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THE WEIGHING AND MEASURING OF CHEMICAL SUBSTANCES

BY

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AND

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WITH 26 ILLUSTRATIONS

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CONTENTS

INTRODUCTION

THE subjects dealt with in this book will be limited to the weighing and measuring methods suitable for use in the chemical works. We shall entirely omit any reference to the finer forms of weighing and measuring instruments such as are employed in the laboratory. Furthermore, we shall concern ourselves with the instruments and methods, and leave the choice of system, metric or otherwise, to the user.

As far as is possible we have endeavoured to confine our attention to the general mechanical principles and theoretical considerations which apply to the various types of instruments described. In nearly all cases there are many makers of each kind of apparatus. Details as to size, etc., can be obtained by consulting their trade catalogues.

Materials naturally fall into the three classes: Gases, Liquids, and Solids. Gases will not be dealt with here, but will receive separate and special attention in another number of this series.

Both solids and liquids can be dealt with either by weight or volume, although in the case of solids measurement by volume tends to be inaccurate, particularly where the material is of uneven size.

Methods of weighing can be divided into:

1. Those involving the use of the ordinary beam scale, spring balance, the more generally useful platform balance, and weighbridge for large quantities.
2. Automatic methods with either intermittent or continuous delivery; if necessary with recording devices.

Similarly the measuring devices can be divided into:

1. Those of simple nature involving the use of portable measures for small quantities and tanks of known capacity for larger amounts.
2. Automatic measuring methods closely analogous to those of weighing.
3. Methods depending on the laws of hydraulic flow, and flow measurement generally.

Recording devices can in general be attached to instruments of the second and third class. Class three is of the greatest importance where large quantities of liquid have to be measured.

In the case of solids weighing is the only method of real importance where any degree of accuracy is required. Approximations may, however, be obtained from measurements of volume where the material is homogeneous or of an even granular nature. Rough estimates can be made in the same way of large quantities of crude material and fuel.

It is not intended to elaborate simple methods of weighing and measuring such as involve the use of ordinary beam scales and measures of fixed capacity.

In dealing with large quantities of material the situation of the apparatus for weighing or measuring should be carefully thought out, as much time and labour can be saved by an adequate arrangement consistent with suitable protection of the more or less delicate apparatus employed. With solids such methods as belt conveyers will help to simplify this problem. Liquids are much more easily dealt with by means of pipe lines, suitable pumps, acid eggs and the like.

With regard to these problems of conveyance of material no definite laws can be laid down ; each case must be considered on its merits, so that the most convenient system can be adopted. In any case the matter is foreign to the subject of this book.

At the risk of seeming to point out the obvious, we would emphasize the necessity not only of weighing out the components of a charge, but also of keeping a strict watch and check on all quantities of material from the time they enter the works until their final dispatch. Such records are absolutely necessary to determine the charges with which any particular process is to be saddled, and furthermore they help to point out those stages in a process where wastage takes place and which are most likely to repay further research.

We would also point out the advisability of keeping such records in a way which will be intelligible to costing clerks and accountants who may be quite unfamiliar with the details of the processes to which these records apply.

For information concerning the arrangement of such cost records the reader should consult one of the special works on this subject.

From the chemist's point of view a convenient method, where possible, is to work in molecular proportions, i.e. the weights of the reacting substances are taken as so many kilogramme molecules or cwt. molecules.

The writers wish to thank Mr. E. A. Griffiths for his permission to describe and reproduce a diagram of his electrical depth-measuring appliance and also for permission to copy the diagram of the recording specific gravity apparatus from his book on *Engineering Instruments and Meters*.

THE WEIGHING AND MEASURING OF CHEMICAL SUBSTANCES

I

THE WEIGHING AND MEASURING OF LIQUIDS: INTERMITTENT METHODS

By reason of their mobility, liquids offer greater facility and variety of means of handling than do solids; moreover, liquids offer the alternative methods of weighing and measuring with almost equal accuracy.

The simplest problem in dealing with liquids is to ascertain the volume or weight of the contents of any vessel. Where the vessel can be handled this presents no difficulty and requires no explanation, but where the quantity is too large for this, several other methods are available. The depth may be measured by means of a dip rod and the volume or weight calculated from the measurements of the tank. With rectangular tanks of uniform cross section this is quite simple. Surface area of liquid × depth = volume. The same applies to vertical cylinders, the area being given by the formula $\frac{\pi d^2}{4}$. Horizontal cylinders are not so simple.

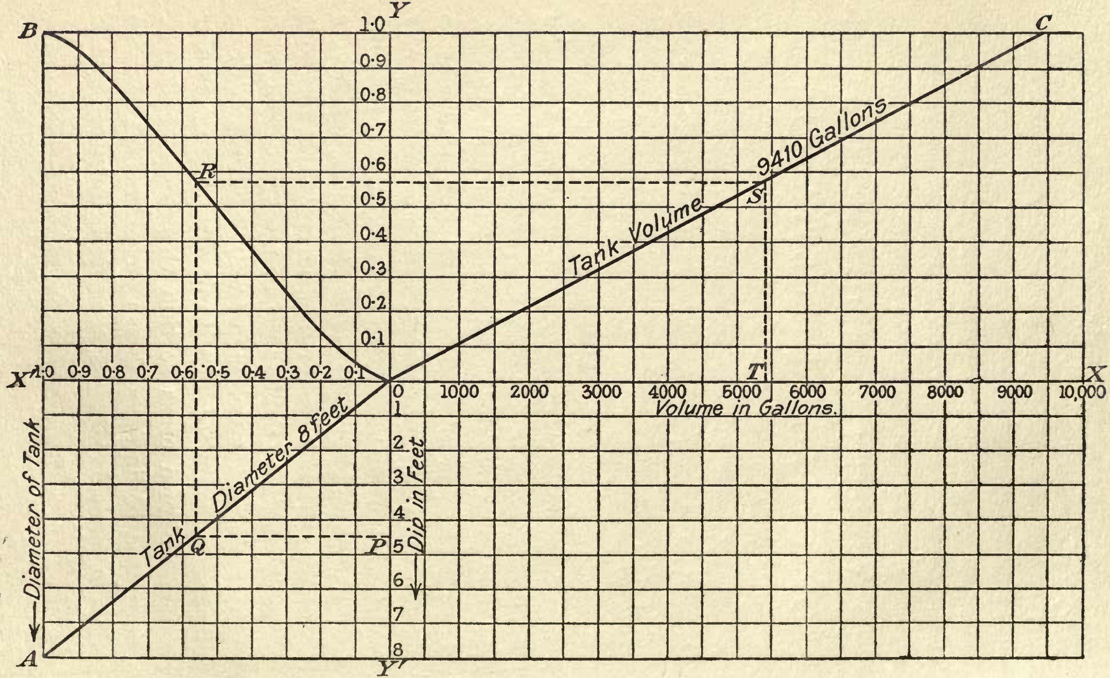


FIG. 1.—Polar diagram for obtaining volume of liquid in horizontal cylindrical tanks.

We give a polar diagram reduced in size showing relation between dip and volume.

In order to explain the use of this diagram, consider the case of a Lancashire boiler from which the flues have been removed, such as is commonly used as a storage tank: Diameter 8 ft., length 30 ft., giving a total capacity $\frac{\pi d^2}{4} \times 30$, equalling 1,508 cu. ft. or 9,410 gallons. Suppose the depth of liquid in the boiler, as measured by dip, to be 4 ft. 6 in. The lines OY′ and X′A proceeding vertically downwards from the axis of X are divided into feet and inches according to some convenient scale. The horizontal lines YC and OX proceeding at right angles to the axis of Y are divided into gallons (or any other capacity measurement desired). The diameter of the vessel is first marked off along X′A, in this case 8′, and joined by a straight line to the origin O. The total capacity is marked off along YC, in this case 9,410 gallons, and joined by the straight line to O. The diagram is now complete for the conversion of any dip reading to volume for this particular vessel. Taking our dip reading P of 4 ft. 6 in. on OY′, we proceed horizontally as shown by the dotted line until we meet OA in Q. From Q we proceed vertically, cutting the curve OB in R, then again horizontally to meet OC in S, and from S vertically downwards to T, which gives the volume sought, in this particular case 5,453 gallons.

Where there are a number of vessels of different dimensions separate diameter and capacity lines may

TABLE 1

Volume of Liquid in Horizontal Cylindrical Tanks

A	B	A	B	A	B	A	B	A	B
0·01	·00169	0·21	·1527	0·41	·3860	0·61	·6389	0·81	·8677
·02	·00477	·22	·1631	·42	·3985	·62	·6513	·82	·8847
·03	·00875	·23	·1738	·43	·4111	·63	·6637	·83	·8873
·04	·01343	·24	·1857	·44	·4236	·64	·6759	·84	·8967
·05	·01869	·25	·1954	·45	·4364	·65	·6880	·85	·9059
·06	·02450	·26	·2066	·46	·4490	·66	·7002	·86	·9149
·07	·03077	·27	·2178	·47	·4617	·67	·7123	·87	·9236
·08	·03748	·28	·2292	·48	·4744	·68	·7241	·88	·9320
·09	·04458	·29	·2407	·49	·4873	·69	·7359	·89	·9401
·10	·05206	·30	·2523	·50	·5000	·70	·7477	·90	·9479
·11	·05985	·31	·2641	·51	·5127	·71	·7593	·91	·9554
·12	·06797	·32	·2759	·52	·5256	·72	·7708	·92	·9625
·13	·07640	·33	·2877	·53	·5383	·73	·7822	·93	·9692
·14	·08509	·34	·2998	·54	·5510	·74	·7934	·94	·9755
·15	·09408	·35	·3120	·55	·5636	·75	·8046	·95	·9813
·16	·1033	·36	·3241	·56	·5764	·76	·8143	·96	·9866
·17	·1127	·37	·3363	·57	·5889	·77	·8262	·97	·9912
·18	·1253	·38	·3487	·58	·6015	·78	·8369	·98	·9952
·19	·1323	·39	·3611	·59	·6140	·79	·8473	·99	·9983
·20	·1423	·40	·3735	·60	·6265	·80	·8577	1·00	1·0000

be drawn on the same diagram, and if desired distinguished by various colours.

The fundamental curve OB may be plotted from the figures given in Table I, p. 14: column A being the abscissæ and column B the ordinates.

In the case of dish-ended tanks formulæ for calculating the volume have been put forward at various times; but these are all laborious in their application. The best method in such cases is to calibrate by means of a smaller fixed measure.

There are various methods of obtaining a measure of the depth of liquid. A glass tube gauge may be fitted to the side of the vessel and a scale graduated to read off the amount of liquid present. Such glass gauges are, of course, fragile and are generally fitted with a hinged metal shield which may render observation difficult. The tube soon gets dirty, or may become blocked, and in any case a cock should be fitted at the bottom to facilitate removal of the tube and to provide a shut off in case of accident. There is obviously a limit to the height of the vessel which can be fitted with such a gauge.

A cruder method consists in having a float in the vessel and a counterbalance outside, connected by means of a chain or cord working over a pulley on the edge of the tank. A pointer on the counterbalance indicates the volume on a divided scale.

The pneumatic depth gauge, of which there are several kinds under as many trade names, affords a convenient means of measuring the depth of liquid in any tank, and one which can be used where the tank is inaccessible or the depth too great to be taken easily by means of a dip rod.

This instrument consists of a hand-worked air pump which forces air down a pipe reaching to the bottom of the tank and terminating in an air bell. A pressure gauge is supplied so that the *minimum* pressure necessary to force air out of the bottom of the pipe can be measured. This pressure will be a function of the depth of liquid and its specific gravity. It follows that to convert this figure to volume or weight we must know the dimensions of the vessel just as in the methods previously mentioned. In other words, this kind of gauge is only a dip rod of convenient form and gives no further information than that more simple piece of apparatus. The advantage consists in the greater convenience of its use, and also in that the pump and gauge may be situated, if necessary, at a considerable

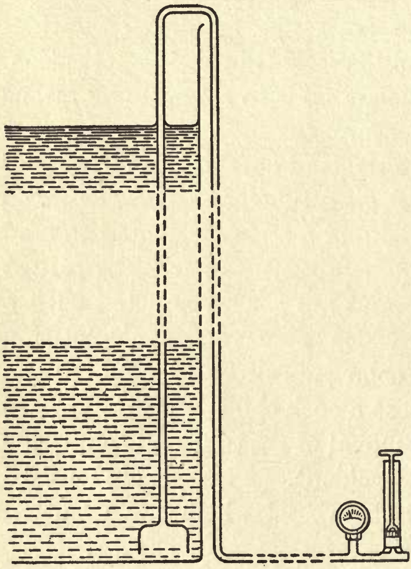


Fig. 2.

distance from the tank. In general, when the same gauge is used for different vessels and liquids, the pressure is read in lbs. per sq. in. and a conversion chart made for each vessel. But if the gauge is to be used solely for one size of vessel and one particular liquid, it may be graduated to read directly in volume or weight instead of pressure. These instruments are also graduated to read in feet of water, in which case specific gravity must be taken into account when measuring any liquid other than water.

The following factors for tanks of uniform cross section may be of use to the reader:

In these factors P = observed air pressure in lbs. per sq. inch.
ρ = density of liquid.
S = sectional area of tank in sq. feet.

Depth of liquid in feet $= \frac{7P}{3\rho}$ or more accurately $\frac{2{\cdot}31P}{\rho}$

Volume of liquid in galls. $= \frac{14{\cdot}4PS}{\rho}$

Weight of liquid in lbs. = 144PS.

The pneumatic depth gauge is quite serviceable for purposes of stock-taking where the contents of large storage tanks have to be measured, but the writers consider that where relatively small differences in depth have to be measured, as in gauging the amount of liquid for certain process work, it may fail in accuracy, for it is important to remember that a difference in pressure of 1 lb. per sq. in. corresponds to a difference in depth of 2 ft. 3 in. of water, so that a relatively small error in pressure corresponds to a large error in depth; or if a mercury gauge is used then 1 in. of mercury is

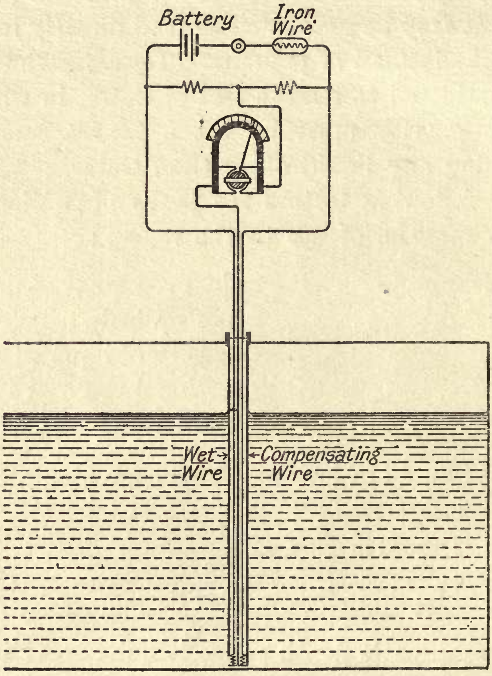


Fig. 3.

equal to a depth of 13·6 in. of water: a reduction in measurement which mitigates against accuracy.

The requirements of modern aircraft have produced a very ingenious form of depth gauge, designed and patented by Mr. E. A. Griffiths, and which would appear to have a future in the chemical works.

This instrument was originally designed to measure the depth of petrol in aircraft tanks. The principle depends on the variation of electrical conductivity of a thin wire with variations of temperature.

A thin platinum or other metal wire is electrically heated to a temperature of about 20° C. above the surrounding air. The wire is insulated and suitably protected by a tube projecting to the full depth of the tank. The portion of the wire immersed in the liquid is cooled to practically the same temperature as the liquid, while the part above is at a temperature about 20° C. higher. Since the resistance of metals such as platinum, cobalt and nickel increases with rise of temperature, it follows that the average temperature of the wire, and consequently its resistance, will be proportional to the immersion depth. The influence of changes of temperature of the liquid and the atmosphere is completely eliminated by arranging alongside a similar wire totally sealed off from the liquid. These two wires constitute arms of a Wheatstone bridge. The changes of resistance of the partially immersed wire with the variations of height of the liquid are indicated on a galvanometer. Since the sensitiveness of any bridge arrangement is a function of the current, it is necessary to keep this constant. The customary procedure is to have an adjustable series resistance in the battery circuit and by a throw-over switch employ the same indicator as an ammeter when it is necessary to adjust the current. In the apparatus under discussion advantage is taken of the constant low voltage obtainable by interposing an iron wire resistance.

We have so far dealt merely with the measurement of liquids for stock. When it is required to measure repeatedly one definite quantity of liquid, as occurs in nearly all process work, there are a number of devices from which to choose so that the operation may be rendered at the same time simple and accurate. The liquid may be pumped into a vessel above the apparatus until it reaches a definite level, which may be indicated by any of the ordinary gauge methods, or where the tank is inaccessible by a float making electrical contact at a given height, and ringing a bell or lighting a lamp.

If greater accuracy is required a tank is constructed with a V-notched division, the bottom of the V being some little distance below the top of the tank. This partition divides it into two equal portions, the capacity of each being equal to the required amount for the batch. Each half of the tank is provided with an inlet from storage tank and an outflow. The two outflow pipes are each fitted with a cock and unite in a single discharge.

Fig. 4 gives a diagrammatic representation of the arrangement. Compartment A is first filled to overflowing, the surplus liquid running into B. A is then used for the charge, and the next quantity measured in B, surplus running into A, and so on. This obviates the necessity of watching the liquid until it reaches a given mark and prevents the admission of an excessive quantity to the charge.

The great advantage of this arrangement is that it does away with the necessity of pumping up a definite volume of liquid—an operation which is difficult to accomplish accurately with a pump or air-lift.

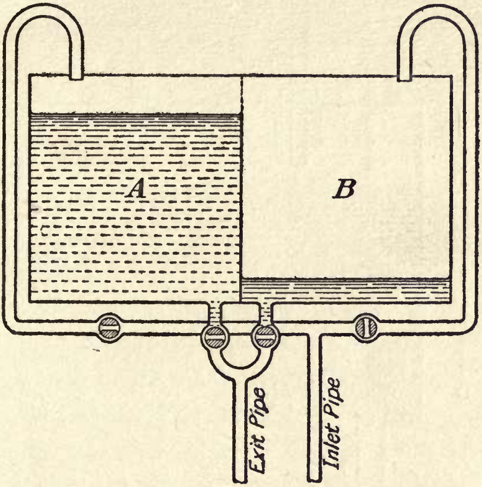


Fig. 4.

Other simple methods involve the use of acid eggs, which hold just sufficient material for one charge, and are filled completely and blown out each time.

In those cases where a fuming liquid, or one in which air contact must be reduced to a minimum, is to be accurately apportioned, the arrangement illustrated in Fig. 5 will be found of use.

A tank capable of holding the complete charge and forming one side of a balance is fitted with liquid-sealed inlet, air vent and outlet pipes. The air vent is led to the outside of the building or to an absorption chamber. The outlet pipe communicates with the reaction vessel or to a pipe leading to it. The charge

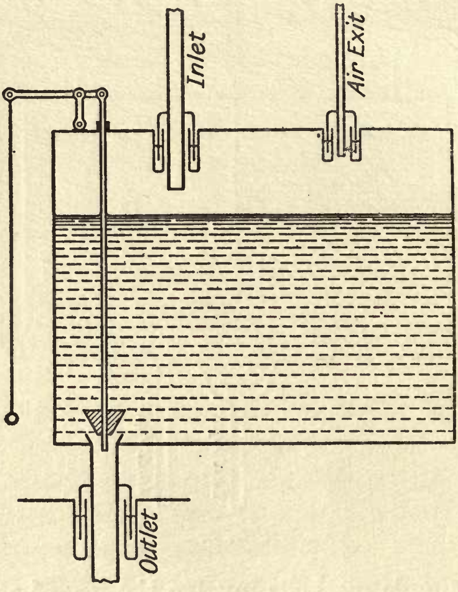


FIG. 5.

can thus be weighed accurately without danger to the workmen.

We now come to a class of instruments in which the measurement of the fluid involves the alternate filling of two buckets which are fixed together: the action depending on the weight of liquid, which at a certain moment is sufficient to overbalance the system, emptying the one bucket and bringing the other beneath the inlet. In order to make this clear we have selected a simple example of the many instruments of this type.

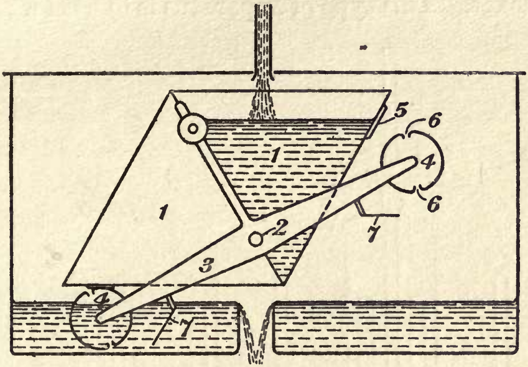


FIG. 6.

The divided bucket 1 is mounted so as to turn on a shaft 2. From the diagram it will be seen that when a bucket has received sufficient liquid from the inflow, which is continuous, it overbalances, empties itself and brings the other bucket in position to be filled. One of the problems in this kind of apparatus is to get the buckets to overbalance suddenly and so quickly transfer the supply to the empty bucket, and then break the fall so that the apparatus is not injured. In the type illustrated this is accomplished by means of the arm 3 which moves independently of the bucket and carries the hollow chambers 4 at each end. When the bucket tips, a buffer 5 strikes the chamber 4 and forces it under the surface of the liquid, the other chamber being at the same time raised out of the liquid. The depressed chamber then fills with liquid through openings 6 and the other chamber empties. Vanes 7 are fitted to the arm 3 to assist in cushioning the fall of the bucket. This type of apparatus is in use for adding

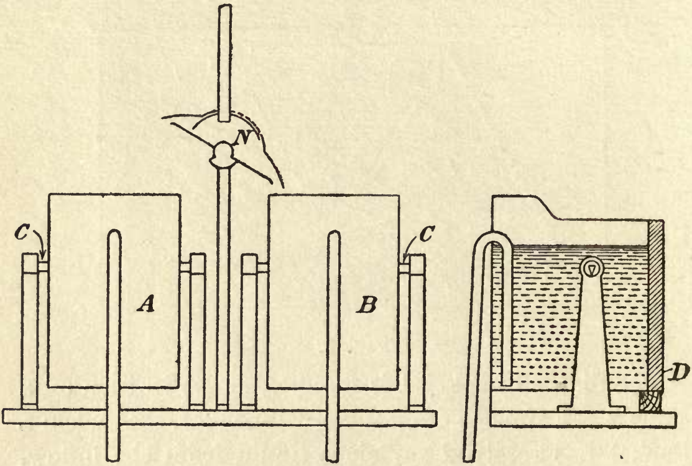


FIG. 7.

water-softening preparations to a constantly running supply of water. It can be used in any case where a small quantity of one liquid is to be added regularly to a large quantity of another which flows through the large tank.

The Leinert liquid balance offers considerable advantages over this type. Larger quantities of liquid can be handled by it as the movement of the bucket is more restricted so that there is less wear and tear in the working of the apparatus. It is of simple construction. In Fig. 7 the two vessels A and B are mounted on knife edges C arranged on axes which do not pass through the centres of gravity of the loaded vessels. They are arranged to tip alternately and to be emptied by a siphon, as shown in the end elevation. The tilting trough N, the motion of which is limited, is adapted to fill the vessels A and B alternately, and is situated in the rear of the apparatus. As one of the vessels, say B, tips, the rear portion of the vessel coming up reverses the trough N, diverting its flow to vessel A. There is no fixed connection between the trough and either A or B, nor does it rest on the tank during the time of filling. When B tips, the flow of liquid is started in the siphon and after a certain amount of liquid has been withdrawn from the vessel the weighted end D restores it to the horizontal, the siphon continues and empties it completely. The recording or counting mechanism is connected to the trough N.

There is a very efficient class of liquid weighing apparatus in which the supply of liquid is controlled by the make and break of an electric circuit. As an example of this class we shall describe a machine made by the Sturtevant Engineering Co. for weighing charges of acid for use in a superphosphate manufacturing plant. The apparatus is simple in construction. An ordinary platform balance has a tank fixed to the platform to receive the acid. Above the tank, but not attached to it in any way, is a stand pipe fitted with a plug valve at its lower end. Just above the plug valve is a T joint and a pipe leading to the acid storage tank. The stand pipe is carried up to a height above the storage tank and a rod connected to the plug of the valve runs through the pipe, coming out at the top and terminating in a soft iron block. Above the block is an electro-magnet. The tank has a plug-valve outlet, and both the tank and pipes are constructed of acid-resisting material. The electro-magnet is operated from a circuit completed by two rods attached to the end of the steelyard and dipping into mercury pots when the steelyard is down. Starting with the tank empty, the hand lever of the balance is pulled down and the circuit completed, the electro magnet attracts the iron block and lifts the plug valve, allowing the acid to run into the tank. As soon as the predetermined weight is obtained the steelyard rises and breaks the circuit. The plug valve then falls by its own weight and cuts off the supply of acid. The hand lever of the balance is released and the acid run out of the tank. As soon as the tank is empty and its exit valve closed, the apparatus is ready for a fresh cycle. They are constructed to weigh up to 10 cwt., but there is no reason why larger machines could not be built if desired.

Other makes of this type are more complicated. In the smaller kinds the valve is controlled in both directions by electro-magnets. These smaller instruments weigh in pounds and ounces and form a very efficient machine for the packing department.

We may here describe a piece of apparatus known as the Rabe measuring cock, which is of use only for controlling the flow of liquid from a constant level cistern, as any variation in head will give different rates of flow for the same reading. Such a constant level cistern is easily arranged by having an inflow pipe

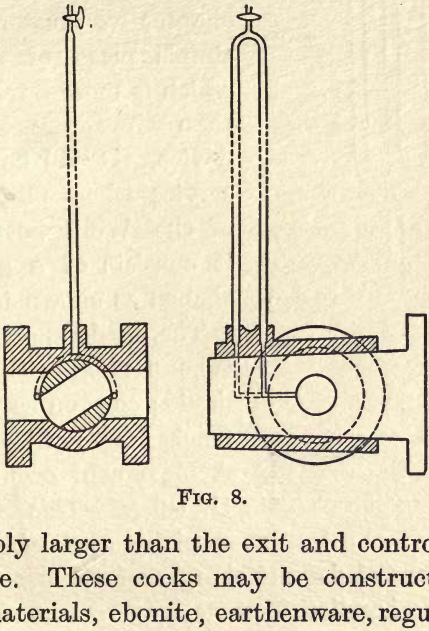


Fig. 8.

considerably larger than the exit and controlled by a float valve. These cocks may be constructed of all sorts of materials, ebonite, earthenware, regulus metal, etc.

The plug of the cock, Fig. 8, is provided with a pointer moving over a scale (not shown in the diagram) and a glass manometer connecting to opposite sides of the plug so that the difference in pressure may be determined. It can be seen that this cock is of quite limited application, but it provides a method of controlling flow with constant head, and by means of the indicator the cock can be opened to the exact point for a particular flow.

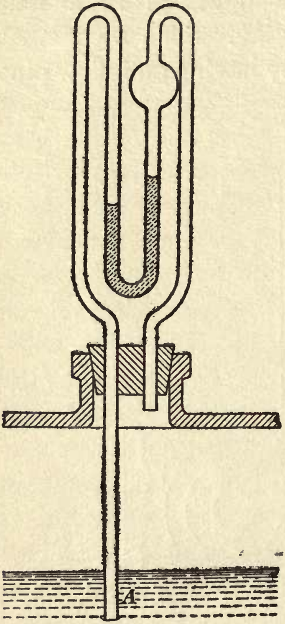


Fig. 9.

Before concluding this chapter we must mention a simple piece of apparatus which is more an indicating than an actual measuring device. It will be found of service when filling vessels of the Wolff bottle type; it consists of a glass tube shaped as shown in Fig. 9.

The shaded portion of the tube is filled with coloured liquid; as soon as the liquid reaches the level of the end A movement occurs in the U tube. This device is specially applicable to the measurement of definite charges of those acids which have to be handled in stoneware vessels, as it avoids the use of a level indicator or gauge which would require a bottom connection to the stoneware measuring vessel.

II

MEASURING OF LIQUIDS: CONTINUOUS METHODS

In the previous chapter we have described methods which belong to classes 1 and 2 of the division adopted in our introduction.

We shall now pass on to the description of the numerous automatic and recording methods which offer such ready means of measuring the volume of large quantities of liquid without the necessity of interrupting the even flow of the liquid.

The various types of liquid-flow meters may be classified as follows:

(1) The displacement meter, of which the Worthington piston meter is a typical example.

(2) Continuous-flow type, embracing turbine meters and the non-mechanical Venturi, weir, and V-notch meters.

The Worthington piston meter is similar in construction and action to the ordinary double acting pump of that name. The strokes of the plunger are recorded by a counter.

A meter constructed on quite a different principle and adapted for small flow is the nutating piston meter, which consists of a vulcanite disc mounted on a ball working in sockets at top and bottom of the chamber as in Fig. 10. The disc just touches the sides of the chamber all round and has a radial slot. A partition, fixed to the side of the chamber and extending to the ball, fits in the slot, preventing short-circuiting of the water, but leaving the disc free to tilt. Water enters at a point close to one side of this partition, and as the exit is near the other side of the partition the water has to force its way round the chamber. In doing so it tilts the disc, so that flow is diverted to the opposite side of the disc. This second quantity of water, in finding its way round, again tilts the disc, forcing out the first quantity; and so the tilting is repeated, the effect being to give a circular motion to the spindle projecting from the top of the ball, although the disc itself does not rotate. The spindle operates a counter. The correct functioning of this meter depends on the accurate fit of the disc and ball in the casing, so that liquids containing solids in suspension cannot be used owing to the abrasion which would be caused.

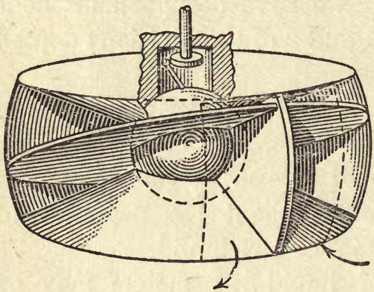


FIG. 10.

Turbine meters, except for the measurement of a steady flow of water, are hardly adapted for chemical work. Their internal construction is delicate, and, like the nutating and reciprocating piston meters above mentioned, they cannot be used where there is danger of abrasion or corrosion. Moreover, when the flow is a small fraction of the capacity of the meter the leakage error may assume serious proportions.

In view of the limitations of the foregoing we are, when measuring chemical liquids, almost restricted to those instruments which contain no moving parts, such as Venturi meters, V-notch and weir recorders. When the liquid is under pressure and when appreciable

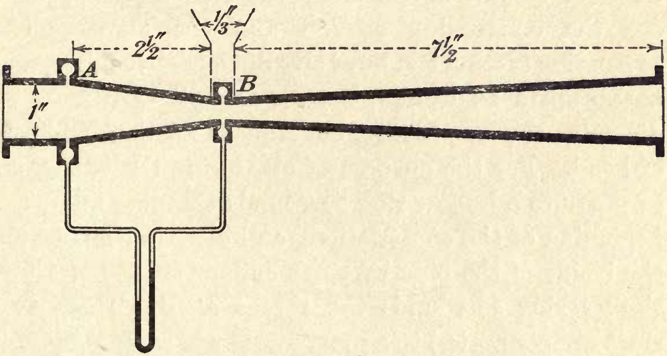


FIG. 11.

loss of head is not permissible, the V-notch and weir recorders are unsuitable, and we are restricted to the Venturi tube meter, although the open types are less expensive to install.

The principle upon which the Venturi meter is constructed depends upon the variations in pressure which are observed when a stream of fluid flows through a *horizontal* pipe of varying section.

The diagram, Fig. 11, shows the arrangement of the tubes, which consist of three main portions: (1) a converging cone, in length $2\frac{1}{2}$ times the diameter of the main pipe, reducing the diameter to about $\frac{1}{2}$ or $\frac{1}{3}$ (usually $\frac{1}{3}$); (2) a short throat, and (3) an expanding cone restoring the pipe to its original diameter. The latter cone is in length equal to $7\frac{1}{2}$ times the diameter of the main pipe. This proportion is quite arbitrary, but the ratio given is found to cause the minimum loss of head. So far as actual measurement of volume is concerned the only essential parts are the converging section and the throat. The expanding section can be of any dimensions and expand as abruptly as desired, but too abrupt an increase in diameter causes eddying, consequent friction, and loss of head. For the purpose of measuring the variations in pressure a hollow ring surrounds the pipe at A, the beginning of the constriction, and communicates with the inside of the pipe by three or four small holes. A similar ring surrounds the throat at B. These two rings are connected to a manometer as shown diagrammatically. The reduction in pressure at B is a measure of the volume of liquid passing through the pipe. It is, of course, understood that the pipe is running full of liquid throughout its length.

As the same quantity of fluid flows through the sections A and B its velocity must be inversely proportional to the sectional area at these points. Therefore the kinetic energy must be greater at B than at A, which gain is obtained at the expense of pressure energy.

Hence the apparent anomaly of a reduced pressure at B.

Neglecting the slight friction at the interior surface of the pipe and also the internal friction of the liquid due to its viscosity, the total energy at any time is constant, and, therefore, what is gained in kinetic must be lost in pressure energy. Considering this mathematically:

H = pressure head in lbs. per sq. in. at A.
V = velocity at A in feet per sec.
h = pressure head at B in lbs. per sq. in.
g = acceleration due to gravity.

Liquid moving with a velocity V has a kinetic energy equal to $\frac{1}{2}MV^2$, where M = mass. Now we can calculate the equivalent head which would be necessary to give this velocity by equating potential energy Mgx to kinetic energy, which gives $x = \frac{V^2}{2g}$.

Thus the total equivalent head at A $= H + \frac{V^2}{2g}$.

Now at B if the diameter is $\frac{1}{3}$ of that at A its area will be $\frac{1}{9}$, and as the same quantity of liquid passes both points, the velocity at B must be 9V. In the same way as at A we find that the equivalent head of liquid moving with a velocity 9V is $\frac{(9V)^2}{2g}$.

Thus the total equivalent head at B equals $h + \frac{81V^2}{2g}$.

Now according to Bernoulli's theorem the total energy at any point in the tube is constant, and since the tube is horizontal the potential energy is the same at A and B. Therefore we can equate the sum of pressure and kinetic energies as represented by their total equivalent heads.

Thus $$H + \frac{V^2}{2g} = h + \frac{81V^2}{2g}$$

$$\therefore V^2 = \frac{2g(H - h)}{80}$$

i.e. difference of pressure is proportional to square of velocity. Owing to viscosity the actual velocity is less than the theoretical, but with suitable liquids and big pipes we can get V equal to 99·5 per cent. of the theoretical. The usual factor is, however, 0·96 to 0·99.

There are various methods of using this difference in pressure to obtain a direct indication of the volume of fluid passing through the pipe, the simplest being an ordinary U tube filled with mercury and graduated to read directly in volume. We show in Fig. 12 a modification of the ordinary U tube which magnifies the

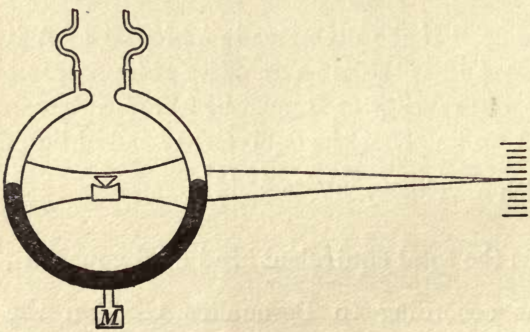


FIG. 12.

movement. It consists of a tube shaped as shown, the ends being connected through flexible pipes with the Venturi meter. The circular tube is partially filled with mercury, and the whole system rests on knife edges. Any difference in pressure will force the mercury round the tube, disturbing the balance which

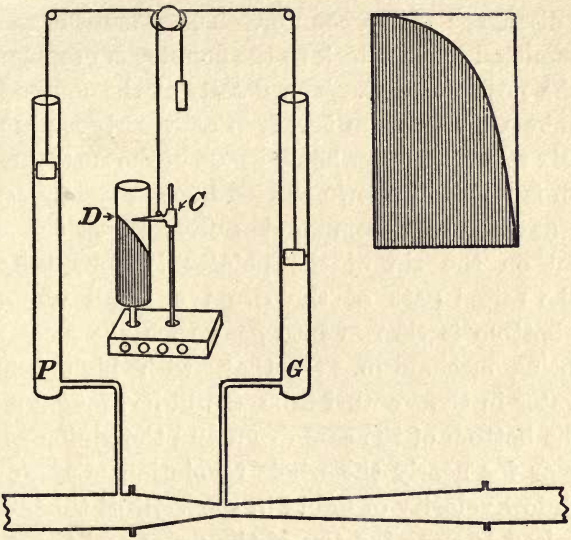


FIG. 13.

is restored by the movement of the counter weight M. The movement of the tube is indicated by a pointer against a scale.

The flexible connections are in actual practice done away with and pressure is admitted through glands and tubes in the knife edges.

A still more elaborate system is arranged to give a permanent record of the quantity passed, Fig. 13. The two floats, which work in tubes P and G connected to the pressure indicating tubes of the Venturi meter, communicate their difference in level through a differential gear to a pointer C, which, through the interposition of the drum D, causes a clock to engage and disengage with a counter. The amount of motion transmitted by the clock to the counter is proportional to the position of C. The details of the method are ingenious. The drum is driven at a fairly rapid rate, say six revolutions per hour. Part of the surface of the drum is raised as shown shaded in the diagram and in the flat figure accompanying it. When the small wheel on the tip of the pointer is forced up on to the raised part of the drum a small pinion at the bottom is thrown into gear with the clock and counting mechanism. So that, with high velocity of water in the Venturi tube, C will be brought nearly to the bottom of the cam drum and the pinion will be in gear for nearly the whole revolution of the drum. With low velocity of liquid in the Venturi tube, C will be raised to near the top of the drum and the pinion will be out of gear for most of the time. By making the curve of the raised surface on the drum parabolic the counter records actual volume of liquid because difference in level is proportional to Q^2. This apparatus is only suitable for low pressures as the tube P must be long enough to take the whole head of liquid.

The high-pressure recording Venturi meter is simply a modification of the U tube first described. It does not involve the use of differential gear. On the top of each mercury column iron floats of equal weight connect through stuffing boxes to a rack and pinion recording device. Integration of the chart gives total volume.

In the chemical works the Venturi meter has not received the recognition it deserves. There is considerable scope for this type of meter as it is of simple construction, has no moving parts, and can be constructed of any suitable metal to resist acid, etc., and if a recorder is used with it there is no necessity for the corrosive liquid passing through the pipe to come in contact even with the floats or recording apparatus, as mercury, oil or other inactive liquid can be interposed.

A special type of Venturi tube has been constructed by Messrs. Geo. Kent, which acts as an injector and automatically introduces the correct proportion of the fluid in a water-softening apparatus. This device has obviously other applications in chemical plant where relatively small quantities of one liquid have to be added in definite proportion to a large bulk of another.

The Venturi meter can be constructed for almost all volumes. For purposes of measuring large volumes of water it furnishes the most accurate method. They have been fitted to water mains up to 35 ft. in diameter, and there seems to be no reason why larger ones should not be made up to the maximum possible size of pipe. Such meters are capable of measuring many million gallons of water per hour. On the other hand, they can be made for pipes of as small as 4 in. diameter and for flows as low as 0·2 ft. per sec. In these cases the volume delivered can be estimated with reasonable accuracy from the theoretical formulæ just given. Smaller sizes still are made, but these do not comply with the theoretical formulæ. They give, however, an accurate measurement if specially calibrated by actual test, which is not difficult.

For liquids in open channels there is a similar device to the Venturi tube, namely the Venturi flume. It consists fundamentally of a narrowed channel similar in form to the longitudinal section of a Venturi pipe. The quantity of water flowing along the channel is calculated from estimates of the surface height at two points: one up stream and the other in the constructed throat. The gauges are fixed in small wells just off the main channel. The difference between the two heights gives the fall in pressure energy which has largely been changed into velocity energy.

From the head at the throat is calculated the cross section of the stream at that point. The velocity through the throat is a function of the fall in level between the two points measured. The volume passed is the product of sectional area and velocity at that section. This method finds useful application in measuring the volume of streams and effluents into which waste liquids are discharged.

The Venturi flume is capable of working over wider variations in the amount of flow than the tube, and with a much smaller loss of head than occurs with the weir type of recorder, which we will next proceed to describe.

In the weir type of meter the determination of volume is effected by measuring the height of liquid above a horizontal weir over which it is discharged. The volume of liquid passed is a function of the height measured. The general arrangement of the weir recorder is similar to that of the V-notch, which we illustrate in Fig. 16.

Several workers have put forward formulæ connecting the two factors, volume and height above weir, one of the earliest and best being that of Chezy.

Chezy gave the following formula :

$$V = C\sqrt{MI}$$

M = hydraulic mean depth of water above the weir.

I = hydraulic gradient.

C = a constant.

This formula has been modified at various times by subsequent workers ; but owing to the variation in the factors involved, and the difficulty in defining exact values for M and I, it is not of great value. Consequently, in practice, instruments of the weir type are always calibrated from known rates of flow. The weir is fitted to one side of a square tank and the level of the liquid ascertained by means of a float sufficiently far from the weir not to be affected by the fall which occurs near the weir.

In order to make the apparatus self-recording it is only necessary to have some device which will convert the varying height of the liquid above the weir into volume discharged.

This is accomplished in a number of ways, the results being given as a line indicating volume on a chart held by a clockwork cylinder or disc.

In the case of records from a cylindrical chart the height of the line above the base represents the flow at any instant, and the total volume delivered in any period is given by the area included between the curve, the base line and the time verticals selected.

In the case of the disc records, the area marked out is not proportional to the volume delivered. A special integrating device, or, more accurately, radial averager, is used as shown in Fig. 14.

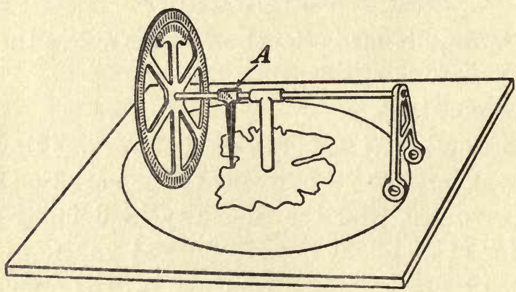


FIG. 14.

A graduated wheel is fitted with a vernier and rotates at the end of an axis free to slide horizontally through an upright post. The post corresponds with the centre of the disc chart, and a pointer A, situated between the wheel and the post, is made to follow the line of the chart. The triangular device at the end of the horizontal axis is merely a convenient arrangement for holding between finger and thumb to guide the pointer. The average radius is read from the rotation of the graduated wheel.

The mechanical arrangement for recording in the case of the Lea weir recorder is worthy of note and is shown in the diagram, Fig. 15.

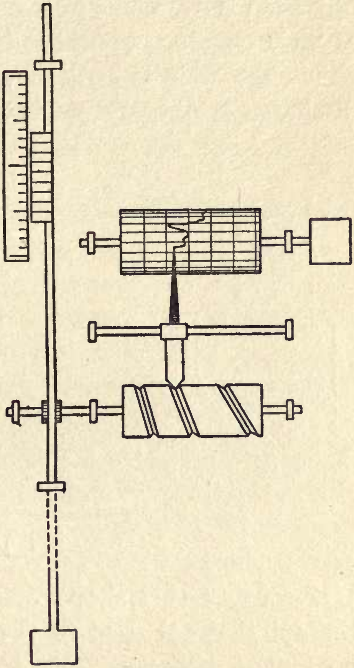


Fig. 15.

It consists of a float, operating a spirally-grooved drum, the expanded form of the spiral being the curve obtained by plotting height of liquid above weir against corresponding volume of flow. The rotation of this drum gives a lateral motion to a pen which records on the cylinder.

It will be noticed that the spiral has to be specially calculated. This is owing to the fact that the volume of discharge is proportional to $H^{1 \cdot 5}$ and not to H, H being the height of liquid above the weir. Thus a relatively small increase in height when much water is passing over the weir represents a great increase in volume as compared with the same change on a small flow. We see, therefore, that the apparatus is less sensitive for large deliveries than for small. This objection is overcome in some types by a special shape of weir opening, in which the width of the opening above the weir is contracted so that the volume of discharge is directly proportional to the value of H.

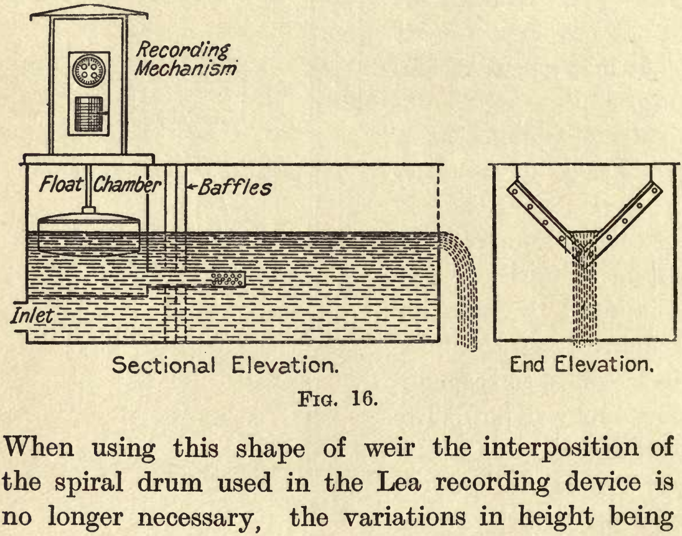


FIG. 16.

When using this shape of weir the interposition of the spiral drum used in the Lea recording device is no longer necessary, the variations in height being directly recorded on the chart, or, if necessary, magnified by a system of levers.

So far we have described the weir type. For smaller deliveries a V-shaped notch is used in its place. The angle of the notch is usually either 90° or 54°. In both cases the volume of fluid discharged is proportional to $H^{2 \cdot 5}$, the factor for the 54° notch being 1·25 and for the 90° notch 2·5, thus the variation of volume with depth is even more pronounced in the case of a notch than with a weir. In order to make the V-notch of use for larger quantities the stream is divided up between a series of notches arranged along the side of the measuring tank. Fig. 16 gives an illustration of V-notch apparatus which in the main is similar to a weir recorder except for the shape of the discharge outlet.

There is a loss of head for both weir and notch type recorders due to the fall which has to be allowed on the down-stream side. This, however, is in many cases no objection, the apparatus being of great use in measuring fairly large rates of flow of effluents, etc.

In fitting any kind of flow-measuring apparatus it is important that the size of pipe should be adequate for the maximum flow which is likely to be demanded. Various rules have been suggested for determining the diameter of pipe necessary for a given flow under a given head of liquid. For these formulæ we would refer the reader to the number of this series dealing with *Flow of Liquid through Pipes*, by Norman Swindin.

For many chemical purposes where only very approximate measurements are necessary, the delivery of a liquid can be estimated by means of an open length of pipe through which the liquid is passed under constant head.

Such devices do not require any ingenuity to design and may be regulated within limits, by having interchangeable pipes of different diameters and length, or by varying the head. Apparatus of this kind may be designed by calculation, but is best calibrated by trial.

The information obtained by recording the discharge

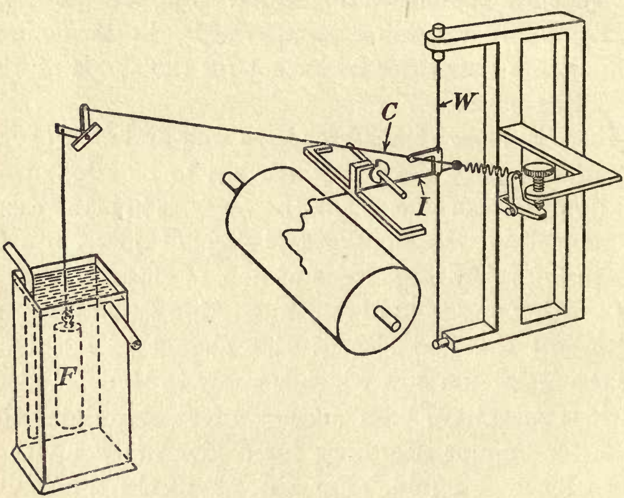


FIG. 17.

of waste acid (or similar material of variable strength) in volume only is incomplete without some further data as to its concentration. In most cases all that is necessary is to obtain a record of the density. It is possible to obtain this record concurrently with that of the volume by means of an apparatus similar to the one shown in Fig. 17.

The float F is totally immersed in the liquid to be tested, a sample of which passes through the tank. Movement of the float due to difference in gravity is communicated by means of a wire and L lever to the indicator I, which is suspended and moves against torsion in the wire W. The indicator I swings above the drum, which is rotated by clockwork, and a clock-driven cam, C, operating every half or one minute, depresses the indicator, which makes an ink dot on the chart, a continuous series of dots being recorded. In the intervals between its depression the indicator is free to take up a new position, thus doing away with the friction which occurs with that type of instrument in which a pen is always in contact with the chart. This instrument is made by the Cambridge Scientific Instrument Co.

Considering the foregoing there should be no difficulty in obtaining a meter suitable for any requirement. They are, of course, machines liable to go wrong and require a certain amount of attention. As a measure of precaution it is advisable to fit by-passes and cocks to be used in case of accident. Where convenient a calibrated test tank may be fitted capable of holding a half or one hour's supply and readily connectable to the meter. This is of importance as it is useless to install an expensive meter unless at the same time there is some means of testing its accuracy.

III

THE WEIGHING AND MEASURING OF SOLIDS

In our introduction we gave a rough division of the methods of weighing. The reader will notice as he goes through this chapter that the equal arm balance forms the basis of many instruments of both classes. In its simplest form it combines accuracy with a minimum of mechanical parts, the number of knife edges and consequent sources of friction being reduced to three. It can be seen that sources of error are much smaller than in those cases where there is a complex lever system and a big ratio between the actual weight and the weight of the counterpoise. On the other hand, there are obvious objections to the use of the equal arm balance where large and varying weights have to be handled. We feel that the theory of the equal arm balance would be out of place here.

For heavy weights the commonest appliances are the ordinary platform balance and its larger brother the weighbridge, with which we shall now concern ourselves. It consists of a platform, and a steelyard along which the balancing weight slides. The mechanism covered by the platform consists of a system of levers of the first and second order, the working of which can best be understood with the help of the accompanying diagram (Fig. 18).

This lever system is capable of certain variations. The diagram shows the ordinary type: knife edges are indicated by *Δ* and fixed parts from which the

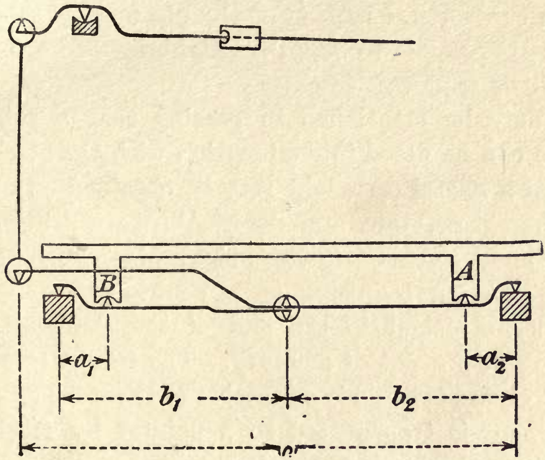


FIG. 18.

apparatus is suspended are shaded. The platform usually rests on four knife edges. The lever ratio for that part of the load which is taken by the front knife edges, one of which is shown at A, is given by $R = \frac{a_2}{c}$, while for the knife edges represented by B, $R = \frac{a_1}{b_1} \cdot \frac{b_2}{c}$. In order that the weight indicated may not vary with the position of the load on the platform, these two values of R must be equal, i.e.

$\frac{a_2}{c} = \frac{a_1}{b_1} \cdot \frac{b_2}{c}$, from which it follows that we must have $\frac{a_1}{b_1} = \frac{a_2}{b_2}$. Weighbridges as built by the various makers range in capacity from 1 cwt. to 100 tons. Owing to the magnification of the movement by the levers the vertical motion of the platform is so small that it is possible to adapt a weighbridge to a section of rail or tramway track.

It may be mentioned in passing that a printing device can be fitted in conjunction with the steelyard so that a record of weight may be obtained on a card showing gross, tare and nett. Where sensitivity is of no great importance the weighbridge can be made direct reading by using as a counterpoise an iron cylinder attached to the end of the steelyard and dipping into a pot of mercury. The height to which the steelyard is lifted is a function of the weight. This movement is transmitted to a pointer by means of a chain and sprocket wheel.

A system of levers similar to that of the weighbridge has been adapted for use as a crane balance, which is a compact instrument suspended from the hook of the hoist and read by the man loading or unloading.

The general apparatus and system of levers is shown in Fig. 19. It will be noticed that the weight is divided between two levers, a method which is adopted in the larger weighbridges. This is in order to minimize the strain on any particular knife edge, and for the same reason the knife edges are made as long as possible. The division of weight between the two levers is immaterial as the subsequent ratios are equal, in much the same way as we have described for the platform balance. The usual ratio of reduction in these appliances is 300 : 1. In order to reduce wear and tear of the knife edges the load is carried by the frame of the balance and not by the levers except at the moment of weighing. This is effected by a lever (not

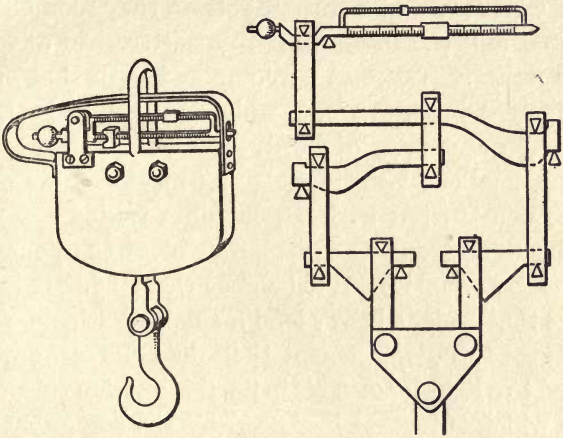


FIG. 19.

shown in Fig. 19) which passes through a slot in the suspension shackle and works an eccentric transmitting the load to the weighing apparatus when required.

In the weighcrane, and in nearly all modern types of weighbridges, there are no loose weights, the balance being effected by a weight sliding along the steelyard. As this weight must necessarily be heavy, and as it is inadvisable—if not impossible—to mark all the divisions on one scale, a second scale is provided parallel and rigidly attached to the main bar. A small weight sliding along the second scale gives fine adjustment, this scale being divided in lbs. when the main scale reads tons and cwts. This can be seen in Fig. 19.

There have been patented several types of weigh-crane in which the lever system is incorporated in the framework of the jib, but as in most cases the knife edges are under constant strain they soon become blunted and the instrument insensitive. In any case their usefulness cannot be compared with that of the instrument just described, which can easily be transferred to any type of hoist.

The smaller platform weighing machines are sometimes constructed with a pendulum taking the place of the steelyard. The displacement of the pendulum from the normal is used to balance the load. It is easy to see that under a heavy load a small additional weight produces less displacement than does the same weight added to a light load. This in itself is a serious disadvantage which is further increased by the somewhat delicate nature of the transmission to the indicating dial.

Among the smaller instruments we must mention spring balances containing either laminated or spiral springs, or, in some cases, combinations of the two. They are usually simple in construction, but as an offset to this it should be remembered that steel springs gradually become weakened by use and still more so by corrosion and there is no great delicacy with big weights. There are many useful adaptations of the ordinary balance and steelyard apparatus for particular purposes; for example, a weighing bin may be substituted for the scale pan on one side of the balance. Material of a granular nature may be fed into this from a hopper regulated by a cut-off until balance is effected, when the contents of the bin may be discharged into any desired receptacle, thus obviating the necessity of tareing the receptacle, or tipping the bin. A time-saving device for filling bags is produced by the Sturtevant Engineering Co. As can be seen from Fig. 20 it consists of two steelyards fixed to

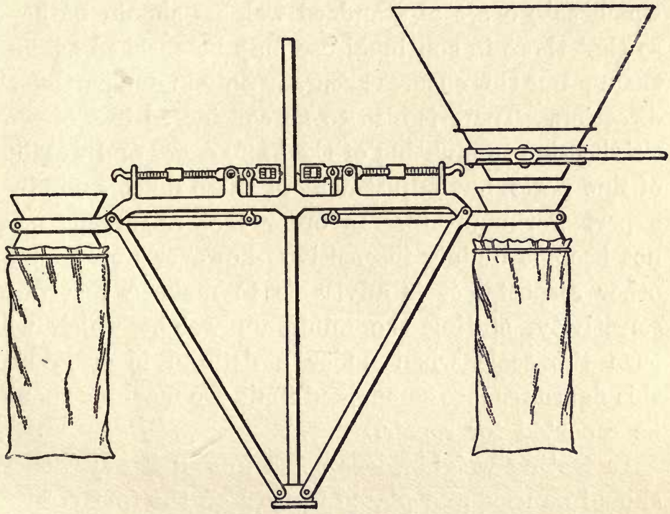


FIG. 20.

a single support which rotates about an upright. There are special adaptations to which the bags are fastened. Whilst a bag is being filled and weighed by one operator, another removes the previously filled bag and fixes an empty one. The machine is then turned half round and the operation is repeated.

Every user of weighing machines will realize the importance of regular examination, and in no place is this more essential than in the chemical works. Perhaps the most convenient method is to place a contract with some reliable firm who will make the necessary periodic examinations, keeping all the apparatus in adjustment and testing the weights. This arrangement is sometimes not practicable, in which case a set of standard weights should be kept so that those in continual use may be checked against them ; but this ensures accuracy only in one particular direction. There is also to be considered loss of sensitivity due to blunting of the knife edges and wearing of fine parts, but adjustment of these defects requires expert workmanship. In order that apparatus may not become unduly insensitive—however well kept in other respects—it is advisable to make a record of sensitivity, stating the minimum weight which will turn the scale when under a definite load. When this figure reaches some fixed limit the machine should be reported for repair.

In testing weighbridges some known heavy weight should be used and placed in turn on the four corners and centrally. The same weight should be indicated in each case.

We shall now turn our attention to the numerous automatic devices for either weighing or measuring solid materials. The measurement of volume of solid materials can only be of use where the substance is either homogeneous or of such evenness that error due to its variation of texture will be small compared with the amounts taken. With material of sufficiently even granular nature we can employ a rotating drum containing a number of pockets which are filled from a hopper and inverted over the receiving bin by the rotation of the drum. This principle has been embodied in a variety of patents, but though simple this construction obviously has serious limitations. We give a diagram showing the arrangement of such a device, Fig. 21.

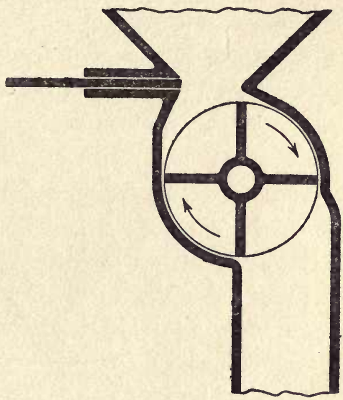


FIG. 21.

Another piece of apparatus in which the quantity of material delivered can be varied by the rate of revolution is provided by a screw rotating in a tube which is supplied with material from a hopper. It may discharge either from its end or through a hole in the bottom at any distance from the feed. The rate of discharge is proportional to the speed of rotation of the screw. By making the core of the screw conical and arranging that various portions of it can be brought beneath the inlet it is possible to vary the delivery independently of the rate of revolution.

This is made use of in Davis' Apportioner, where two or more such systems are driven from the same shaft as shown in Fig. 22. By this means it is possible to mix two or more granular substances in any desired proportions by suitably adjusting the positions of the screws.

The advantage of this device is apparent, as adjustment of the proportions of a mixture may readily be

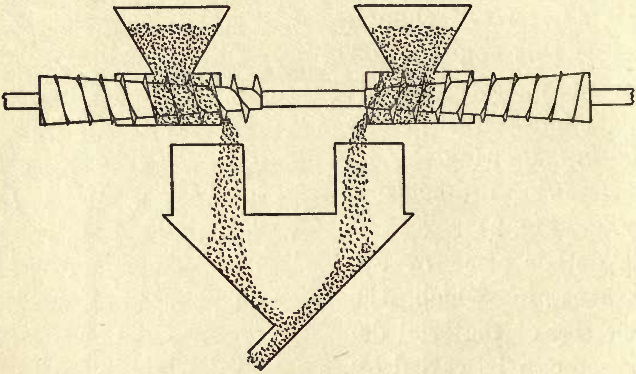


Fig. 22.

made without complicated mechanical arrangements. Frequent checking is necessary, however, if the materials are not always of the same bulk density or texture. The same object is also achieved by the use of various adjustable "bin discharge valves," of which many types are obtainable commercially.

Our next consideration will be the numerous automatic weighing machines such as are used for grain and which are readily adapted to any free running granular material. Such material is most easily handled by a conveyor and the weighing apparatus can be incorporated either in the hopper feeding the conveyor or in the conveyor itself.

In the first case automatic weighing machines can be obtained having a capacity ranging from 1 cwt. to 2 tons. They may be worked either by power or by the gravitational energy of the material, delivering batches of predetermined weight and recording the total weight or its equivalent, the number of batches.

In the second case the weighing apparatus is incorporated in the belt conveyor itself, delivering an absolutely continuous stream of material and totalling the weight.

In the automatic batch weighers the result is obtained by allowing the material to fall from a hopper into a bin until the latter has received a definite weight of material, arrangements being made for stopping the supply at this point, emptying the bin and restarting the operation. Of the two kinds of hopper weighing machines preference may, perhaps, be given to the power-driven type as the feed and discharge are operated by power quite extraneous to the weighing elements themselves, no work being put upon the weighing parts for these operations. Moreover, the additional running cost of the power-driven type is very small. As an example of this kind of apparatus we illustrate diagrammatically the Pooley power-driven grain weigher. The controlling mechanism of this machine is too complicated to be made clear by a single diagram, but we endeavour to give the reader some idea of the principles of action, A weight box A and bin B are at opposite ends of an equal armed balance. A motor M provides power, transmitted by means of a spur wheel and shaft and a cam C, for the opening and closing of the hopper and bin gates. The transmission of power to the cam is controlled by the position of the weight box A, which, through the lever system shown in broken line, causes the spur wheel to come in and out of gear. The feed gates at the bottom of the hopper are operated through levers from this cam. During filling the discharge door of the bin is kept closed by a locking lever device shown on the side of the bin in our diagram.

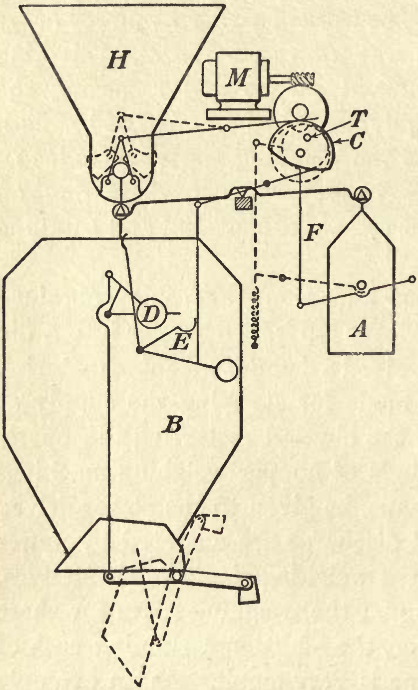
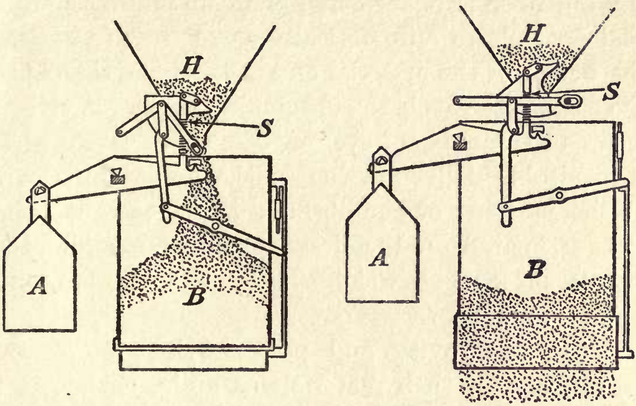


FIG. 23.

When the determined weight has been delivered the bin descends, closing the hopper gates. Then the counterweight D is thrown over by the arm E which is worked from the tappet T on the cam opening the gate. When the load is discharged the bin door is closed by a counterweight and the locking system is returned to its original position. The too abrupt fall of A, which would occur when the weight is released from B, is prevented by the lever F which, by means of an



A. B.

Fig. 24.

eccentric on the cam shaft, lowers A gradually to its original position.

Of the gravity-operated weighers that made by Avery is representative and has a moderate field of use among dry granular materials. Apart from the method of operation its construction is similar to that of the power-driven machine. The material is fed to the bin B (Fig. 24) from a hopper H, and the flow is regulated by a cut-off held fully open by a spring S pressing downwards on the hopper so that the beam begins to turn shortly before the full weight has been delivered. This causes a partial closing of the cut-off, admitting of a fine adjustment of the weight. The supply is cut off completely by the final depression of the hopper. Through the system of levers which links the cut-off indirectly with the bin door, the bin door is opened and the contents discharged. The door closes automatically as soon as freed from the weight of the material and at the same time opens the cut-off, the cycle thus beginning again. A counter records the number of cycles. The small excess which is inevitably delivered, due to the material in the air at the moment of equilibrium, is of constant value. It is estimated on the first weighing and allowed for on all subsequent weighings by adjusting a small sliding counterpoise.

Both the gravity and power weighers are used extensively for such materials as grain, coal, ores or any dry chemical in bulk. Where material is wet or likely to clog a shaking device may be fitted.

Whilst considering bin weighing machines mention must be made of those which consist of two bins which fill and empty alternately, the frequency being controlled by the supply of material. The hoppers are fixed together and the system turns about a knife edge placed beneath the centre of gravity of the vessels, so that when the weight of material run into the raised hopper is sufficient to upset the equilibrium the apparatus tilts suddenly, bringing the empty hopper under the feed and releasing the trap door at the bottom of the full hopper, the system closely resembling the tilting bucket device used for liquids.

As opposed to the intermittent delivery of the automatic hopper machines just described we have the belt weighing machines which deliver continuously. There are again two main types of this kind of machine, one which delivers material and records the weight delivered, the other which besides delivering and recording also regulates the flow on to the belt. Of the former type we shall give as an example the Blake-Dennison weigher. Material is fed on to a belt in the usual way and at any convenient position along the conveyor a number of the rollers supporting the belt are incorporated in the platform of what is virtually a weighbridge. The weight is recorded at intervals of time which correspond with the period required for the weighed portion of the belt to move just clear of the bridge and a new section to take its place. Thus, if the machine is made to weigh lengths of 10 ft. each, it will weigh and record each time 10 ft. has passed, so that every portion of the belt is duly weighed. The weighing apparatus is balanced to the unloaded conveyor and arranged so that the movement of the recorder is proportional to the weight. A pointer shows the weight on the bridge as it varies from moment to moment and a counter totals the periodic records. Permanent records can be obtained by the use of a special chart recorder.

The variant of this apparatus which controls delivery is in its essential parts as follows. A hopper delivers material to a travelling belt which then passes over three rollers, the middle one of which is connected through a system of levers to a simple steelyard having a sliding weight for adjustment of the output of material. This steelyard operates a gate which forms the exit of the hopper. Fig. 25 shows the principle

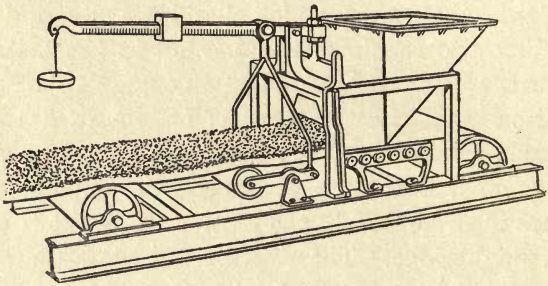


Fig. 25.

of this apparatus which is known as the Schaffer poidometer. This machine is also made with an attachment so that a definite proportion of any fluid may be delivered along with the solid. The driving mechanism of the belt also works a single piston meter, the throw of the piston being adjusted so as to deliver a predetermined amount of liquid.

Conversely, by the use of a Venturi meter for the liquid it is possible to reverse the process and deliver solids in proportion to liquid.

There is an instrument used for estimating the discharge of granular material from overhead bins which is more closely allied to a liquid flow meter than to any of the above weighing machines. It is made by the Bailey Meter Co. and consists of a helical vane (Fig. 26) suspended in the centre of the pipe

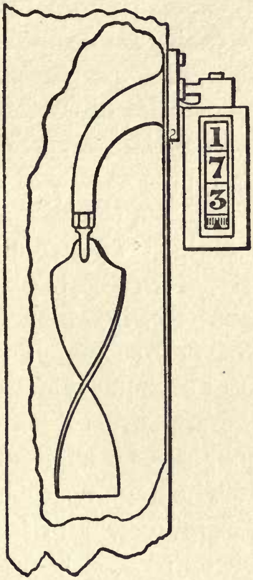


FIG. 26.

conveying the material. The flow of material rotates the vane and records on a counting mechanism, connection being made by a flexible shaft enclosed in a dust-proof tube. The makers claim that this instrument shows consistent accuracy and may be used for ore, soda ash or the bulk estimation of any crushed material. The counter can, of course, be made to register in weight or volume for any particular material.

Throughout this book we have refrained from giving definite advice as to the type of appliance for use in any particular case. We have to some extent indicated the limitations of the instruments described. The reader must make his own final decision as to type of apparatus, taking into consideration the degree of accuracy required and the particular conditions of his case. The possibilities of combining two or more distinct appliances for the proportional measurement of the materials in a process should not be overlooked as this frequently reduces the labour of control. We may mention a use which is not confined to the chemical works, namely, for ascertaining the efficiency of the boiler plant; for, in order to carry out any efficient scheme of fuel economy, it is necessary to have records of coal consumption and water evaporation. Most of the apparatus described in the latter part of this chapter can be adapted for coal control, whilst the reader will have no difficulty in selecting a meter for the measurement of feed water.

For ordinary chemical works purposes it should be remembered that simplicity and certainty are the most important requirements, and it is now generally acknowledged that in so far as reaction products are concerned the simpler proportion delivering appliances deserve most careful attention, as by their use weighing operations are largely diminished.

With the development of continuous methods of manufacture the application of the various flow meters and automatic appliances is becoming more favoured, and it may be stated that careful consideration of the weighing, measuring, and proportioning of materials by continuous methods is one of the essentials of modern production, in which the tendency is to dispense with batch working as much as possible.

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