, Wheatstone bridge, etc., is shown diagrammatically in fig. 165.

The unbalancing of the bridge and the consequent deflexion of the galvanometer pointer is caused to operate the regulator in the following manner:—

A motor (see fig. 166) revolves a contact drum fitted with a number of contact strips of varying lengths. The motor is also employed to produce an oscillatory motion of two magnetically controlled pawls by means of an eccentric. The galvanometer needle is alternatively clamped between two contacts by means of a magnet, and unclamped by a spring which operates when the magnet is not functioning.

When the Wheatstone bridge is balanced and the galvanometer pointer is undeflected, the latter rests upon an insulating strip (the pointer in this position is shown in fig. 166 as a dotted circle) and there is not any flow of current through the magnet controlling the pawls, as the strips on the contact drum move past their respective brushes. If, however, the bridge is unbalanced (owing to a variation of the temperature from 2° F.), the needle will be deflected either to the right or to the left according to the algebraic sign of the variation from 2° F. It will in this case, when clamped, complete the circuit through one or the other of the contact strips on the revolving drum. The longest contact strip is brought into action by the greatest deflection. During the period in which the contact strip is in action, one or the other of the pawls is caused by its controlling magnet to engage in the ratchet wheel. The latter is therefore rotated through a certain distance, and its rotation operates a rheostat in series with the heater. This action continues until the bridge is again in balance

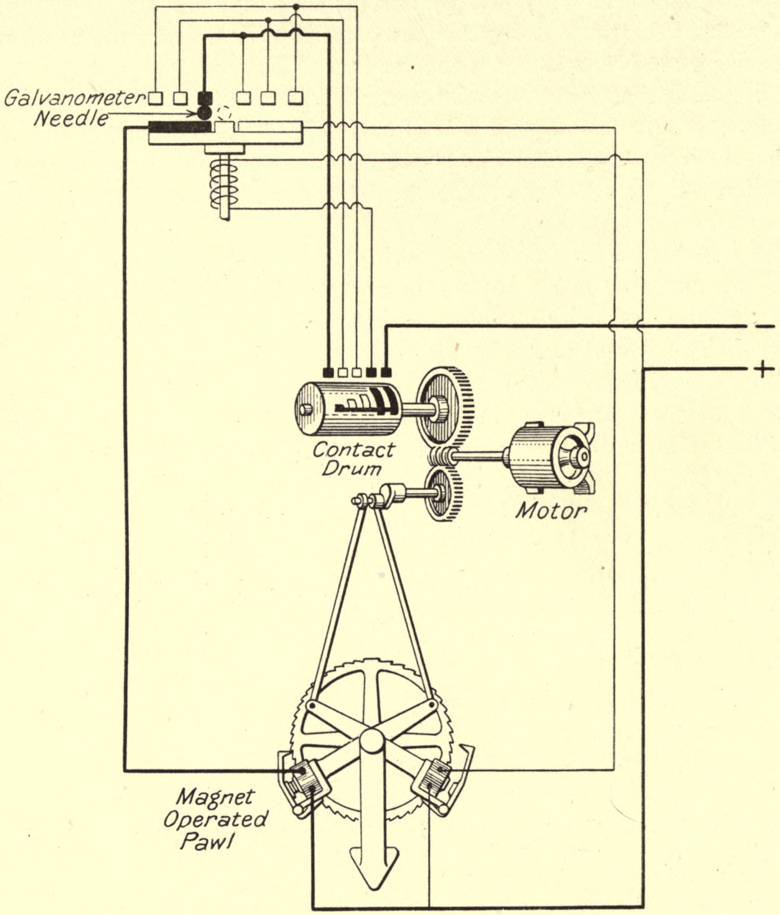


Fig. 166.—Diagram of Current Regulator for Thomas Meter.

by the readjustment of the heater current to the precise amount required to produce the 2° F. rise in temperature.

Front and back views of the regulator are illustrated in fig. 167.

(4) *The Temperature Difference Coil.*—The meter readings are automatically given at standard conditions, say 60° F. and 30-inch pressure, owing to the principle upon which the meter is operated, as already explained. The readings are in terms of saturated gas at 60° F., and a correction has to be made if the measurements are made at temperatures other than 60° F., due to the fact that at higher temperatures the amount of water vapour in saturated gas will be greater, and the amount of electrical energy required to maintain the 2° F. temperature difference will also be greater, with a consequence that the meter readings will be higher. The necessary correction is applied automatically by means of the temperature difference coil. This coil is in series with the inlet thermometer, and is composed sometimes of manganin (and therefore of constant resistance) and sometimes partly of manganin and partly of nickel. The construction and resistance of this coil are adjusted so that the increased energy required due to the excess of water vapour (or *vice versa*) is corrected for by a slight alteration in the temperature difference produced—*i.e.* the latter is in this case not quite 2° F. when the bridge is in balance.

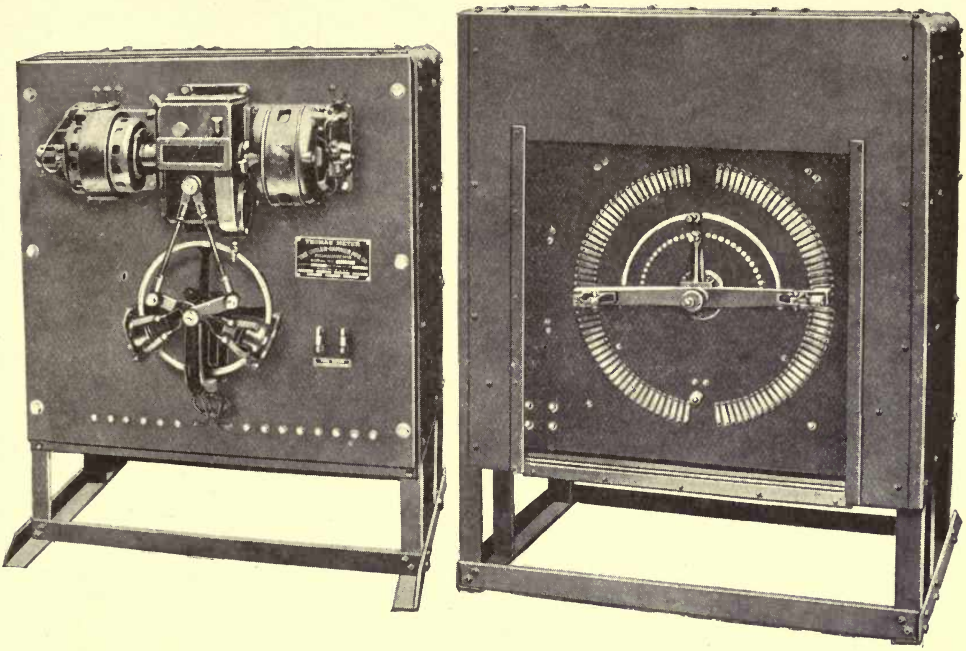


FIG. 167.—CURRENT REGULATOR FOR THOMAS METER.

(5) *The Housing.*—The housing is constructed of cast iron, and forms part of the main through which the gas is flowing. It is located at whatever point the measure-

ment is desired. The thermometers, heating unit and temperature difference coil, are situated in the housing as shown in section in fig. 168. A typical housing is shown in fig. 169. In the case of meters of comparatively small capacity the housing is of the return flow type, the measuring appliances being jacketed with the flowing gas. This reduces heat losses to a minimum. This type of housing is shown in fig. 170.

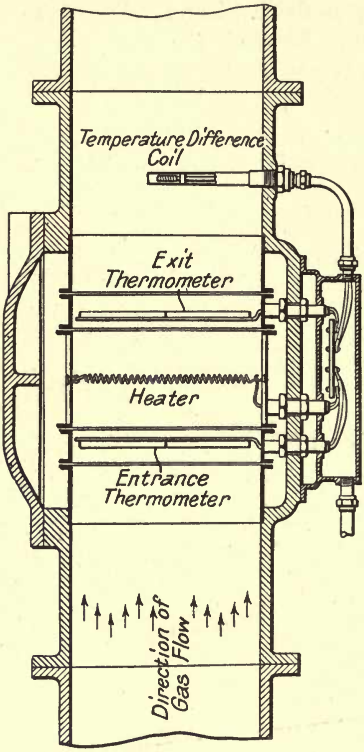


Fig. 168.—Section of Thomas Meter Housing.

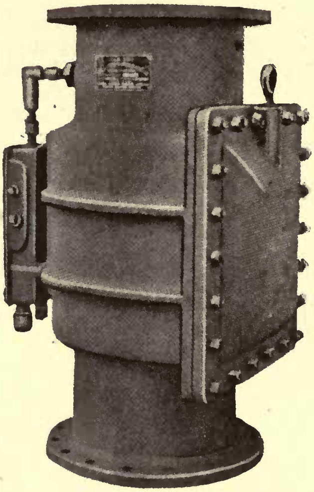


Fig. 169.—Thomas Meter Housing.

(6) *The Integrating Wattmeter.*—The integrating wattmeter, which measures the total energy supplied to the heater unit over any given period, is a standard instrument of the usual type. It consists of a motor, the field coils of which are in series with the heater and carry the total current. The armature is of high resistance, and is connected as a shunt across the terminals of the heater. The movement of the ratchet wheel of the regulator is caused to operate a secondary resistance, the amount of which varies with the load. The function of this secondary resistance is to reduce the percentage error due to the load characteristic curve of the wattmeter, as ordinarily used, so that the reading is substantially accurate at all loads. The number of revolutions are registered by the usual counting mechanism, but the dials are not calibrated in watts but read directly in standard cubic feet, and do not require any correction.

(7) *The Recording Wattmeter.*—This is also a standard instrument, and consists of a fixed coil carrying the total current, in series with the heater, and a movable

coil of high resistance which is connected as a shunt across the terminals of the heater. The shunt coil carries a pen which inscribes the record in terms of standard cubic feet per hour.

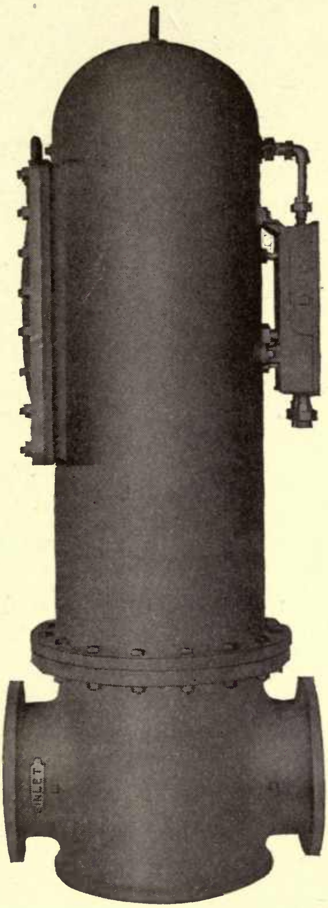


Fig. 170.—Jacketed Thomas Meter Housing.

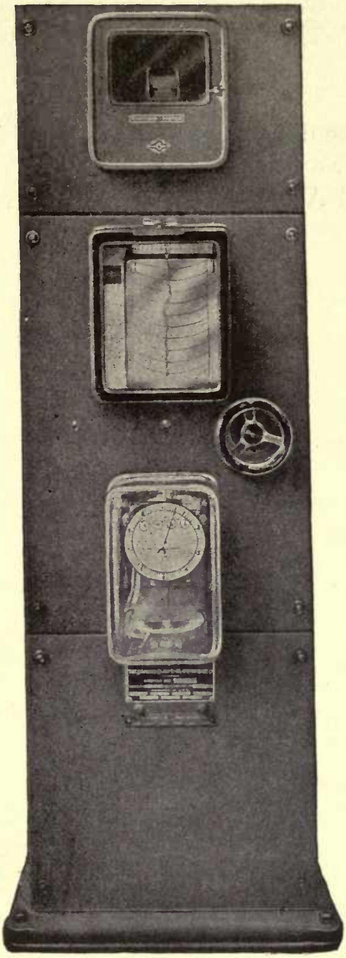


Fig. 171.—Instrument Panel for Thomas Meter.

The integrating and recording instruments may be situated in any suitable place, and need not be placed anywhere near the actual metering point. Fig. 171 shows these instruments mounted upon a panel.

B. STEAM METERS

The operation of steam meters depends upon the same laws as apply to that class of gas meter which functions by the employment of a differential pressure producing device. They differ considerably in actual detail from these gas meters, owing to the widely differing nature of the flow to be measured. As in the case of the gas meters already described, they comprise two essential portions :—

(*a*) The apparatus for producing the differential pressure.

(*b*) The apparatus for recording the rate of flow and integrating the total amount.

(*a*) *Apparatus for producing the Differential Pressure*

The differential pressure producing appliances used in the construction of steam meters are :—

(1) A Pitot tube arrangement consisting of two small tubes, the opening of one facing the direction of the steam flow, and that of the other being disposed in the opposite direction.

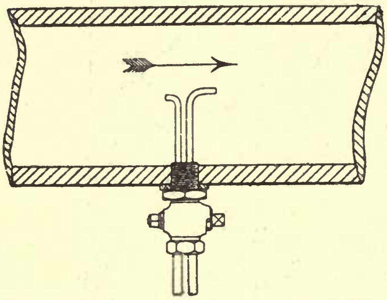


Fig. 172.—Pitot Tube for Curnon Steam Meter.

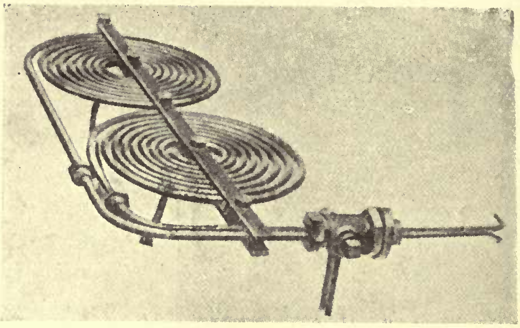


Fig. 173.—Condensing Coil and Diaphragms for Curnon Steam Meter.

(2) A restricting orifice inserted in the steam pipe.

If the steam be supplied at a constant pressure the flow is proportional to the square root of the pressure difference, and can be transmitted directly to a square-root chart, or through a special mechanism to a uniformly divided chart. A constant steam pressure is not, however, generally met with in practice, and steam meters are usually constructed so that the varying steam pressure is automatically compensated and the record obtained is independent of steam pressure changes.

The Curnon Steam Meter

The principle of the Pitot tube is employed in this instrument for the production of the differential pressure whereby the flow is deduced.

A plug (fig. 172) is screwed into the steam pipe and contains two bent tubes, one pointing against and one with the flow of the steam. A slight increase of pressure is produced in the " upstream " tube and a slight decrease occurs in the " down-stream " tube. The two pressures are transmitted through two horizontal condensing coils (fig. 173), which are normally full of water, to two sides of a diaphragm. The condensing coils are of such length that when the diaphragm moves from zero to full load the displacement of water does not empty the coils ; thus a difference of level is not produced and the pressure difference between the two sides of the diaphragm is the same as that between the two tubes. The coils are rapidly filled up again by condensation.

The diaphragm consists of two plates between which is a flexible sheet of special fabric, unaffected by water. This does not exert any controlling effect upon the diaphragm, the movement of which is controlled by a spring of incorrodible alloy. The diaphragm is contained in a circular box at the back of the meter, and the spaces on either side of it are filled with water. Its motion is transmitted by a spindle to the linkwork (*q.v.*).

A double cock is provided on the top of the diaphragm box, by means of which the meter may be isolated from the steam pipe, and the two sides of the diaphragm put into communication. The pen should then fall to zero.

The correction for the variation in steam pressure is automatically applied by measuring this pressure with a Bourdon tube. The movement of the latter, and of the diaphragm are combined by a special linkwork.

If P is the steam pressure and p the pressure difference measured by the diaphragm

$$\text{Rate of flow} = \mathrm{K}\sqrt{\mathrm{P}p}, \text{ where } \mathrm{K} = \text{constant.}$$

The arrangement of the linkwork, which combines the movements of the diaphragm and Bourdon tube according to this formula, is shown diagrammatically in fig. 174.

The main link OA, pivoted at O and swinging horizontally, is moved by a Bourdon tube acting through an oblique connecting-rod BD. The movements of B are thus proportional to the pressure P of the steam.

OF is the position of the main link at absolute zero pressure, and its angular movement is about 60 degrees. E is the end of a long lever attached to the spindle, which transmits the motion of the diaphragm through a practically frictionless stuffing-box. The link AC is pivoted at A, and is of exactly the same length as OA and CF. It will be seen that when p is zero, C is exactly over O, and the point F does not move however OA may be turned by variations of pressure. This is obviously a necessary condition if the movement of F is to represent the product Pp. But when the diaphragm is actuated, OC forms virtually one arm of a bell-crank lever, of which OB is the other arm, and the proportions of the various links are so chosen that the movement of F is accurately proportional to the product. In order to obtain a chart having equal divisions over the greater part of the scale, a device is introduced between F and the pen arm, which makes the movements of the latter nearly proportional to

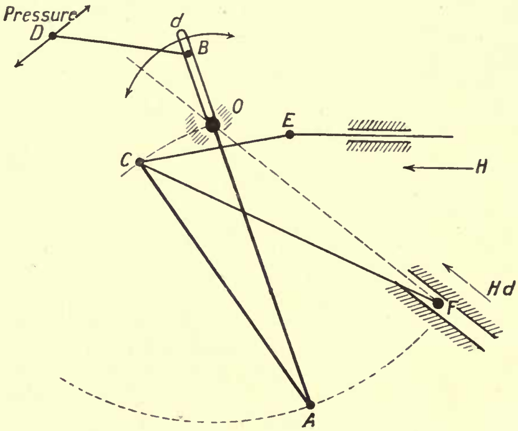


Fig. 174.—Linkwork for Curnon Steam Meter.

the square root of the movement of F—*i.e.* to the square root of Pp. The end F of the long link CF (fig. 175) is attached to one arm of a bell-crank lever—moving in a vertical plane—to the other arm of which is attached a link which directly operates the pen arm. In the zero position the bell-crank lever and CF are in the same position as a steam-engine mechanism just off dead centre.

The general arrangement of the meter is shown in fig. 176.

Kent Steam Meter

This instrument is operated by the measurement of the pressure difference on the two sides of a restricting orifice. The latter consists of an orifice carrier, which fits inside the bolts connecting two flanges, and to which the carrying bars and cooling chambers are attached (see fig. 177).

The latter are bolted to the valves on either side of the orifice fitting (attached to the orifice carrier by the carrying bars). They are in communication with the pressure passages on the two sides of the orifice and serve to condense steam, so that the pressure pipes and the recorder are always filled with water, and hence the reading cannot be affected by movements of the water in the pipes whereby the pressures are transmitted.

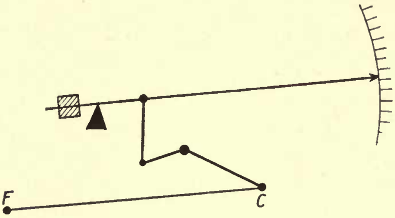


Fig. 175.—Square-root Linking.

The pressure passages on the two sides of the orifice are as close to the orifice plate as possible. The form of the orifice depends upon the degree of restriction required, which in turn depends upon the velocity of travel of the steam.

In the case of high velocities only a slight restriction is required to bring about the desired difference in pressure, and the orifice is in this case D-shaped, as shown in fig. 178. A circular orifice is only adopted when a considerable restriction of the pipe is required.

The most suitable pressure difference corresponds to about 50 to 55 inches of water or $1\frac{3}{4}$ lbs. per square inch. This pressure drop is only local, and the greater part of the lost pressure is recovered in the downstream after passing through the orifice.

The pressures on the two sides of the orifice are transmitted through water-filled pipes to the recording apparatus. The latter consists of a series of diaphragm chambers (fig. 179), the movement of which is controlled by a spring attached to the diaphragm spindle. The upstream, or greater pressure is transmitted to the exterior of the diaphragms and the downstream pressure is communicated to the interior. If the steam pressure is constant, the flow of steam is proportional to the square root of the pressure difference, and the motion of the diaphragm spindle, which is proportional to the differential pressure, is transmitted to a pen, recording on a square-root chart, by amplifying mechanism. If, however, as is usually the case, the steam pressure is not constant, automatic compensation can be provided. Reference to the diagram in fig. 180 will indicate the method whereby this compensation is effected.

The spindle, which is operated by the aneroid diaphragms used to measure the pressure difference over the orifice, is indicated at A. A crank and link connect A

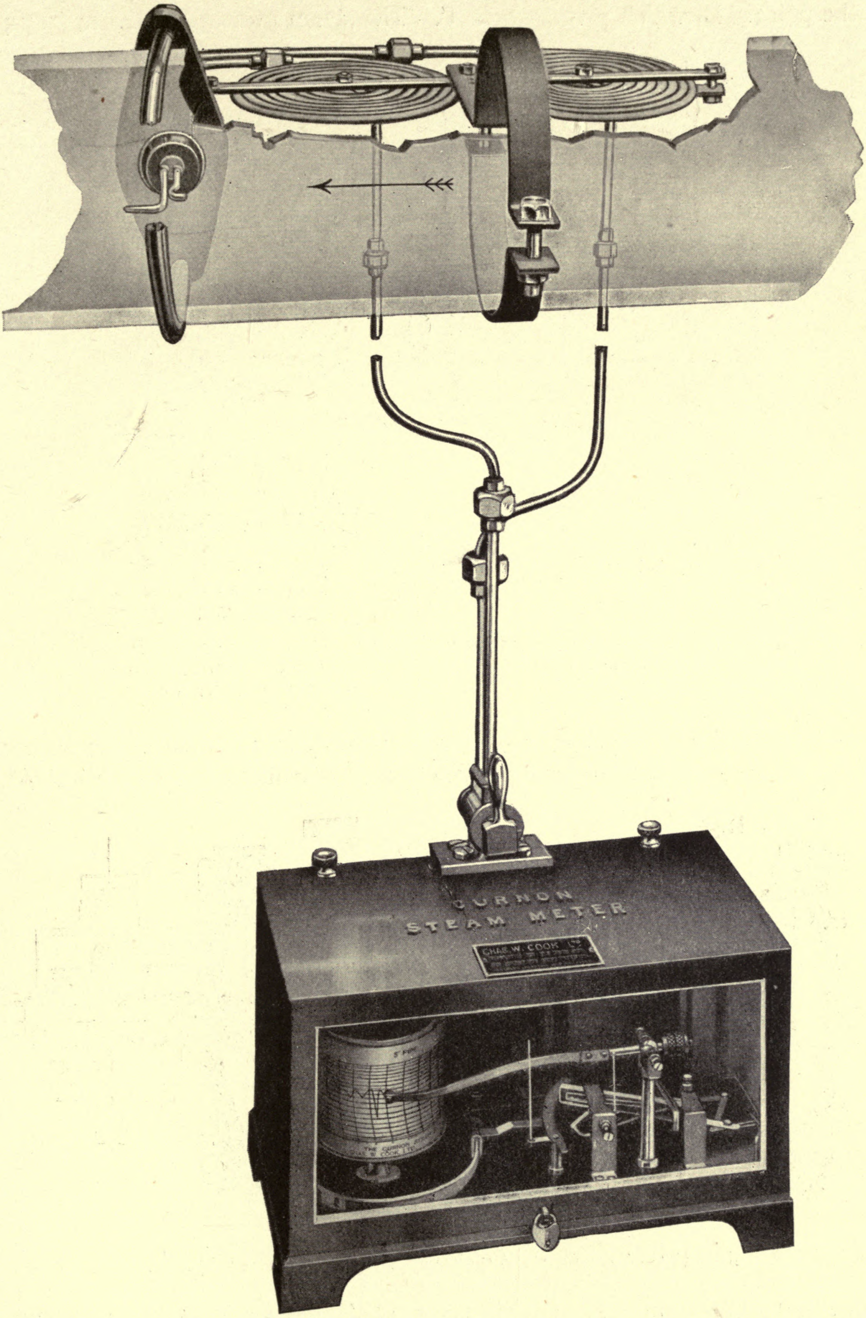


FIG. 176.—CURNON STEAM METER.

with the pointer B, which pivots about C. The steam pressure in the main pipe is measured by a series of diaphragms—shown separately on the right of the diagram—and is opposed by a helical spring. The rod D transmits the movement of the diaphragms to the pointer E and the lever F. There are thus two pointers, one indicating the difference of pressure across the orifice and the other the actual steam pressure. Their movements are combined and transmitted to a pen arm G, which

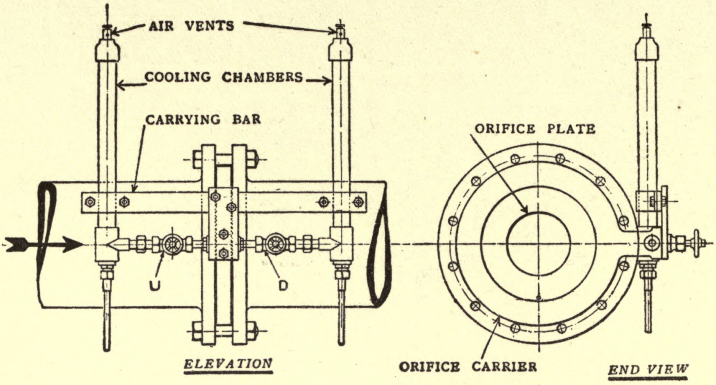


Fig. 177.—Restricting Orifice for Kent Steam Meter.

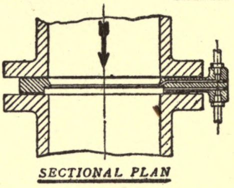


Fig. 178.—Section of Restricting Orifice for Kent Steam Meter.

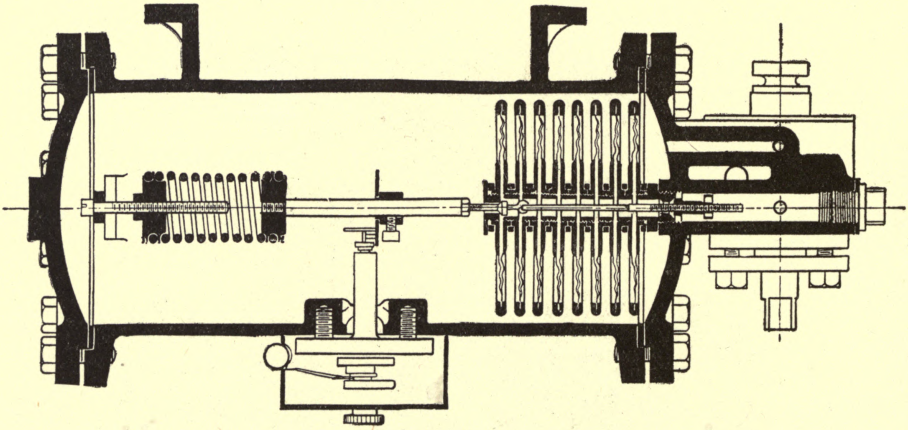


Fig. 179.—Recording Apparatus for Kent Steam Meter.

consequently makes a record representing the weight of the steam being metered. The combination of the two movements is effected by the link H and quadrant J.

In the positions shown in the diagram both the pointers E and B are at zero, and the end of the link H is over the pivot C. The result is that the individual movement of neither of the pointers E and B will affect the pen arm G. If, however, the flow pointer B and quadrant J move round the pivot B, an increase in the steam pressure will force down F and H and produce a movement in G which will vary in proportion to the movements of E and B. The various links are so proportioned that the resultant movement of the pen arm G is a true measure of the weight of steam passing the orifice.

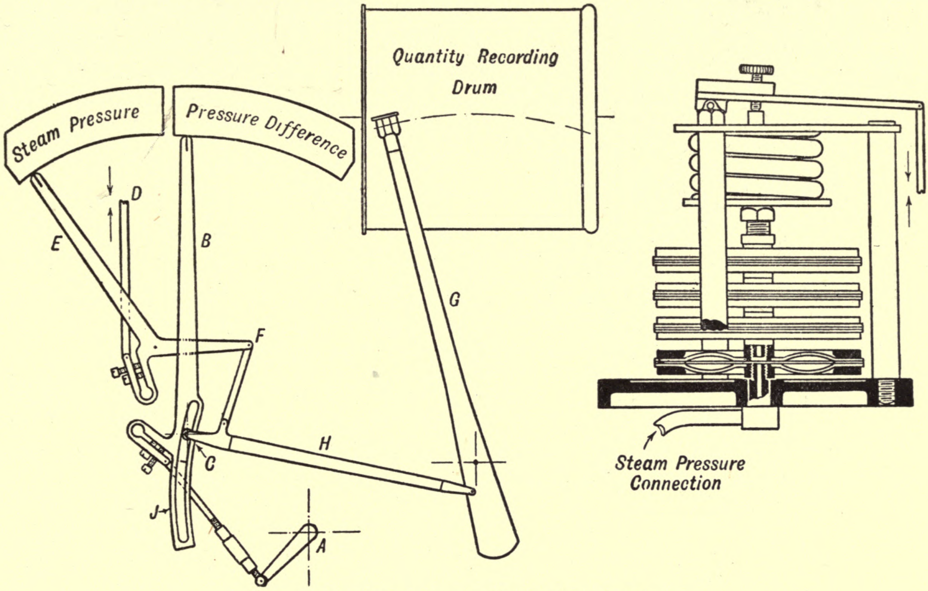


Fig. 180.—Diagram of Kent Steam Meter.

The meter can be provided with an integrating device, whereby the total amount of steam measured during any interval is registered. The counter mechanism consists of a spindle which is rotated by clockwork once every two minutes, and a clutch which is thrown into gear at the commencement of each revolution and out of gear at a point in the revolution corresponding to the quantity to be added on to the counter reading.

The complete recording and integrating instrument is shown in fig. 181.

Kent Steam Meter for Water Gas Plant

This instrument has been designed for use specially in conjunction with water gas plants. The spacing of the chart is considerably wider than in the Standard Kent Steam Meter. This enables the cycle of operation in the plant to be shown clearly, and consequently the consumption of steam for each process can be closely estimated.

The apparatus consists of two parts.

1. *The Nozzle.*—This is situated in the main, and shaped as shown in fig. 182. A hole is drilled in the main at a specified distance from the nozzle on the upstream side. The recording apparatus is connected to this hole by a length of copper pressure tubing. The recorder is thus actuated by the upstream pressure only, instead of by the difference of pressure set up by an orifice. Measurement in this manner is only possible if the steam is passing above the "critical velocity." When the latter is exceeded, pressure variations on the downstream side of the nozzle are without effect upon the flow of steam through the latter. This "critical velocity" occurs whenever the absolute pressure on the upstream side of the nozzle is more than twice the absolute pressure on the downstream side. The nozzle employed is designed so as to ensure this condition.

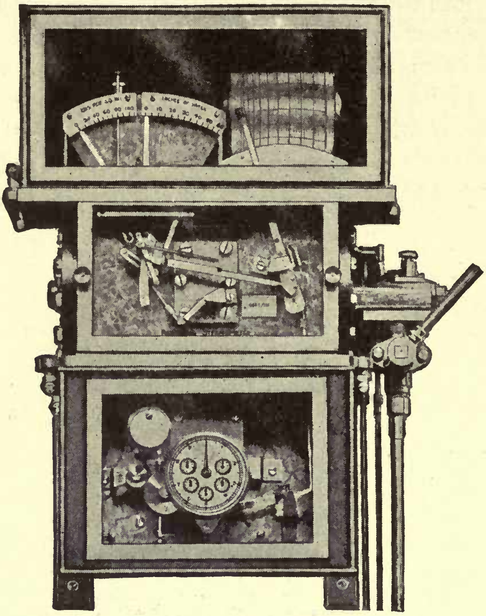


Fig. 181.—Kent Steam Meter.

2. *The Recorder.*—This consists of a diaphragm chamber, the motion of the diaphragms being magnified and transmitted to the pen arm. The latter inscribes the record upon a square-root chart in terms of pounds per hour of steam passing.

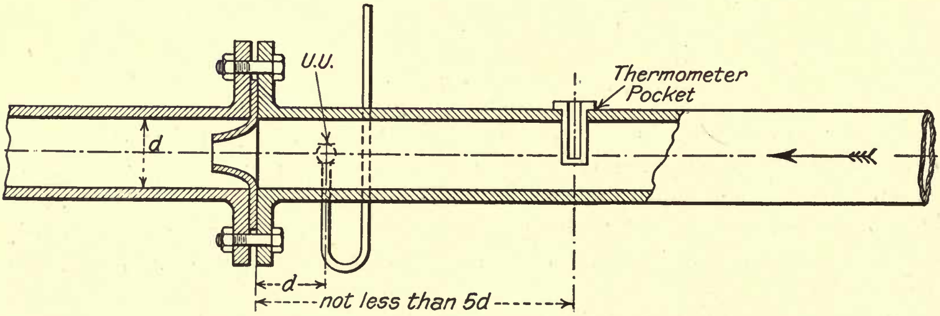


Fig. 182.—Nozzle of Kent Steam Meter for Water Gas Plants.

The Sarco Steam Meter

This instrument also functions by the measurement of the pressure difference on the two sides of a restricting orifice. The orifice in question consists of a special disc provided with ports, projecting into the steam pipe (see fig. 183). One of these ports establishes connection for the measurement of the upstream pressure, and the other exerts a similar function for the downstream pressure. These two pressures are transmitted to the recorder by $\frac{3}{8}$-inch diameter copper pipes, which are filled with water.

The recorder is constructed as follows :—

The orifice is fixed inside the bolts of the steam-pipe flanges as shown in fig. 183. The upstream (or high-pressure) side of the orifice is connected to the chamber A (fig. 184), containing mercury. The pressure tends to force the mercury out of this chamber and along the tube C into the specially shaped vessel D. The latter is suspended on the springs E. The pipe from the low-pressure side of the orifice connects to a base B, and thence to the top of the vessel D. This pressure tends to force the mercury back into the chamber A, and hence the difference of pressure on the two sides of the orifice determines the amount of mercury which flows into the vessel D, and consequently regulates the position which it assumes. Its movements are transmitted to the chart by means of an arm and the lever G.

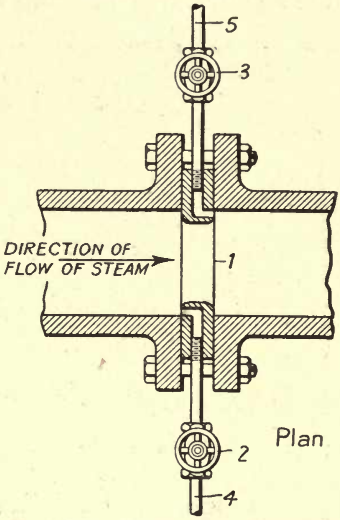


Fig. 183.—Restricting Orifice for Sarco Steam Meter.

The compensation for variable steam pressure is applied by a special arrangement,

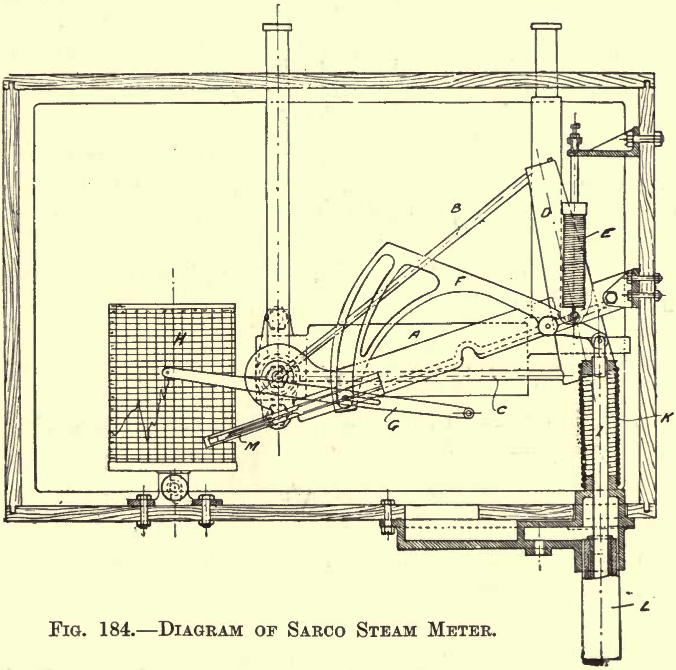


Fig. 184.—Diagram of Sarco Steam Meter.

consisting of a plunger L, working in oil, which actuates a strong spring K. Fluctuations in the steam pressure cause this spring to expand or to contract, thus moving the segment lever F, which in turn adjusts the fulcrum of the pen lever G, and so corrects the record automatically. The recording apparatus is shown in fig. 185.

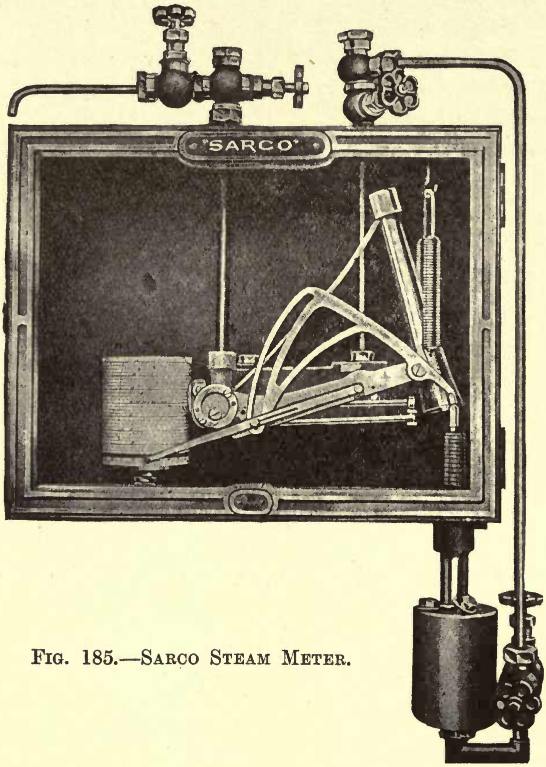


FIG. 185.—SARCO STEAM METER.

C. LIQUID FLOW METERS

Meters for measuring the rate of flow of a liquid are of varied construction, and the choice of a particular form of meter will be governed by the conditions—certain forms being more suitable for particular purposes than other types.

The most important types of liquid-flow meters are :—(*a*) Notch or weir meters, in which the liquid flow passes through or over a notch or weir of special shape. The rate of discharge is a function of the head which is recorded on the chart in terms of rate of flow.

(*b*) Venturi meters which operate by the production of a differential pressure, the amount of which is a function of the rate of flow, and is measured.

(*c*) Meters operated by the rotation of a balanced piston or displacer, the number of revolutions of which are a function of the flow.

(*a*) NOTCH OR WEIR METERS

The rate of flow through or over an orifice notch or weir of continuous shape is expressed by the relation—

$$Q = KA\sqrt{h}$$

when Q=the rate of flow
A=the submerged area of the weir.
h=the head.
K=constant.

The rate of flow is therefore a function of the head, and measurements of the latter can be translated by the mechanism into terms of flow.

A notch or weir meter therefore comprises two separate parts :—

1. A weir or notch fixed into a tank through which the liquid flow is discharged. The head is maybe measured by a float or by any other suitable device.

2. The recording and integrating apparatus whereby the position of the float, which is determined by the head, is recorded upon a chart, which thus registers the rate of flow. The total flow over any interval is registered by integrating mechanism.

The Yorke Weir Meter

Reference to the formula $Q = KA\sqrt{h}$ shows that in the case of meters employing a V-notch or weir the rate of flow is proportional to the square root of the head.

In such instruments the chart employed must be divided on a square-root scale, or special mechanism must be employed to convert the linear motion of the float into a square-root motion of the pen.

The difficulty in obtaining a uniformly divided scale has been surmounted in a very simple manner by Yorke, who, instead of employing a V-shaped weir of the conventional type, devised the expedient of constructing a weir, the breadth of which is inversely proportional to the square root of the corresponding head. In this case the head is directly proportional to the flow, and a uniformly divided chart is employed without the use of any mechanical device between the float and pen.

The weir can be placed in any type or shape of tank, and may be situated in any portion of it. A Yorke weir fitted to a tank is shown in fig. 186.

The head of water is measured by a float which is directly connected with the pen.

The integrating mechanism consists of a circular ground-glass plate (fig. 187) disposed in a horizontal plane, driven by the same clockwork which actuates the recording drum.

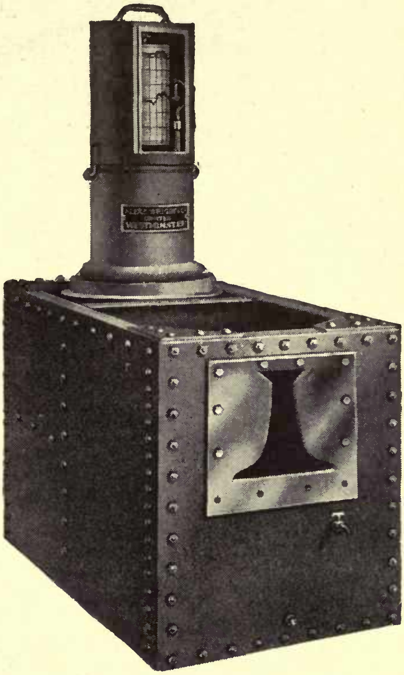


Fig. 186.—Yorke Weir, mounted on a Tank.

A small index, provided with a driving wheel in contact with the glass plate, is connected to the float rod by a chain. As the float rises, so the index moves outwards from the centre of the glass plate. The index driving-wheel is driven by friction from the glass disc, and thus the farther the index moves from the centre, the greater is the number of revolutions of the index wheel per revolution of the glass plate. The index wheel therefore rotates a number of revolutions per hour which is proportional to the height of the float, and hence the number of revolutions as shown on the index can be adjusted to give the total actual flow in terms of gallons or any other convenient unit.

The recording and integrating apparatus may be situated at a distance from the weir tank if desired.

The complete recording and integrating apparatus is shown in fig. 188.

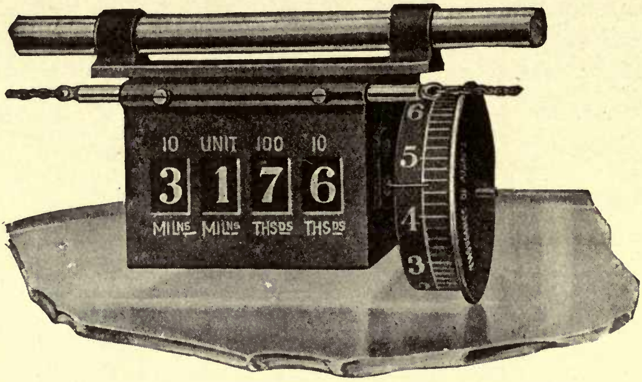


FIG. 187.—INTEGRATING MECHANISM OF YORKE WATER METER.

KENT V-NOTCH WATER METER

A V-notch is employed in Kent's weir type meter, and the linear motion of the float is converted by a specially shaped cam into a square-root motion actuating the pen and integrator.

The liquid stream flows through a tank over the sill of the V-notch into the centre portion of the tank, and out of the tank through the outlet pipe (see fig. 189).

The height to which the water rises in the tank regulates the position of the float. The latter actuates the mechanism shown diagrammatically in fig. 190.

The float carries a rack which rotates a specially shaped cam by means of the rack wheel. This cam serves to convert the linear motion of the float into a square-root motion. A roller arm rests upon the cam, the position of which is determined by the position and shape of the latter. This roller arm rotates a carriage arm which moves the counter (or integrating) carriage backwards and forwards.

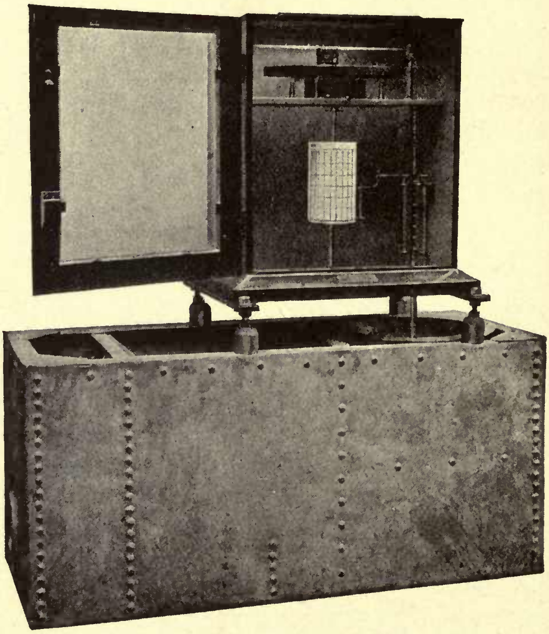


FIG. 188.—YORKE WATER METER.

The counter carriage (bearing the index) is connected to the pen arm, and is provided with a small glass friction wheel which moves across a large glass driving disc, driven at a uniform rate by the clock mechanism of the recording drum. The speed of rotation of the small driving wheel will depend upon its distance from the centre of the large glass disc. The position of the counter carriage therefore determines the number of revolutions recorded upon the counter and the position of the pen arm.

The weir type of liquid flow meter is relatively inexpensive, and is specially suitable for the metering of liquids exerting a strong chemical action. It is a comparatively simple matter to protect the weir tank and float from chemical action.

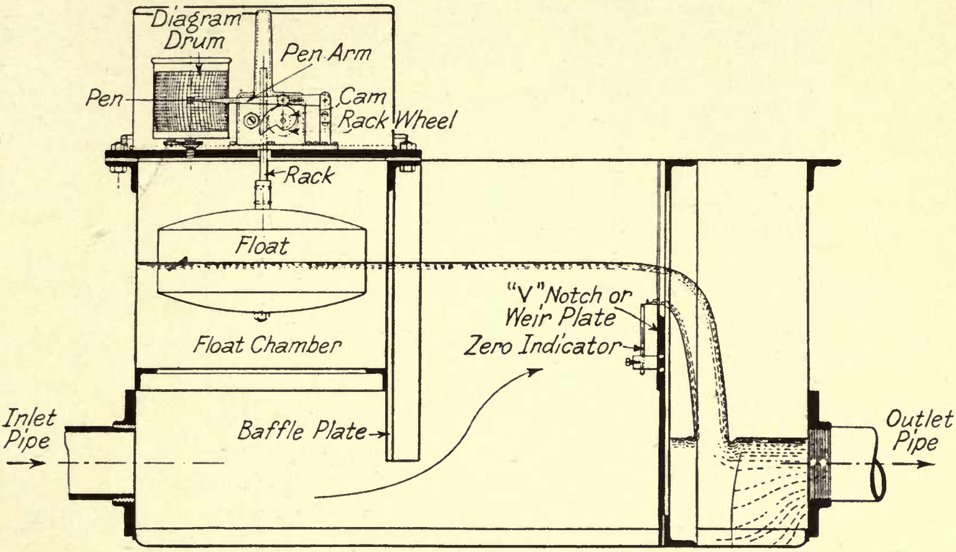


FIG. 189.—SECTION OF KENT WATER METER.

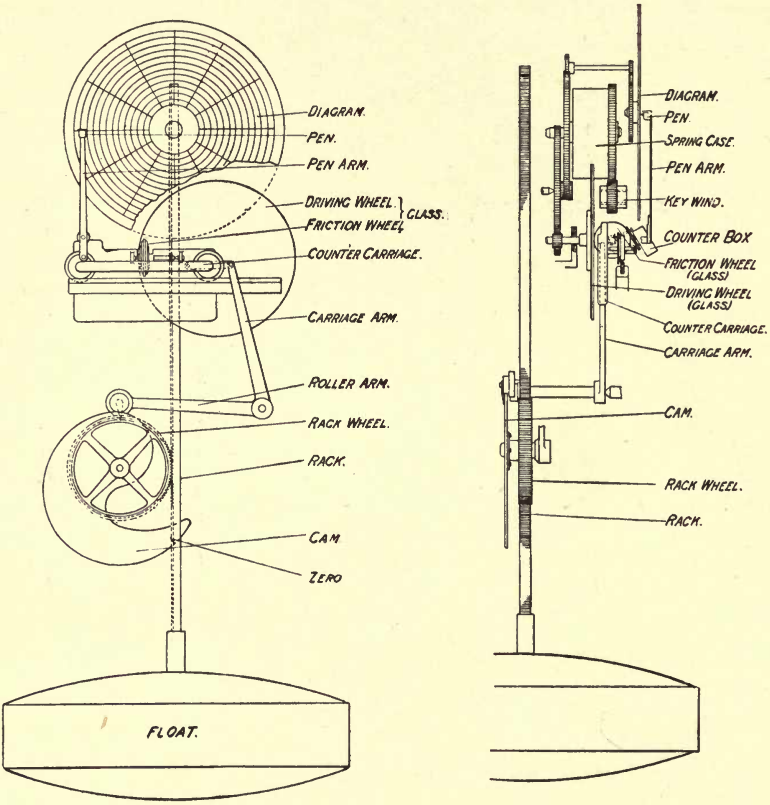
SHOTTER ELECTROLYTIC FLOW METER

The Shotter electrolytic flow meter is a novel type which has recently been developed, in which the observation of the rate of flow and the integration of the total flow are both effected by electric conductivity measurement.

The meter is of the notch or weir type of instrument, as the flow is deduced from measurement of the liquid level flowing through a notch or weir. The apparatus differs from any of the weir meters previously described in respect to the method employed for the measurement of the liquid level and the consequent deduction of the rate of flow.

The method adopted depends upon the depth of immersion of electrodes placed in the liquid above the weir. The higher the liquid level the deeper is the immersion, and consequently the less the electrical resistance of the circuit. The conductivity is made a measure of the flow of liquid by specially shaping one of the electrodes, as described below. A second set of electrodes with a constant depth of immersion, excited by the same voltage, forms part of the " control " circuit.

Description of Apparatus.—The general arrangement of the instrument is shown diagrammatically in fig. 191. W is the notch or weir through which the liquid flows, E being the zero line. B is a battery and A is a " ratiometer " which measures the ratio of the two currents flowing through its two coils C and D.



Front View Side Elevation.

FIG. 190.—DIAGRAM OF KENT WATER METER.

Two electrolytic paths are provided for the current. In one of these the dimensions are constant and independent of the level of the liquid, as it is always completely submerged below the zero line. This path is represented in the diagram by the lower set of electrodes. The other electrolytic path is variable and its dimensions vary with the liquid level.

It is arranged so that there is not any current when there is not any flow of liquid over the notch. The requisite variation of the conductivity according to the head or flow is obtained by specially shaping the tubes containing the electrodes. These tubes, which are made of suitable insulating material such as porcelain, are shaped so that the conductivity is a linear function of the flow, and hence, roughly speaking, they are practically the inverse of the Yorke weir. The exact shapes, which depend upon whether a V notch or a rectangular notch is employed, are shown diagrammatically in fig. 192.

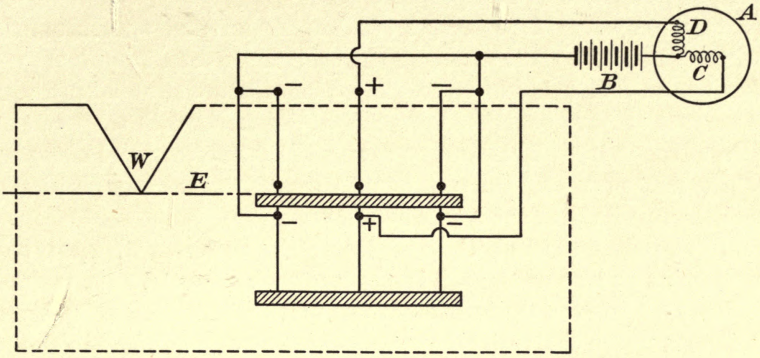


Fig. 191.—Diagram of Shotter Flow Meter.

The control electrolytic path is formed in porcelain tubes of circular or any other convenient cross-section.

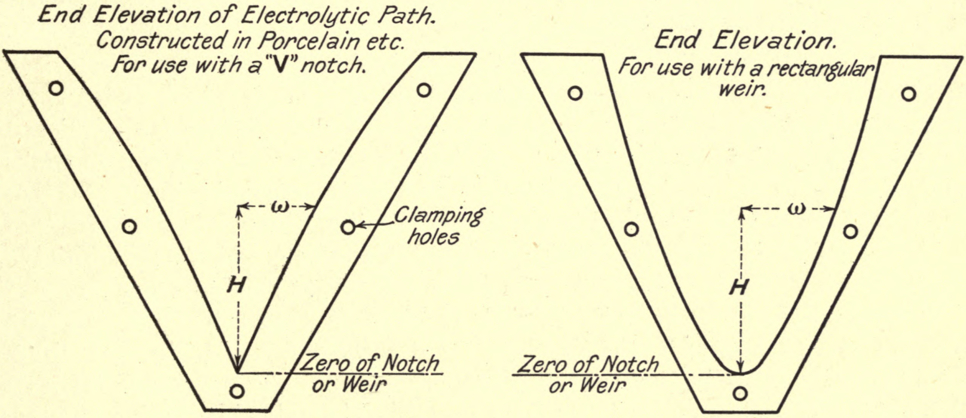


Fig. 192.—Electrodes for Shotter Flow Meter.

The flow measurements are deduced by measuring the ratio of the two currents that flow—one through the fixed path and the other through the variable path—from the battery which forms a source of E.M.F. common to both circuits. The *ratio* thus measured is a function of the depth of the liquid in the variable circuit only, and is independent of all variables such as E.M.F. of battery, back E.M.F., specific conductivity of the liquid and temperature.

It is of course obvious that both electrolytic circuits must be identical, and this is ensured by situating both electrolytic paths in the weir tank, so that the liquid is continually flowing through both paths.

The anodes are constructed of platinum wire of about 45 s.w.g., and the cathodes are composed of nickel or graphite.

The ratiometer consists of two coils wound upon the same aluminium frame and provided with an iron core ; the arrangement being carried on two pivots working in jewelled bearings so that it is free to rotate. The coils are situated in the field of a permanent magnet and are connected respectively in series with the two electrolytic paths by thin silver strips. These are so arranged that no torsional effect is exerted, and the moving frame carrying the coils is quite free to assume any position of equilibrium due to the resultant of the forces acting upon it.

When current passes through the ratiometer coil in series with the fixed path, the pointer remains at zero as the coil is disposed with respect to the magnetic field, so that there is no tendency towards any movement when the coil is excited. The record coil, in series with the variable path, is disposed at a considerable angle to the plane of the other coil, and when a current passes through it the resultant force tends to rotate the coil. This rotation moves the first coil out of its position of equilibrium, upon which another torque is set up—the final position assumed by the moving system is dependent upon the ratio of the current strengths flowing through the two coils.

The ratiometer pointer is depressed on the chart by means of a locking bar. The record is produced by a steel point, attached to the pointer, which marks the chart by means of a carbon ribbon.

The complete recording and integrating mechanism comprises a master clock fitted with an instantaneous contact attached to the seconds wheel, and a chart drum which is driven forward by a ratchet and pawl and the locking bar mentioned above. A traversing arm, operated by electro-magnetic means in a plane parallel to the needle, has attached to it one portion of an electro-magnetic clutch, the other part of the clutch being attached to a train of indicating wheels.

At the end of the traversing arm is fixed a pair of contacts, which engage with the needle, and which open the circuit when driven against the fixed needle.

The operation of the mechanism is briefly as follows :—The master clock completes a circuit every ten seconds, the circuit comprising the clutch coil, the chart drum operating coil and the locking-bar coil, consequently the needle is locked in the position which it has taken up due to the flow ; secondly, the train of indicating wheels is connected by means of the clutch to the traversing arm and, thirdly, the chart drum is moved forward a definite amount. A contact is attached at the end of the travel of the armature operating the locking arm. This puts into circuit the traversing arm coil ; this arm, which is damped by means of an oil dashpot, slowly moves from zero in the direction of the locked needle, carrying with it the integrating mechanism. As soon as the contact on the traversing arm is opened by coming into contact with the needle, the three-coil circuit mentioned above is opened, consequently releasing the clutch, the locking-bar, and the drum-driven armature ; the locking-bar, in turn, open-circuiting the traversing arm coil. A contact is also fitted to the clutch or locking-bar in parallel with the instantaneous contact on the clock, which keeps the circuits maintained until the traversing-arm contacts are opened. The traversing arm now returns to its zero position, but of course does not carry with it the integrating mechanism.

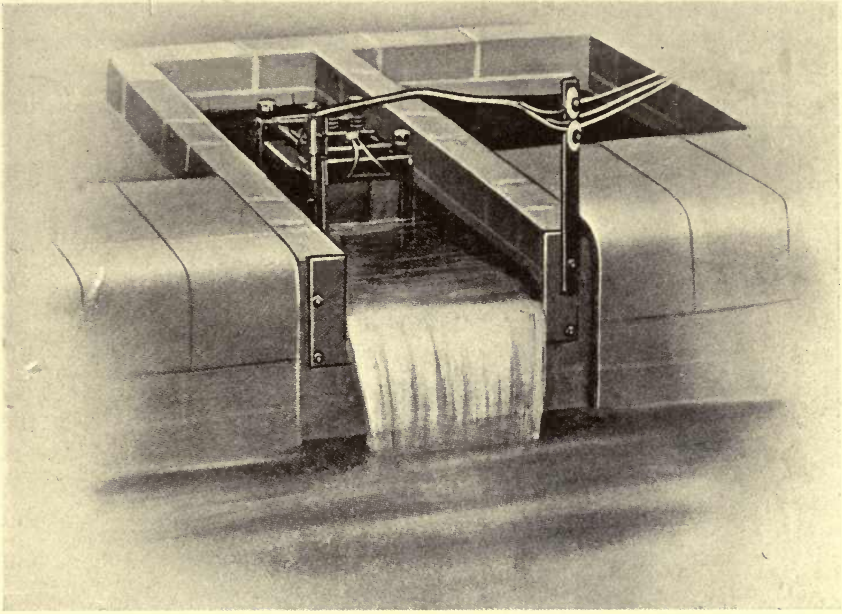


Fig. 193.—Transmitting Apparatus for Shotter Flow Meter.

As a result of the use of an electrical method for the measurement of the head of liquid flowing over the notch, the recorder can be situated at any distance from the latter and more than one recorder can be used with the same notch if desired.

The transmitter, fitted in a tank, is shown in fig. 193.

Electro Water Flow Meter

The Electro Water Flow Meter, for the measurement of liquid flows, is actuated in a similar manner to the Electro Gas Flow Meter already described, and in this case also the recording and integrating instruments can be situated at any distance from the metering point.

(*b*) VENTURI METERS

The Venturi type of liquid flow meter is operated by measurement of the differential pressure existing between the upstream cone and the throat of a Venturi tube, which forms part of the circuit in which the liquid is flowing. The theory and operation of a Venturi meter for measuring liquid flows is exactly the same as that of a Venturi meter designed for gas measurement. The instrument differs from the latter merely in respect to certain details necessitated by the difference in the magnitude of the differential pressure to be measured.

Compensation for specific gravity variations is not required in the case of Venturi meters for liquid flows.

Venturi meters are usually employed for the measurement of very large flows, and are not often installed in gasworks. Meters of the types described are employed for smaller volumes.

The installation of a Venturi meter is advantageous if it is essential that the liquid circuit be entirely enclosed.

(*c*) DISPLACEMENT METERS

Displacement meters consist of a balanced piston or displacer of special shape which rotates in a chamber forming part of the pipe line. The total flow is measured by counting mechanism, which registers the number of revolutions of the displacer.

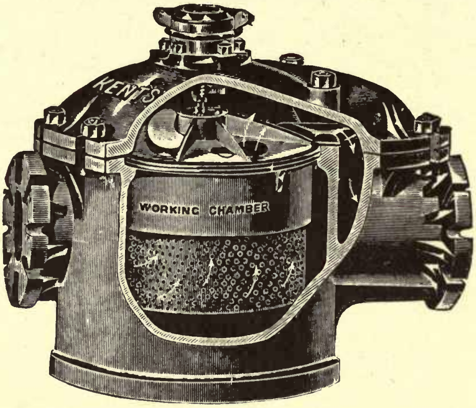


FIG. 194.—KENT DISPLACEMENT WATER METER.

Kent's Uniform Water Meter—an appliance of this type—is shown in fig. 194.

The path of the liquid stream flowing through the meter is indicated by arrows. An elliptically shaped displacer is situated inside the working chamber.

CHAPTER IX

RECORDING DENSIMETERS AND DEPTH GAUGES

RECORDING DENSIMETERS

Recording densimeters are designed to give a continuous record of the variation in density of a liquid. It is well known that the density of a liquid is very greatly affected by its temperature. Furthermore, variations in temperature may well occasion greater changes in density than those actually due to the possible variations in composition which the instrument is required to regulate.

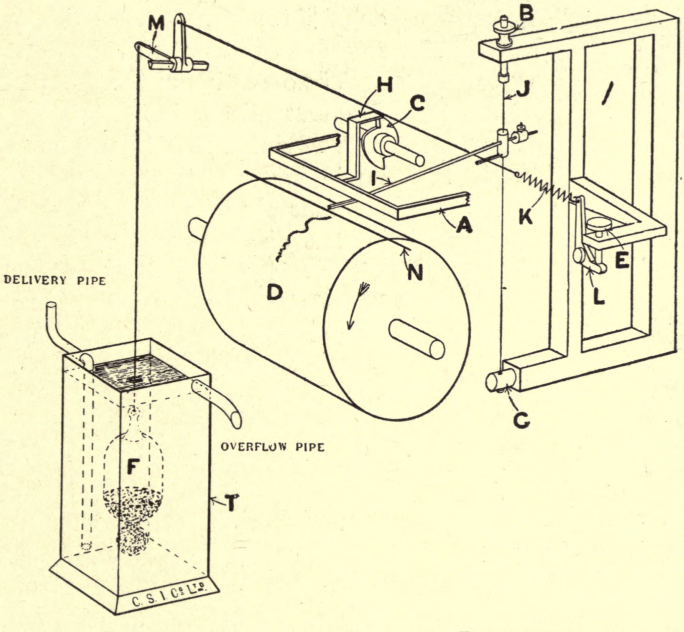


Fig. 195.—Diagram of Cambridge Densimeter.

For this reason the record obtained with a densimeter which does not correct for temperature changes should always be considered in conjunction with a continuous temperature record of the liquid taken simultaneously with the density record; unless the temperature is nearly constant. Given a knowledge of the effect of temperature variation upon the density of the liquid in question, the density and temperature records taken in conjunction afford all the information necessary.

A recording densimeter has been constructed in which temperature variations are automatically compensated. A continuous temperature record is not required with this apparatus.

THE CAMBRIDGE RECORDING DENSIMETER

In this instrument, the varying displacement of a sinker totally immersed in the liquid (the specific gravity of which is to be recorded) is opposed by the resistance to torsion of a stretched steel wire and by a spiral spring. Variations in the specific gravity of the liquid occasion concomitant changes in the displacement of the sinker, with the result that the angle through which the steel wire is twisted varies.

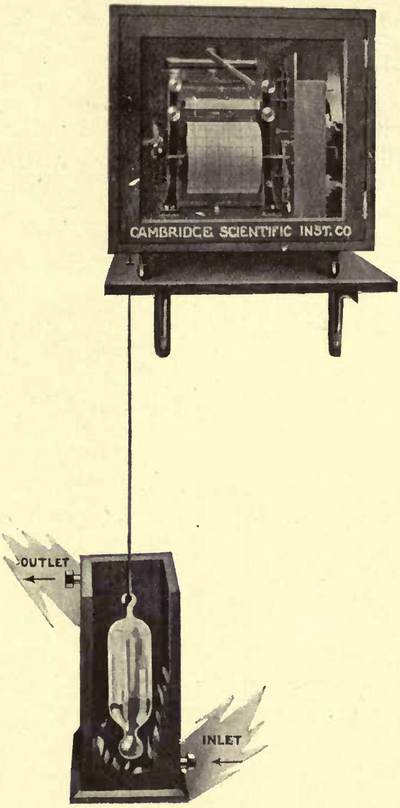


FIG. 196.—CAMBRIDGE DENSIMETER.

The torsion wire carries a boom, the movements of which vary according to the angle of torsion. The position of the boom is recorded on a chart scaled in terms of density.

The operation of the instrument is shown diagrammatically in fig. 195.

The sinker F is totally immersed in the liquid under test, a sample of which flows continuously through the tank T.

The displacement of the sinker changes with variations in density of the liquid, and it therefore rises or falls in the liquid until its displacement is exactly balanced by the opposing forces exerted by the torsion wire J and the spring K.

The sinker is connected by a vertical thread or wire to a bell-crank lever M connected to the boom I. The latter is attached to the vertical steel torsion wire J, and is counterpoised by a weight as shown.

The boom swings above the chart drum D, and its position is recorded thereon by means of the Thread Recorder previously described (see Chapter II. p. 22).

Fig. 196 shows the complete instrument.

THE PRECISION RECORDING DENSIMETER

This instrument was designed by Simmance and the author, and is intended to correct automatically for temperature variations so that the record obtained is always in terms of density referred to a particular temperature.

The principle of the apparatus is in effect a " balancing " of the weight of the liquid displaced by a sinker, totally immersed in the liquid, against the displacement of a vertical cylinder which rises or falls in distilled water. Hence, the lighter the liquid, the density of which is to be recorded, the less is the weight of liquid displaced by the sinker, and correspondingly there is a smaller immersion of the vertical cylinder in order to compensate by the increase of weight for the lessened displacement, or, as is the same thing, for the increased weight of the immersed sinker.

This up and down movement of the float causes the recording pen to move across the chart and so to inscribe the density.

The float consists of a cylinder of such dimensions that its volume is almost equal to that of the sinker. This portion is always totally immersed in the liquid.

Fig. 197.—Float for Precision Densimeter.

It is surmounted by a cylindrical neck of small diameter, as shown in fig. 197. It is gold or platinum plated to avoid corrosion.

The volumes of the sinker and of the immersed portion of the float are practically identical over the range covered by the instrument, and as a result the indication of the apparatus is unaffected by changes in temperature. In other words, the density recorded will always be that of the liquid referred to a standard temperature, and changes in temperature will not affect the accuracy of the record.

The distilled water must be at the same temperature as the liquid in order to effect this compensation. The water chamber in which the float rises and sinks is therefore surrounded by a jacket of the liquid, the density of which is being recorded.

The arrangement is shown in fig. 198.

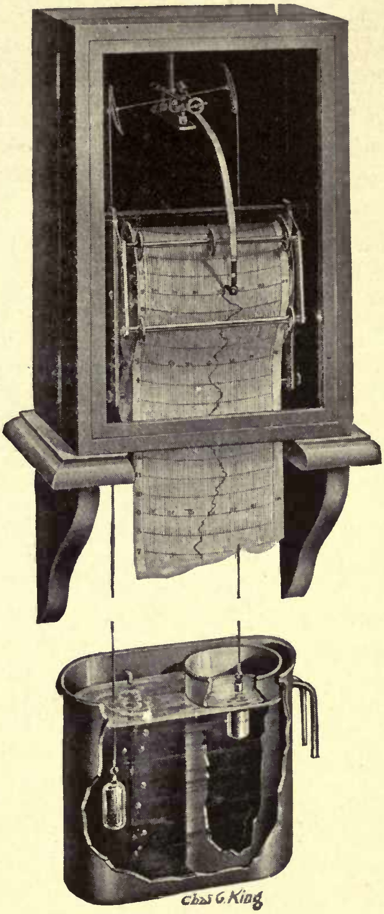


Fig. 198.—Precision Densimeter.

The distilled water chamber must always be filled with water, and any losses by evaporation must be replaced by occasional small additions.

The sensitivity of the reading depends upon the diameter of the narrow cylindrical neck of the float, and can be varied as desired within wide limits. Any number of different ranges can be recorded, using the same instrument, merely by using different sinkers. The latter must all be identical in volume, but will vary considerably in weight according to the range required. They are constructed of glass, and are loaded with shot to the desired weight.

Density determinations can be indicated at a distance by a variant of the Pneumercator Depth Gauge described below.

DEPTH GAUGES

These instruments are designed for the measurement of the depth of liquid contained in a tank. Measurement by means of sounding rods is inconvenient, and cannot be employed if the tanks are under pressure or vacuum. Even in the case of measurements made at atmospheric pressure, the presence of a high concentration of fumes in the atmosphere above the tank will be a frequent occurrence. In such cases it will be necessary to protect the operator against the fumes by a suitable breathing appliance before the measurement with the sounding rod can be effected.

The Pneumercator Depth Gauge depends upon the maintenance of a hydrostatic balance between the head of liquid to be measured and a column of mercury or other indicating liquid.

The pressure is transmitted by air confined in a capillary tube connecting the " balance chamber," situated in the bottom of the tank, and the gauge.

The apparatus consists of :—

1. A balance chamber.
2. A pressure gauge.
3. A control valve.
4. A small air pump.
5. The connecting tube.

1. *The Balance Chamber.*—This is a hemispherical vessel provided with a sharp-edged orifice which determines the datum line near its base. The chamber is situated as near as possible to the bottom of the tank containing the liquid.

The head of liquid in the tank compresses the air trapped in the balance chamber, and this pressure is transmitted to the pressure gauge.

Before a reading is taken, air is pumped into the balance chamber in order to expel any excess liquid through the orifice, thus driving the level of the liquid in the chamber down to the datum line. When the liquid level reaches this position, excess air escapes, as shown in fig. 199.

When this operation has been performed, the air pressure in the balance chamber exactly balances the pressure due to the head of liquid in the tank above the datum line.

2. *The Pressure Gauge.*—This is put into communication with the balance chamber and serves to measure the pressure of the air in the latter (fig. 200). The gauge can be calibrated to read in terms of either the depth, weight or volume of liquid in the tank.

A knowledge of the specific gravity of the liquid is of course essential for the calibration of the pressure gauge.

3. *The Control Valve.*—This serves to connect the balance chamber with the air

pump, and also to shut off the air pump and effect the connection between the balance chamber and the pressure gauge. The zero of the instrument can also be checked at any time by placing the control cock at the " vent " position.

4. *The Air Pump.*—This, as already explained, is employed to restore the datum line before taking a reading. If insufficient air has been pumped in before the reading is taken, a repetition of the operation will give a higher reading on the gauge.

5. *The Connecting Tube.*—The connecting tube serves to transmit the pressure from the balance chamber to the pressure gauge. It consists of fine bore metallic capillary tubing and may be of any desired length, so that the depth indicator can be situated at any distance from the tank and at any level.

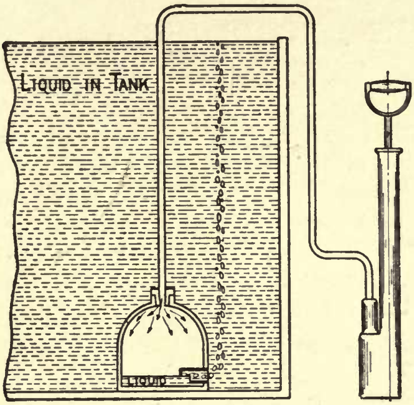


FIG. 199.—DEPTH GAUGE AFTER BALANCING.

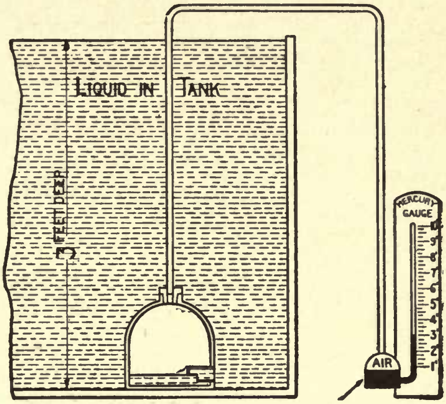


FIG. 200.—PRESSURE CHAMBER AND INDICATOR OF DEPTH GAUGE.

If the storage tank is under pressure or vacuum, an additional connection is run from the top of the tank to the top of the indicating mercury column. This height of the latter will thus correspond only to the hydrostatic pressure exerted by the liquid.

USE OF THE GAUGE FOR INDICATING DENSITY AT A DISTANCE

If the depth of liquid in a container is fixed, the pressure which it exerts is proportional to its density, and the arrangement described can then be employed to indicate density at a distance from the container.

A special duplex balance chamber is inserted in the tank, and the pressures of the liquid at two levels, three feet apart, are measured by differential gauge calibrated in terms of density.

APPENDIX I

A THERMOSTAT FOR RECORDING CALORIMETER ROOMS

It has already been pointed out in Chapter VI. that recording calorimeters of all designs are preferably maintained at as constant a temperature as possible. In order to achieve this end effectively it is therefore desirable to control the temperature of the room, in which the recording calorimeter is installed, with a suitable type of thermostat.

Simmance has devised a special type of thermostat, which is employed to control the gas supply to a luminous flame stove. The temperature of the calorimeter room can be maintained quite uniform by the use of this device.

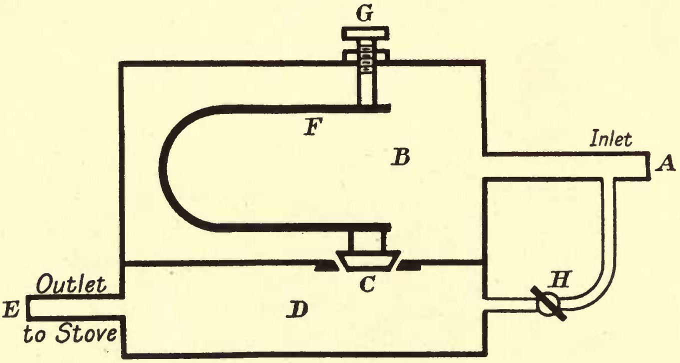


Fig. 201.—Diagram of Thermostat for Calorimeter Room.

The gas supply is passed through a long pipe so that the gas is at the same temperature as the room by the time it reaches the thermostat. The latter is shown diagrammatically in fig. 201.

The gas enters the thermostat at A, filling the upper chamber B. It then passes through the valve C to the lower chamber D, and leaves the thermostat at E. The chamber B contains a bimetallic U-shaped element F which controls the valve C. This bimetallic element is composed of thermostatic metal (see Chapter VI. p. 151), the more expansible member being on the inside so that increase of temperature causes the element to open outwards and thus to close the valve C. Any change in the temperature of the room is communicated to the gas supply and thus to the element F. The adjustment of the thermostat is effected by a screw G (to which the element F is attached) which works in a stuffing-box.

A by-pass H, controlled by a cock, is provided, so that the supply of gas is never entirely shut off.

APPENDIX II

ELECTRICALLY CONTROLLED THERMOSTAT FOR COLD JUNCTION

THE thermostat is constructed as follows :—

Four heating coils are placed in the base of an oil bath ; these coils are in series with two carbon filament high-resistance lamps. A bimetallic strip carrying an adjustable platinum contact as its end is so arranged that when a definite temperature is reached the distortion of this strip causes a contact to be broken, which inserts both lamps into the circuit. The resistance of these lamps decreases the power dissipated in the heating coils. The temperature then begins to drop until the bimetallic strip makes contact, and thereby shunts one lamp, which causes more power to be dissipated in the heating coils. The oil bath containing the bimetallic strip, heating coils and thermo-couple is placed in an outer metal tank, the space between the two vessels being well packed to prevent undue heat loss. The lamps are mounted on top of the tank and act as pilot lights as well as functioning as series resistances.

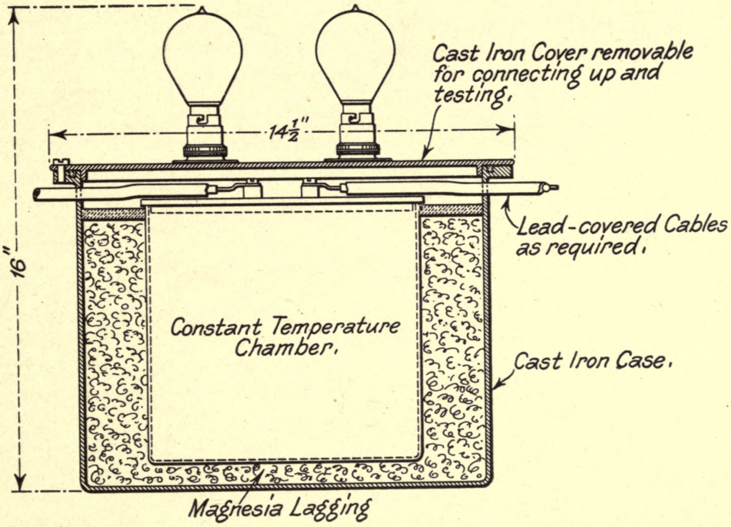


FIG. 202.—COLD JUNCTION THERMOSTAT.

The cold-junction temperature can be controlled by this thermostat to within $\frac{1}{2}$°.

The apparatus is shown in section in fig. 202.

APPENDIX III

TABULAR NUMBERS

THE tabular numbers in the subjoined table are calculated from the formula :—

$$n = \frac{17{\cdot}64(h-a)}{460+t}$$

where h = barometric height in inches.
t = temperature in degrees Fahrenheit.
a = tension of aqueous vapour at 60° F.

This table is applicable to the correction of moist saturated gas only.

The volume at standard conditions (60° F. and 30 inches pressure), corresponding to a volume measured under any other conditions, is obtained by dividing the latter volume by the tabular number corresponding to the conditions in question.

BAR.	THER. 32°	34°	36°	38°	40°	42°	44°	46°	48°	50°	52°	54°	56°
28·0	998	993	988	984	979	974	970	965	960	956	951	946	942
28·1	1002	997	993	988	983	978	973	969	964	959	955	951	945
28·2	1006	1001	996	991	986	981	977	972	967	963	958	953	949
28·3	1009	1004	1000	995	990	985	980	976	971	966	961	957	952
28·4	1012	1007	1002	998	993	988	984	979	974	970	965	960	955
28·5	1016	1011	1006	1001	997	992	987	983	978	973	968	964	959
28·6	1020	1015	1010	1005	1001	995	991	986	981	977	972	967	962
28·7	1023	1018	1013	1009	1004	999	994	990	985	980	975	970	966
28·8	1027	1022	1017	1012	1007	1003	998	993	988	984	979	974	969
28·9	1031	1026	1021	1016	1011	1006	1001	997	992	987	982	977	973
29·0	1034	1029	1024	1019	1014	1010	1005	1000	995	990	986	981	976
29·1	1038	1033	1028	1023	1018	1013	1008	1004	999	994	989	984	979
29·2	1041	1036	1031	1026	1021	1017	1012	1007	1002	997	992	988	982
29·3	1045	1040	1035	1030	1025	1020	1015	1011	1006	1001	996	991	986
29·4	1048	1043	1038	1033	1028	1024	1019	1014	1009	1004	999	995	990
29·5	1052	1046	1041	1036	1032	1027	1022	1018	1013	1008	1003	998	993
29·6	1055	1050	1045	1040	1036	1031	1026	1021	1016	1011	1006	1001	996
29·7	1059	1054	1049	1044	1039	1034	1029	1025	1019	1015	1010	1005	1000
29·8	1063	1058	1053	1048	1043	1038	1033	1028	1023	1018	1013	1008	1003
29·9	1066	1061	1056	1051	1046	1041	1036	1031	1026	1022	1017	1012	1007
30·0	1070	1065	1060	1055	1050	1045	1040	1035	1030	1025	1020	1015	1010
30·1	1073	1068	1063	1058	1053	1048	1043	1038	1033	1029	1024	1019	1014
30·2	1076	1071	1066	1062	1057	1052	1047	1042	1037	1032	1027	1022	1017
30·3	1080	1075	1070	1065	1060	1055	1050	1045	1040	1036	1030	1025	1020
30·4	1084	1079	1074	1069	1064	1059	1054	1049	1044	1039	1034	1029	1024
30·5	1087	1082	1077	1072	1067	1062	1057	1052	1047	1042	1037	1032	1027
30·6	1090	1085	1080	1075	1071	1066	1061	1056	1051	1046	1041	1036	1031
30·7	1094	1089	1084	1079	1074	1069	1064	1059	1054	1049	1044	1039	1034
30·8	1098	1093	1088	1083	1078	1073	1068	1063	1058	1053	1048	1043	1037
30·9	1101	1096	1091	1086	1081	1076	1071	1066	1061	1056	1051	1046	1041
31·0	1105	1100	1095	1090	1085	1080	1075	1070	1065	1060	1055	1049	1044
BAR.	THER. 32°	34°	36°	38°	40°	42°	44°	46°	48°	50°	52°	54°	56°

BAR.	THER. 58°	60°	62°	64°	66°	68°	70°	72°	74°	76°	78°	80°	82°	84°
28·0	937	932	927	922	917	912	907	902	897	892	887	881	875	870
28·1	941	936	930	926	921	916	911	905	900	895	890	884	879	873
28·2	944	939	934	929	924	919	914	909	904	898	893	887	882	876
28·3	947	942	937	932	928	922	917	912	907	902	896	891	885	880
28·4	951	946	941	936	931	926	921	915	910	905	900	894	888	883
28·5	954	949	944	939	934	929	924	919	914	908	903	897	892	886
28·6	958	953	947	943	938	932	927	922	917	912	906	901	895	889
28·7	961	956	951	946	941	936	931	925	920	915	909	904	898	893
28·8	964	959	954	949	944	939	934	929	924	918	913	907	901	896
28·9	968	963	958	953	948	942	937	932	927	921	916	910	905	899
29·0	971	966	961	956	951	946	941	935	930	925	919	914	908	903
29·1	975	969	964	959	954	949	944	939	933	928	923	917	911	906
29·2	978	973	968	963	958	952	947	942	937	931	926	920	914	909
29·3	981	976	971	966	961	956	950	945	940	935	929	923	918	912
29·4	985	980	975	969	964	959	954	949	943	938	932	927	921	915
29·5	988	983	978	973	968	962	957	952	947	941	936	930	924	919
29·6	992	986	981	976	971	966	960	955	950	944	939	933	927	922
29·7	995	990	985	980	974	969	964	959	953	948	942	937	931	925
29·8	998	993	988	983	978	972	967	962	957	951	946	940	934	928
29·9	1002	997	991	986	981	976	970	965	960	954	949	943	937	932
30·0	1005	1000	995	990	985	979	974	968	963	958	952	946	941	935
30·1	1009	1003	998	993	988	983	977	972	966	961	955	950	944	938
30·2	1012	1007	1002	996	991	986	980	975	970	964	959	953	947	941
30·3	1015	1010	1005	1000	995	989	984	978	973	968	962	956	950	945
30·4	1019	1014	1008	1003	998	993	987	982	976	971	965	959	954	948
30·5	1022	1017	1012	1006	1001	996	990	985	980	974	969	963	957	951
30·6	1026	1020	1015	1010	1005	999	994	988	983	977	972	966	960	954
30·7	1029	1024	1018	1013	1008	1003	997	992	986	981	975	969	963	957
30·8	1032	1027	1022	1017	1011	1006	1000	995	990	984	978	972	967	961
30·9	1036	1031	1025	1020	1015	1009	1004	998	993	987	982	976	970	964
31·0	1039	1034	1029	1023	1018	1013	1007	1002	996	991	985	979	973	967
BAR.	THER. 58°	60°	62°	64°	66°	68°	70°	72°	74°	76°	78°	80°	82°	84°

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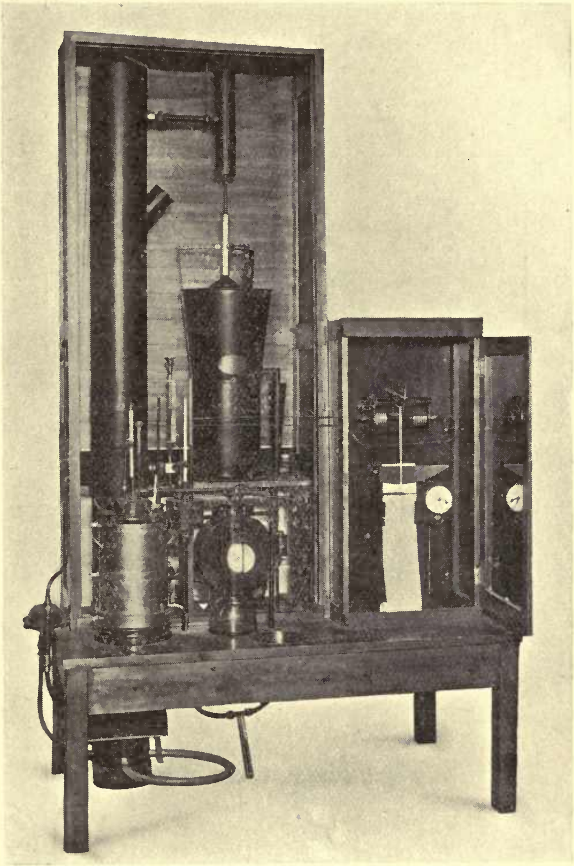

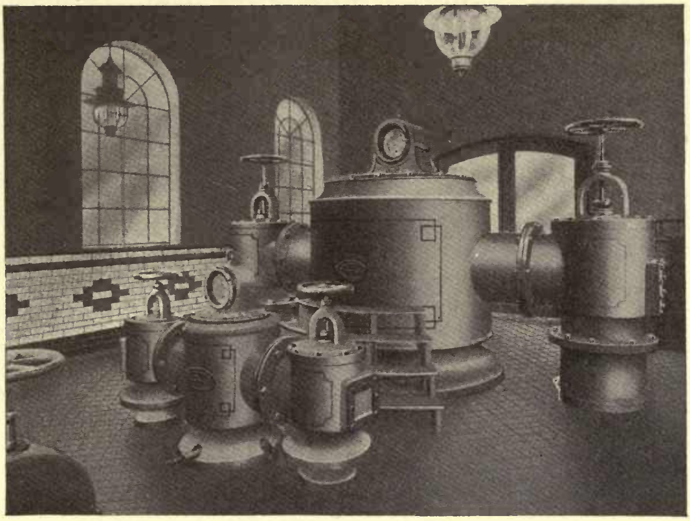

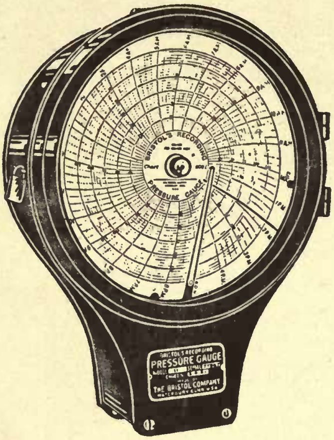
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