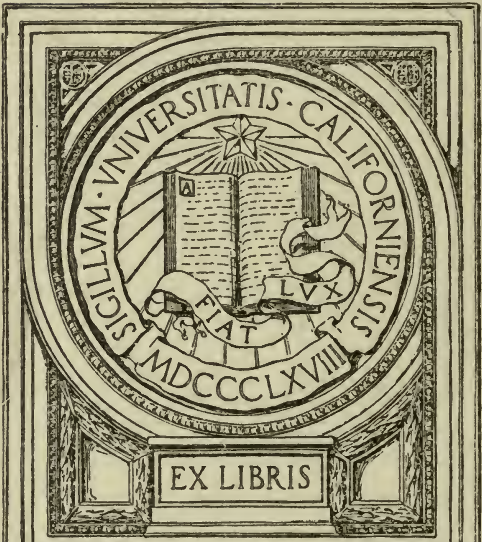

GAS AND FUEL ANALYSIS FOR ENGINEERS.

A COMPEND FOR THOSE INTERESTED IN THE ECONOMICAL APPLICATION OF FUEL.

PREPARED ESPECIALLY FOR THE USE OF STUDENTS
at the
MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

BY

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PREFACE.

THIS little book is an attempt to present in a concise yet clear form the methods of gas and fuel analysis involved in testing the efficiency of a boiler plant. Its substance was given originally, in the form of lectures and heliotyped notes, to the students in the courses of Chemical, Mechanical, and Electrical Engineering, but in response to requests it has been deemed expedient to give it a wider circulation.

At the time of its conception, nothing of the kind was known to exist in the English language; in German we now have the excellent little book of Dr. Ferdinand Fischer, "Taschenbuch für Feuerungs-Techniker."

The present book is the result of six years' experience in the instruction of classes of about one hundred students. It is in no sense a copy of any other work, nor is it a mere compilation. The author has in every case endeavored to give credit where anything has been taken from outside sources; it is, however, difficult to credit single ideas, and if he has been remiss in this respect it has been unintentional.

The study of flue-gas analysis enables the engineer to investigate the various sources of loss; and if this compend stimulates and renders easy such investigation, the writer's purpose will have been accomplished. The necessary apparatus can be obtained from the leading dealers in New York City.

The author wishes to acknowledge his indebtedness to our former Professor of Analytical Chemistry, Dr. Thomas M. Drown, and to Mrs. Ellen H. Richards, by whose efforts the department of Gas Analysis was established.

He will also be grateful for any suggestions or corrections from the profession.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
BOSTON, November, 1896.

PREFACE TO THE NINTH EDITION.

THE changes in the present edition include the following: General revision and addition of numerous explanatory notes and references; the calculation of losses in chimney gases by the molar or volumetric method and the rewriting of the chapter on pyrometry.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
Cambridge, March, 1920.

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GAS AND FUEL ANALYSIS.

CHAPTER I.

INTRODUCTION AND METHODS OF SAMPLING.

UNTIL within recent years, the mechanical engineer in testing a boiler plant has been compelled to content himself with the bare statement of its efficiency, little or no idea being obtained as to the apportionment of the losses. Knowing the composition and temperature of the chimney-gases and the analysis of the coal and ash, the loss due to the formation of carbonic oxide, to the imperfect combustion of the coal, to the high temperature of the escaping gases, can each be determined and thus a basis for their reduction to a minimum established.

By the simple analysis of the chimney-gases and determination of their temperature, a very good idea of the efficiency of the plant can be obtained previous to making the engineering test. For example, in a test which the author made in connection with his students, the efficiency was increased from 58 to 70 per cent, upon the results of the gas analysis alone.

To this end a representative sample must be collected according to the method about to be described.

SAMPLING.*

Before proceeding to take a sample of the gas, the plant—for example, a boiler setting—from which the gas is to be taken should be thoroughly inspected, and all apertures by which the air can enter, other than those so intended, carefully stopped up. This includes not only cracks in the setting and leaks about clean-out doors, but also the bricks and mortar of the setting itself; these are porous, and unless glazed or hard-burned, should be given a thin coat of size and also of whitewash. Material gains in economy have been effected by covering the whole setting with a thick coating of asbestos cement, protected by a coating of canvas, which was kept painted.

The best place to take a sample from a fire tube boiler is in the uptake just as it leaves the boiler: in a water tube boiler from the last pass. Leakage from the damper should be avoided by inserting the tube on the grate side of the damper. The tube should be long enough to reach about halfway across the flue and project out about a foot from it, so that the gas may be cool that flows through the type. A suitable tube is then inserted air-tight and in the gas-duct, connected with the sampling or gas apparatus, and suction applied, thus drawing the gas out. Cork, putty, plaster of Paris, wet cotton-waste, or asbestos may be used to render the

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* See Bureau Mines Bulletin 97, "Sampling and Analyzing Flue Gases," 1915.

joint gas-tight. The place of insertion should be chosen where the gas will be most completely mixed and least contaminated with air. The oil-bath containing the thermometer is similarly inserted near the gas-tube, and the temperature read from time to time.

1. **Tubes.**—The tubes usually employed are Bohemian-glass combustion tubing or water-cooled metal tubes; those of porcelain are also sometimes used. Glass and porcelain tubes when subjected to high temperatures must be previously warmed or gradually inserted: the former may be used up to temperatures of 600° C. (1112° F.). Uncooled metal tubes, other than those of platinum, should under no circumstances be used.*

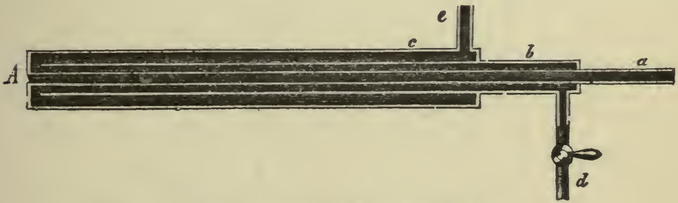

FIG. 1.—GAS-SAMPLING TUBE.

The metal tube with the water cooling is made as shown in Fig. 1, *c* being a piece of brass pipe 3 feet long, $1\frac{1}{4}$ inches outside diameter, *b* the same length, $\frac{7}{8}$ inch in diameter, and *a* $\frac{1}{4}$ inch in diameter. The

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* Fischer, "Technologie der Brennstoffe," 1880, p. 221, states that the composition of a gaseous mixture was changed from 1.5 to 26.0 per cent carbon dioxide, by the passage through an iron tube heated to a dull red heat, the carbonic oxide originally present reducing the iron oxide with the formation of carbon dioxide; this can take place at 250°. (Campbell "Manufacture of Iron and Steel, p. 53.")

water enters at *d* and leaves at *e*. The walls of the tubes are $\frac{1}{16}$ inch thick. The joint at *A* should be brazed; the others may be soldered.

Quartz tubes can be used in place of the water-cooled metal tubes and have the advantage that they require no previous warming.

2. Apparatus for the Collection of Samples.—A convenient sampling apparatus is shown in Fig. 2.

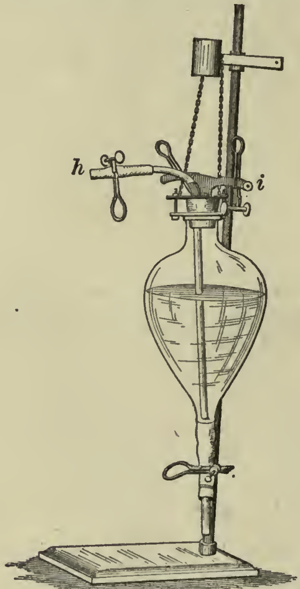

FIG. 2.—SAMPLING APPARATUS.

It may be made from a liter separatory funnel—instead of the bulb there shown—fitted with a rubber stopper carrying a tube passing to the bottom and a T tube; both of these, except where sulphur-containing gases are present, can advantageously be made of $\frac{3}{16}$-inch lead pipe. The stopper should not be fastened down with wire between the tubes after the manner of wiring effervescent drinks, as this draws the rubber away from the tubes and occasions a leak. The fastening shown consists of a brass plate fitting upon the top of the stopper, provided with screws and nuts which pass through a wire around the neck of the separatory. A chain fastened to the plate serves as a convenient method of handling it.

In using the apparatus, the bulb is filled with water by connecting the stem with the water-supply and opening one of the pinchcocks upon the T tube; the water thus entering from the bottom forces the air out before it. One branch of the T is connected with the sampling-tube and the other with the suction-pump, the stopcocks being open, and a current of gas drawn down into the pump; upon opening the cock upon the stem, the water runs out, drawing a small portion of the gas-current passing through the T after it into the bulb. It is then taken to a convenient place for analysis, the tube *h* connected with a head of water, a branch of the T *i*, with the gas apparatus, and a sample of gas forced over into the latter for analysis.

Enough water should be left in the bulb to seal the stopcock on the bottom and prevent leakage. This apparatus is better adapted for the needs of the classroom than for actual practice, as it enables the same sample to be given to eight or ten students. As has been shown by several years' experience, the water exercises no appreciable solvent action upon the gaseous mixture in the time—about half an hour—

necessary to collect and distribute the samples. It is often necessary to attach about a yard of $\frac{1}{4}$-inch rubber tubing to the stem of the bulb to prevent air being sucked up through it when taking a sample.

FIG. 4.—GAS-TUBE.

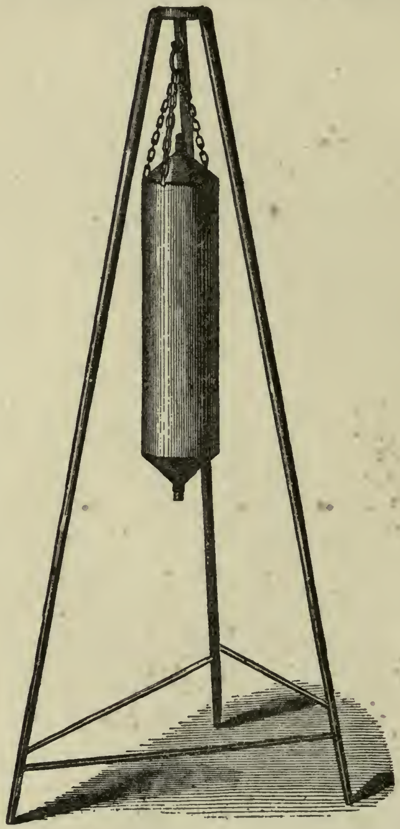

FIG. 3.—SAMPLING APPARATUS FOR MINE-GASES.

In the actual boiler-test it is preferable to insert a T instead of this apparatus in the gas-stream, connect the gas apparatus to the free branch of this T, and draw the sample. In making connections with gas apparatus the air in the rubber connectors should be displaced with water by means of a medicine-dropper.

In the Saxon coal-mines, zinc cans* of ten liters capacity, of the form shown in Fig. 3, are used by Winkler for sampling the mine-gases; they are carried down filled with water and this allowed to run out, and the gas thus obtained brought into the laboratory and analyzed. Small samples of gas may very well be taken in tubes of 100 cc. capacity like Fig. 4, the ends of which are closed with rubber connectors and glass plugs. Rubber bags are not to be recommended for the collection and storage of gas for analysis, as they permit of the diffusion of gases, notably hydrogen.

3. Apparatus for Producing Suction.—I. WATER-PUMPS—(*a*) Jet-pumps, depending for their action upon a considerable head of water, and (*b*) those depending rather upon a sufficient fall of water.

(*a*) *Jet-pumps.*—The Richards jet pump † is shown in section in Fig. 5 and much resembles a boiler injector; it consists of a water-jet *w*, a constriction or waist *a*, a waste-tube *o*, and a tube for the inspiration of air. The jet of water forms successive pistons across *a*, drawing the air in with it and is broken up into foam by the zigzag tube *o*.

This pump is known in Germany as Muencke's, and in England as Wing's: Chapman's pump is also a modified form.

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* If used with gases containing CO_2, it attacks the zinc. Murmann, Oest. Ch. Ztg., 17, 69 (1914).

† Richards, Am. Jour. of Science (3), 8, 412; Trans. Am. Inst. Min. Engrs., 6, 492 (1874).

It may be easily constructed in glass, the jets passing through rubber stoppers which are wired down,

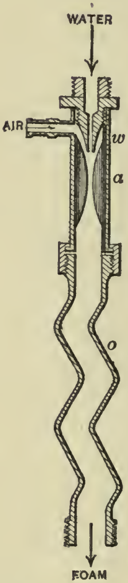

FIG. 5.—RICHARDS' JET-PUMP.

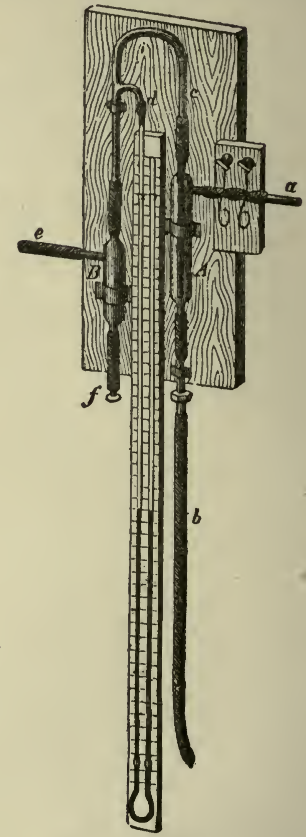

FIG. 6.—BUNSEN'S PUMP.

thus admitting of adjustment to the conditions under which it has to work.*

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* The pump will also work well using steam.

(*b*) *Fall-pumps.*—Bunsen's pump, Fig. 6, consists of a wide glass tube *A*, drawn out at the bottom for connection with a ¼-inch lead pipe *b*, and at the top for connection with *c*, the tube through which the air is drawn; this tube is usually fused in, although it may be connected with rubber; *a* is a rubber tube provided with screw cocks connected with the water-supply; *d* is connected with a mercury column, and the vessel *B* serves for the retention of any water which might be drawn back into the apparatus evacuated.

The tube *b* for the best results should be 32 feet in length, equal to the height of a column of water supported by the atmosphere, although for the ordinary purposes of gas-sampling it may be shorter.

When water is admitted through *a* it fills *b*, acting as a continually falling piston drawing the current of air through *e* and its connections. These various forms of water-pumps should give a vacuum represented by the height of the barometer less the tension of aqueous vapor at the temperature at which they are used, or about 29 inches of mercury.

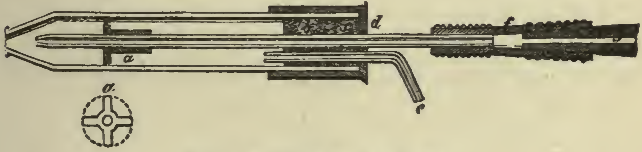

FIG. 7.—STEAM AIR-PUMP.

II. STEAM-PUMPS.—Kochinke describes the apparatus in use in the Muldner Hütten in Freiberg, shown at one-fifth size in Fig. 7. It consists of a glass tube drawn down to an opening 6 mm. in diameter; concentric with this, and held in place by the washer *a*, is the steam-jet 2 mm. in diameter, passing through the cork *b*, the cement *c*, and covering *d*. It is connected with the steam-pipe at *g* by webbed rubber tubing *f*; the air enters at *e*. This is said to give very good results and be economical in use of steam.

In case neither water nor steam be available, recourse must be had to the ordinary rubber syringe-bulbs, provided with suitable valves, obtainable at any rubber store, or to a bottle aspirator. This consists of two one-gallon bottles, provided with doubly perforated rubber stoppers, carrying tubes of glass or lead bent at right angles. In each bottle one of these tubes passes nearly to the bottom, and these are connected together by a piece of rubber tubing a yard long, carrying a screw pinchcock. The other tube in each case stops immediately under the stopper. Upon filling one of the bottles with water, inserting the stopper and blowing strongly through the short tube, water will fill the long tubes thus forming a siphon, and upon lowering the empty bottle, a current of air will be sucked in through the short tube originally blown into; this may be regulated by the screw pinchcock.

In inserting the gas-sampling tube care should be taken not to insert it so close to the source of heat as to draw out the gases in a dissociated, i.e. partly decomposed, condition.

In case of very smoky fuels it is well to filter the gases through rolls of fine wire gauze or asbestos; in sucking them through a washing-bottle, the water may change the composition of the sample.

Where a continuous sample is to be taken, the water in the containers should be replaced by strong brine.

CHAPTER II.

APPARATUS FOR THE ANALYSIS OF CHIMNEY-GASES.

GASES are analyzed by absorbing the various constituents, and observing the diminution in volume: in case the gas be unabsorbable, as for example, methane, CH_4, it is burned, and the carbon dioxide and water determined, from which the methane can be calculated.

In the writer's opinion the apparatus which is best adapted for this purpose is that of Orsat; it is readily portable, not liable to be broken, easy to manipulate, sufficiently accurate, and—in the modification about to be described—always ready for use, there being no stopcocks to stick fast.

As the Bunte and Elliott apparatus are also used for this purpose, they too will be described.

Fischer's apparatus, using mercury, is rather too difficult for the average engineer; Hempel's, Elliott's or Morehead's apparatus for the analysis of illuminating-gas might also be used; it is, however, not customary.

ORSAT APPARATUS.

Description.—The apparatus Fig. 8, is enclosed in a case to permit of transportation from place to place; furthermore, the measuring-tube is jacketed with water to prevent changes of temperature affecting the gas-volume. The apparatus consists essentially of the levelling-bottle *A*, the burette *B*, the pipettes *P′*, *P″*, *P‴*, and the connecting tube or "header" *T*.

Pipette *P′* is filled with potassium (or sodium) hydroxide solution (see Reagents) so that when it is drawn up into the front arm, about half an inch in depth is left in the rear arm. Pipettes *P″* and *P‴* are similarly filled with potassium (or sodium) pyrogallate and cuprous chloride solution respectively. These reagents require to be protected from the oxygen of the air by collapsible rubber bags. As the oxygen

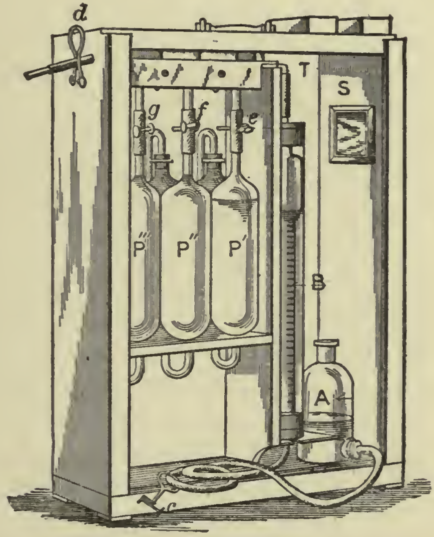

FIG. 8.—ORSAT'S GAS APPARATUS.

in the air over the reagent is absorbed, a diminution in pressure takes place, rendering it difficult to bring the reagent to the point on the stem: the obvious remedy is to remove the bag temporarily and adjust the reagent as shown below (manipulation): only about ½ inch should be in the rear arm. When the apparatus is first set up, one or two blank analyses should be made, to saturate the water and reagents with the gases. For example the potassium hydroxide absorbs carbon dioxide, it also absorbs about 3 cc. of oxygen, 2 cc. of carbon monoxide and 1.5 cc. of nitrogen by virtue of the 100 cc. of water which it contains. A change of temperature of 1° makes a change of 0.36% of the volume of the gas; a change of pressure of 1 mm. produces 0.13% change in volume.

Manipulation.—The reagent in the pipettes should be adjusted in the capillary tubes to a point on the stem about midway between the top of the pipette and the rubber connector. This is effected by opening wide the pinchcock upon the connector, the bottle being on the table, and very gradually lowering the bottle until the reagent is brought to the point above indicated. Six inches of the tubing used correspond to but 0.1 cc., so that an error of half an inch in adjustment of the reagent is without influence upon the accuracy of the result. The reagents having been thus adjusted, the burette and connecting tube are completely filled with water by opening *d* and raising the leveling-bottle. The apparatus is now ready to receive a sample of gas (or air for practice). In case a flue-gas is to be analyzed *d* is connected with *i*, Fig. 2, *A* lowered and about 102 cc.

of the gas forced over by opening *h*; or *d* may be connected with a T joint in the gas-stream; the burette after filling is allowed to drain one minute by the sand-glass, *c* snapped upon its rubber tube, and the bottle *A* raised to the top of the apparatus. By gradually opening *c* the water is allowed to run into the burette until the lower meniscus stands upon the 100 or 0 mark (according to the graduation of the apparatus). The gas taken is thus compressed into the space occupied by 100 cc., and by opening *d* the excess escapes. Open *c* and *bring the level of the water in the bottle to the same level as the water in the burette* and take the reading, which should be 100 cc. Special attention is called to this method of reading: if the bottle be raised, the gas is compressed; if lowered, it is expanded.

Determination of Carbon Dioxide.—The gas to be analyzed is invariably passed first into pipette *P′*, containing potassium hydrate for the absorption of carbon dioxide, by opening *e* and raising *A*. The gas displaces the reagent in the front part of the pipette, laying bare the tubes contained in it, which being covered with the reagent present a large absorptive surface to the gas; the reagent moves into the rear arm of the pipette, displacing the air over it into the flexible rubber bag which prevents its diffusion into the air. The gas is forced in and out of the pipette by raising and lowering *A*, the reagent finally brought approximately to its initial point on the stem of the pipette, the burette allowed to drain one minute, and the reading taken. The difference between this and the initial reading represents the cubic centimeters of carbon dioxide present in the gas. To be certain that all the carbon dioxide is removed, the gas should be passed a second time into *P'* and the reading taken as before; these readings should agree within 0.1 per cent.

Determination of Oxygen.—The residue from the absorption of carbon dioxide is passed into the second pipette, *P''*, containing an alkaline solution of potassium pyrogallate, until no further absorption will take place. The difference between the reading obtained and that after the absorption of carbon dioxide, represents the number of cubic centimeters of oxygen present.

Determination of Carbonic Oxide.—The residue from the absorption of oxygen is passed into the third pipette, *P'''*, containing cuprous chloride, until no further absorption takes place; that is, in this case until readings agreeing exactly (not merely to 0.1) are obtained. The difference between the reading thus obtained and that after the absorption of oxygen, represents the number of cubic centimeters of carbonic oxide present.

Determination of Nitrogen and Hydrocarbons.—The residue left after all absorptions have been made may consist, in addition to nitrogen, the principal constituent, of hydrocarbons and hydrogen. Their determination is difficult for the inexperienced, and, if desired, a sample of the flue-gas should be taken, leaving as little water in the apparatus as possible, and sent to a competent chemist for analysis.

Accuracy.—The apparatus gives results accurate to 0.2 of 1 per cent.

Time Required.—About twenty minutes are required for an analysis; two may be made in twenty-five minutes, using two apparatus.

Notes.—The method of adjusting the reagents is the only one which has been found satisfactory; if the bottle be placed at a lower level and an attempt made to shut the pinchcock *c* upon the connector at the proper time, it will almost invariably result in failure.

The process of obtaining 100 cc. of gas is exactly analagous to filling a measure heaping full of grain and striking off the excess with a straight-edge; it saves arithmetical work, as cubic centimeters read off represent percent directly.

It often happens when *e* is opened, *c* being closed, that the reagent in P' drops, due not to a leak as is usually supposed, but to the weight of the column of the reagent expanding the gas.

The object of the rubber bags is to prevent the access of air to the reagents, those in P'' and P''' absorbing oxygen with great avidity, and hence if freely exposed to the air would soon become useless.

Carbon dioxide is always the first gas to be removed from a gaseous mixture. In the case of air the percentage present is so small, 0.08 to 0.1, as scarcely to be seen with this apparatus. It is important to use the reagents in the order given; if by mistake the gas be passed into the second pipette, it will absorb not only oxygen, for which it is intended, but also carbon dioxide; similarly if the gas be passed into the third pipette, it will absorb not only carbonic oxide, but also oxygen as well.

The use of pinchcocks and rubber tubes, original with the author, although recommended by Naef,* is considered by Fischer,† to be inaccurate. The experience of the author, however, does not support this assertion, as they have been found to be fully as accurate as glass stopcocks, and very much less troublesome and expensive.

In case any potassium hydrate or pyrogallate be sucked over into the tube *T* or water in *A*, the analysis is not spoiled, but may be proceeded with by connecting on water at *d*, opening this cock, and allowing the water to wash the tubes out thoroughly. The addition of a little hydrochloric acid to the water in the bottle *A* will neutralize the hydrate or pyrogallate, and the washing may be postponed until convenient.

After each analysis the number of cubic centimeters of oxygen and carbonic oxide should be set down upon the ground-glass slip provided for the purpose. By adding these numbers and subtracting their sum from the absorption capacity (see Reagents) of each reagent, the condition of the apparatus is known at any time, and the reagent can be renewed in season to prevent incorrect analyses.

BUNTE APPARATUS.

Description.—The apparatus Fig. 9 consists of a burette—bulbed to avoid extreme length—provided

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* Wagner's Jahresb. 1885, p. 423.

† Technologie d. Brennstoffe, foot note p. 295.

at the top with a funnel *F* and three-way cock *j*, and a cock *l* at the bottom. These stopcocks are best of the Greiner and Friedrichs obliquely bored form. The burette is supported upon a retort-stand with a spring clamp.

A "suction-bottle" *S*, an 8-oz. wide-mouthed bottle, fitted similarly to a wash-bottle, except that the delivery-tube is straight and is fitted with a four-inch piece of ¼-inch black rubber tubing, serves to withdraw the reagents and water when necessary. A reservoir to contain water at the temperature of the room, fitted with a long rubber tube, should be provided for washing out the reagents and filling the burette.

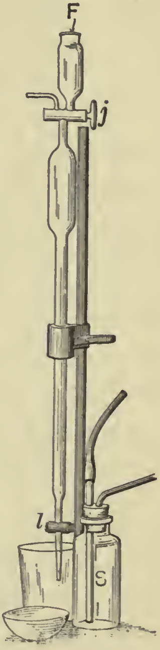

Fig. 9.—Bunte's Gas Apparatus.

Manipulation. — Before using the apparatus, the keys of the stopcocks should be taken out, wiped dry, together with their seats, and sparingly smeared with vaseline or a mixture of vaseline and tallow and replaced. The completeness of the lubrication can be judged by the transparency of the joint, a thoroughly lubricated joint showing no ground glass. The burette is filled with water by attaching the rubber tube to the tip at *l* and opening the stopcocks at the top and bottom; *j* is connected with the source whence the gas is to be taken, turned to communicate with the burette and opened, about 102 cc. of gas allowed to run in, and *j* and *l* closed.

The cup *F* is filled with water to the 25-cc. mark, *j* turned to establish communication between it and the burette, the burette allowed to drain one minute by the sand-glass, and the reading taken, the cup being refilled to the mark if necessary. The readings are thus taken under the same pressure each time, i.e., this column of water plus the height of the barometer; and as the latter is practically constant during the analysis, no correction need be applied, it being within the limits of error.

Determination of Carbon Dioxide.—The "suction-bottle" is connected with the tip of the burette, *l* opened, and the water carefully sucked out nearly to *l*. The bottle is now disconnected, the burette dismounted from its clamp, using the cup as a handle, and the 25 cc. of water turned out. The tip is immersed under potassium hydrate contained in the No. 3 porcelain dish, and the cock *l* opened, then closed, and the tip wiped clean with a piece of cloth. The burette is now shaken, holding it by the tip and the cup, the thumbs resting upon *j* and *l*; more reagent is introduced, the absorption of the gas causing a diminished pressure, and the operation repeated until no change takes place. The cup is now filled with water, *j* opened, and the reagent completely washed out into an ordinary tumbler placed beneath the burette. Four times filling of *F* should be sufficient for this purpose. The cup is now filled to the 25-cc. mark, *j* opened, and the reading taken as before.

The difference between this reading and the initial represents the number of cubic centimeters of carbon dioxide; this divided by the volume of the gas taken gives the per cent of this constituent.

Determination of Oxygen.—The water is again sucked out, and potassium pyrogallate solution introduced, similarly to potassium hydrate; this is displaced by water, and the reading taken as before. The difference between this and the last reading is the volume of oxygen present.

Determination of Carbonic Oxide.—The water is removed for a third time, and acid cuprous chloride solution introduced and the absorption made as before; this is washed out, first with water containing a little hydrochloric acid to dissolve the white cuprous chloride which is precipitated by the addition of water, and finally with pure water, and the reading taken as before. The difference between this and the preceding gives the volume of carbonic oxide present.

Notes.—Especial care should be taken not to grasp the burette by the bulb, as this warms the gas and renders the readings inaccurate. The stopcocks can conveniently be kept in the burette by elastic bands of suitable size. When the apparatus is put away for any considerable time, a piece of paper should be inserted between the key and socket of each stopcock to prevent the former from sticking fast. To ascertain when the absorption is complete, the burette is mounted in its clamp and allowed to drain until the meniscus is stationary, the dish containing the reagent raised until the tip is covered, *l* opened, and any change in level noted. If the meniscus rises, the absorption is incomplete and must be continued; if it remains stationary or falls, the absorption may be regarded as finished. In case the grease from the stopcocks becomes troublesome inside the burette, it may be removed by dissolving it in chloroform and washing out with alcohol and then with water. The object in sucking the water not quite down to *l*, thus leaving a little water in the burette, is to discover if *l* leaks, the air rushing in causes bubbles.

The object in washing out each reagent and taking all readings over water is to obviate corrections for the tension of aqueous vapor over potassium hydrate, hydrochloric acid, or any of the reagents which might be employed. The tension of aqueous vapor over seven per cent caustic soda is less than over water.

Accuracy and Time Required.—The apparatus is rather difficult to manipulate, but fairly rapid—about twenty-five minutes being required for an analysis—and accurate to one tenth of one per cent.

ELLIOTT APPARATUS.

Description.—The apparatus Fig. 10 consists of a burette holding 100 cc. graduated in tenths of a cubic centimeter and bulbed like the Bunte apparatus—the bulb holding about 30 cc.; it is connected with a levelling-bottle similar to the Orsat apparatus. The top of the burette ends in a capillary stopcock, the stem of which is ground square to admit of close connection with the "laboratory vessel," an ungraduated tube similar to the burette, except of 125 cc. capacity. The top of this "vessel" is also closed with a capillary stopcock, carrying by a ground-glass joint a thistle-tube *F*, for the introduction of the reagents. The lower end of this " vessel " is closed by a rubber stopper carrying a three-way cock *o*, and connected with a levelling-bottle *D*. The burette and vessel are held upon a block of wood—supported by a ring stand—by fine copper wire tightened by violin keys.

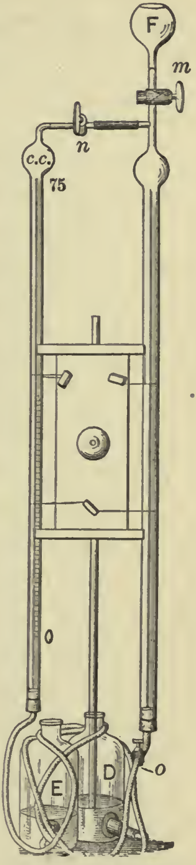

Fig. 10.—Elliott Gas Apparatus.

Manipulation.—The ground-glass joints are lubricated as in the Bunte apparatus. The levelling-bottles are filled with water, the stopcocks opened, and the bottles raised until the water flows through the stopcocks *m* and *n*. *m* is connected with the source whence the gas to be analyzed is to be taken, *n* closed, *D* lowered and rather more than 100 cc. drawn in, and *m* closed. *n* is opened, *D* raised and *E* lowered, nearly 100 cc. of gas introduced, and *n* closed; by opening *m* and raising *D* the remainder of the gas is allowed to escape, the tubes being filled with water and *m* closed. *n* is opened and the water brought to the reference-mark; the burette is allowed to drain one minute, the level of the water in *E* is brought to the same level as in the burette, and the reading taken.

Determination of Carbon Dioxide.—By raising *E*, opening *n*, and lowering *D*, the gas is passed over into the laboratory vessel; *F* is filled within half an inch of the top with potassium hydrate, *o* closed, *m* opened, and the reagent allowed to slowly trickle in. A No. 3 evaporating-dish is placed under *o*, and this turned to allow the liquid in the laboratory vessel to run into the dish. At first this is mainly water, and may be thrown away; later it becomes diluted reagent and may be returned to the thistle-tube. When the depth of the reagent in the thistle-tube has lowered to half an inch, it should be refilled either with fresh or the diluted reagent and allowed to run in until the absorption is judged to be complete, and the gas passed back into the burette for measurement. To this end close *o* and then *m*, raise *E*, open *n*, and force some pure water into the laboratory vessel, thus rinsing out the capillary tube. Now raise *D* and lower *E*, shutting *n* when the liquid has arrived at the reference-mark. The burette is allowed to drain a minute, the level of the water in the bottle *E* brought to the same level as the water in the burette, and the reading taken.

Determination of Oxygen.—The manipulation is the same as in the preceding determination, potassium pyrogallate being substituted for potassium hydrate; the apparatus requiring no washing out.

Determination of Carbonic Oxide.—The laboratory vessel, thistle-tube, and bottle if necessary, are washed free from potassium pyrogallate and the absorption made with acid cuprous chloride similarly to the determination of carbon dioxide. The white precipitate of cuprous chloride may be dissolved by hydrochloric acid.

Accuracy and Time Required.—The apparatus is as accurate for absorptions as that of Orsat; it is stated to be much more rapid—a claim which the writer cannot substantiate. It is not as portable, is more fragile, and more troublesome to manipulate, and as the burette is not jacketed it is liable to be affected by changes of temperature.

Notes.—In case at any time it is desired to stop the influx of reagent, *o* should be closed first and then *m*; the reason being that the absorption may be so rapid as to suck air in through *o*, *m* being closed.

The stopcock should be so adjusted as to cause the reagent to spread itself as completely as possible over the sides of the burette.

By the addition of an explosion-tube it is much used for the analysis of illuminating-gas,* bromine being used to absorb the "illuminants." Winkler † states that this absorption is incomplete; later work by Treadwell and Stokes, and also Korbuly, ‡ has shown that bromine water, by a purely physical solution, does absorb the "illuminants" completely; Hempel § states that explosions of hydrocarbons made over water are inaccurate, so that the apparatus can be depended upon to give results upon methane and hydrogen only within about 2 per cent. It is, however, very rapid, a complete analysis of illuminating gas can be made with it in fifty-minutes.

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* Mackintosh, Am. Chem. Jour. 9, 294.

† Zeit. f. Anal. Chem. 28, 286.

‡ Treadwell's Quan. Analysis (Hall's translation), p. 569.

§ Gasanalytische Methoden, p. 102.

CARBONIC ACID INDICATORS.

These usually depend upon the principle of collecting 100 cc. of the gas, causing it to pass through a suitable absorber and collecting the residue in a bell which floats to a greater or less height according to the residual volume. The fluctuations of this bell are recorded after the usual manner of self-registering barometers or thermometers; the usual time for this analysis and record is five minutes. The Gas-composimeter of Uehling* depends upon the laws governing the flow of gases through small apertures.

They are difficult to adjust and keep in adjustment, requiring to be checked frequently by the Orsat apparatus, and are expensive. They are, however, worth all they cost, both in money and trouble in using, and have come to be regarded almost as much a part of boiler-room equipment as a steam gage. They will repay their cost in a short time. Their indications are within about half of 1 per cent of those given by the chemical apparatus. Only the presence of carbon dioxide is indicated by them, although by the addition of combustion apparatus carbon monoxide is also registered.

References.—For the analysis of flue and chimney gases the following papers of the Bureau of Mines are recommended:

Apparatus for the Exact Analysis of Flue Gas. Burrell and Seibert, Technical Paper 31, 1913.

Sampling and Analyzing Flue Gases. Kreisinger and Ovitz. Bull. No. 97, 1915.

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* Gill, "Engine Room Chemistry."

Instruments for Recording Carbon Dioxide in Flue Gases. Barkley and Flagg. Bull. No. 91, 1916.

Use of the Interferometer in Gas Analysis. Seibert and Harpster, Technical Papers, 185, 198.

Combustion and Flue Gas Analysis. Technical Paper, 219.

CHAPTER III.

MEASUREMENT OF TEMPERATURE.

In the majority of cases, the ordinary mercurial thermometer will serve to determine the temperature of the chimney-gases. It should not be inserted naked into the flue, but be protected by a bath of cylinder, or raw linseed oil, or even sea sand, contained in a brass or iron tube. These tubes may be half an inch inside diameter and two to three feet in length. Temperatures as high as 625° C. have been observed in chimneys: this lasts of course but for a moment, but would be sufficient to burst the unprotected thermometer.

For the observation of higher temperatures, recourse must be had to the "high-temperature thermometers," filled with carbon dioxide or nitrogen under a pressure of about one hundred pounds, giving readings to 550° C.* These may be obtained of the dealers in chemical apparatus; some require no bath, being provided with a mercury-bath carefully contained in a steel tube, and the whole enclosed in a bronze tube.†

These thermometers should be tested from time to time either by comparison with a standard, or by inser-

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* H. J. Green of Brooklyn, N. Y., makes thermometers about three feet long, the scale occupying about one foot, thus avoiding the necessity of withdrawing the thermometer from the bath for reading.

† Hohmann Special Thermometers, made by Hohmann and Maurer Division, Taylor Instrument Co., Rochester, N. Y.

tion in various baths of a definite temperature. Some of the substances used for these baths are: water, boiling-point 100°; naphthalene, Bpt. 218°; tin, melting-point 231°; benzophenon, Bpt. 306°; and sulphur,* Bpt. 445°. Care should be taken that the bulb of the thermometer does not dip into the boiling liquid, but only into the vapor, and that the stem exposure be as nearly as possible that in actual use.

For the measurement of temperatures beyond the range of these thermometers, or even below it, in many cases, the Le Chatelier thermo-electric pyrometer may be used. This consists of a thermo-couple formed by the junction of a platinum and platinum-10% rhodium wire, passing through fire-clay tubes in a porcelain or iron envelope and connected with a galvanometer. The hotter the junction is heated the greater the current or electro-motive force.

If the couple be connected to a millivoltmeter, the temperature of the heated junction can be readily measured. This couple and junction may be calibrated by exposing it to several known temperatures. The boiling-point of sulphur, the melting-point of zinc 419°, aluminum 658°, and copper 1083°, may be used for this calibration. Since there is always a small electro-motive force at the cold junction where the thermocouple joins the lead-wires, or to the instrument

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* In testing the Hohmann thermometers in sulphur-vapor, the bronze tube should be prevented from corrosion by the vapor by a quartz envelope.

† Written in collaboration with his colleague Prof. Charles L. Norton, whose assistance is thankfully acknowledged.

itself, a correction for the cold junction or some compensation device is needed.

For most temperatures up to 1100°, couples of the "base metals" (Ni, Cr, Co, or Fe) may be used instead of platinum. There are a number of such alloys which have a large electro-motive force, the temperature variation of which bears nearly a straight line relation to the electro-motive force. These are relatively inexpensive, strong, and for general pyrometric work are very satisfactory.

Both the base-metal couples and the platinum couples need to be protected from chemical action by sealing or enclosing them in tubes of steel, porcelain, quartz or alundum. Protection tubes of these materials can be had in various sizes from the makers of pyrometers and potentiometers, so that with a multiple switch, permanent records can be made of the variations in temperature at a considerable number of points at one time.

For measuring the temperature of furnaces and fire boxes, optical pyrometers may be used. They are instruments for measuring the intensity of heat radiation given out by the heated body. Some of these instruments measure the total radiation from the hot body in the direction of the instrument. Others measure the temperature by determining the brightness or color of the hot body. A number of such instruments are now on the market. They are accurate and easy to use. For an adequate discussion of pyrometry see "Measurement of High Temperatures" by Burgess and Le Chatelier, or "Pyrometry Volume, April, 1920," of the American Institute of Mining and Metallurgical Engineers.

An error of 5° in the reading of the thermometer affects the final result in the case of a chimney gas by about 20 calories.

In case neither of these methods be available nor applicable, as in case of a locomotive smoke stack, use may be made of the melting-points of certain metals or salts contained in small cast-iron boxes, Fig. 11. The melting-points of certain metals and salts are given in Table X, Appendix. See also Bull. 145, Bur. Mines, "Measuring the Temperature of Gases in Boiler Settings (1918).

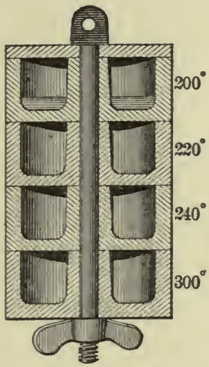

FIG. 11.—MELTING-POINT BOXES.

CHAPTER IV.

CALCULATIONS.

As has been already stated in the Introduction, the object of analyzing the flue-gases is to ascertain, first, the completeness of the combustion, especially the amount of air which has been used or the "pounds of air per pound of coal," and second, the amount of heat passing up chimney.

A. VOLUMETRIC OR MOLAL CALCULATION.*

1. To Ascertain the Pounds of Air per Pound of Coal.—The analysis of a chimney gas during a boiler test at the Rogers Building was as follows:

CO_2 11.5%, O_2 7.4%, CO 0.9%, N_2 80.2%. The coal was of the following † composition: Moisture 1.5%, carbon 83% (of which but 80% burned, 3% going into the ash) hydrogen 2.5%, ash 11.4%, sulphur 1.2%, oxygen and nitrogen (by difference) 0.4%. The table on page 33 shows the composition of the gas in more detail; for other data consult Table VIII, Appendix.

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* The author hereby gratefully acknowledges the assistance of his colleague, Prof. Sherrill, in this calculation.

† For the method of analysis see pages 84 and 85.

COMPOSITION OF THE CHIMNEY GAS (100 MOLS DRY GAS).

Gases.	Mol % or No. of Mols.	Wt. grams, Mols.	Total Mols free and Combined O_2.	No. of Atomic Wts. Combined C.	Wt. C. Burned.	Grms.
CO_2	11.5	11.5×44= 506.0	11.5	11.5	11.5×12	138.0
CO	0.9	0.9×28= 25.2	0.45	0.9	0.9×12	10.8
O_2	7.4	7.4×32= 236.8	7.4			
N_2	80.2	80.2×28=2245.6				
	100.0	3013.6	19.35	12.4		148.8

The weight of coal corresponding to this 148.8 grms. of carbon is $\frac{148.8}{80} \times 100 = 186.1$ grms.

$$80.2 \text{ mols. nitrogen} = \frac{80.2}{79.1} \times 100 = 101.4 \text{ mols. air.}$$

101.4 mols. air weigh 101.4×28.95 grms. = 2936.8 grms., then the pounds of air per pound of coal are $\frac{2936.8}{186.1} = 15.78$.

2. To Ascertain the Quantity of Heat Passing Up Chimney.—The heating value of the coal was 7220 calories per kilo: the mean specific heat of the chimney gases is 0.24: the temperature of the incoming air was 25° C., of the chimney gases was 275° C., a rise of 250° C.

One kilo of coal furnishes 0.8 kilo of carbon and this requires 15.78 kilos of air to burn it, generating 16.58 kilos of dry chimney gases. The heat these carry off is $16.58 \times 0.24 \times 250 = 995$ calories.

We have taken no cognizance of the water vapor passing up the stack: this comes from (*a*) the moisture in the coal; (*b*) the hydrogen in the coal, and (*c*) the moisture in the air.

(*a*) Moisture in coal, 1.5% = .015 kg.

(*b*) The increase in the per cent of nitrogen in the gases over that in the air (79.1), is due to the condensation of the steam coming from the burning of the hydrogen in the coal: 100 volumes of air contain 79.1 volumes of nitrogen which has in the chimney gas become 80.2. The volume of the gas is $\frac{791}{802} = 98.6\%$ of the original volume of air: or 1.4 of the 20.9 volumes of oxygen have combined with (2.8 volumes of) hydrogen to form 2.8 mols. of water: this weighs $2.8 \times 18 = 50.4$ grms. This comes from 186.1 grms. coal as in 1 or is 27.1 grms. per 100. From a kilo of coal then 0.271 kilo of water are formed.

(*c*) Moisture in the air: there were 15.78 kilos of air per kilo of coal (1) or $\frac{15.78}{1.294} = 12.20$ cu. meters; this was 50 per cent saturated with moisture and contained (Table 1, Appendix) 22.9 grms. if saturated.

$$12.2 = 22.9 \times 0.5 = .139 \text{ kilo.}$$

The water vapor is, (*a*) .015 + (*b*) .271 + (*c*) .139 = .425 kg. This carries off $.425 \times .480 \times 250 = 51$ calories. The heat lost is $995 + 51 = 1046$ calories: this divided by 7220, the heating value of the coal, is 14.48 %. That is 14.48% of the heating value of the coal goes up the chimney.

Ratio of Air Used to that Theoretically Necessary.— We note from the Table "Composition of the Chimney Gas," that there were 236.8 grams of oxygen passing through the grate unused, this corresponds to 1025 grms. of air: this corresponds to $\frac{1025}{186.1} = 5.51$ pounds of air per pound of coal: 15.78 pounds of air per pound of coal $- 5.51 = 10.27$ pounds of air actually used to burn a pound of coal. The ratio is $\frac{15.78}{10.27} = 1.536$ of air used, to air theoretically necessary as against 1.533, p. 39.

B. GRAVIMETRIC CALCULATION.

1. To Ascertain the Number of Pounds of Air per Pound of Coal.—A chimney-gas gave 11.5% CO_2, 7.4 O, 0.9% CO., and 80.2% N. Data: atomic weights, $O = 16$, $C = 12$; weight liter $CO_2 = 1.966$ grms., of N 1.251 grms. of CO, 1.251 grms. Find the number of grams of each constituent in 100 liters of the furnace-gas, and from this the weight of carbon and weight of oxygen. 11.5 (liters CO_2) × 1.97 (wt. liter CO_2) = 22.66 grms. CO_2; now $\frac{32}{44}\left(\frac{O_2}{CO_2}\right)$ of this is oxygen = 16.48 grms., 6.18 grms. is carbon. The weight of free nitrogen is $80.2 \times 1.251 = 100.3$ grms. The weight of carbon and oxygen in the carbonic oxide is $0.9 \times 1.25 = 1.12$ grms. CO. Now $\frac{16}{28}\left(\frac{O}{CO}\right)$ is oxygen or 0.64 grm., and 0.48 grm. is carbon. There are then present in 100 liters of the gas 100.3 grms. nitrogen and 6.66 grms. carbon; corresponding to 130.5 grms. air to 6.66 grms. carbon, air being 23.1% oxygen by weight; or 19.59 $\left.\begin{matrix}\text{grms.}\\\text{lbs.}\end{matrix}\right\}$ air per $\left.\begin{matrix}\text{grm.}\\\text{lb.}\end{matrix}\right\}$ *carbon.* If the coal be 83% carbon, this figure must be diminished accordingly, giving in this case 15.66 lbs. air per lb. of *coal*. A gave 15.78, p. 33. Theory requires 11.54 lbs. air per lb. of carbon, but in practice the best results are obtained by increasing this from 30% to 100%.*

2. To Ascertain the Quantity of Heat Passing up Chimney.—Determine the volume of gas generated from 1 kilo of coal when burned so as to produce the gas the analysis of which has just been made according to the directions given. The chemical analysis of the coal is as follows: moisture 1.5%, sulphur 1.2%, carbon 83%, hydrogen 2.5%, ash 11.4%, oxygen and nitrogen (by difference) 0.4%. Then there are in 1 kilo of coal 830 grms. carbon, of this suppose but 800 to be burned, the remaining 30 grms. going into the ash; of the 800 grms. 618/666 or 742 grms. produced carbon dioxide, and 48/666 or 58 grms. produced carbonic oxide. From 6.18 grms. carbon were produced 11.5 liters carbon dioxide in the problem in 1; hence 742 grms. would furnish 1381 liters. $6.18 : 742 :: 11.5 : y$. $y = 1381$. Similarly 58 grms. carbon would furnish 109.0 liters carbonic oxide. $0.48 : 58 :: 0.90 : z$. $z = 109.0$. The volume of oxygen can be found by the proportion $11.5(\% \, CO_2) : 7.4(\% O) :: 13.81 : x$. $x = 888$ liters. In the same maner the nitrogen is found to be 9631 liters. $11.5 : 80.2 :: 1381 : u$. $u = 9631$. One kilo of coal under these conditions furnishes 1.381 cu. meters carbon dioxide, 0.109 c. m. carbonic oxide, 0 888 c. m. oxygen, and 9.631 c. m. nitrogen.

The quantity of heat carried off by each gas is its rise of temperature × its weight × its specific heat.

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* Scheurer-Kestner, Jour. Soc. Chem. Industry, **7**, 616. 0.75 lb. per 1000 B.t.u. Nisbet, Power, **36**, 995 (1912). Kent. *id.*, **43**, 454 (1916).

The specific heats of the various gases are shown in the table below, and for facility in calculation, a column is given obtained by multiplying the weight by the specific heat; multiplying the volumes obtained in the previous calculation by the numbers in this column and by the rise in temperature gives the number of calories (C) that each gas carries away.

TABLE OF SPECIFIC HEATS OF VARIOUS GASES.*

Name of Gas.	Sp. Heat.	Wt. of Cu. M. Kg.	Sp. Heat × Wt. of Cu. M.	Log
Carbon dioxide (10°–350°)..	0.234	1.97	0.463	9.6656
" monoxide..........	0.245	1.26	0.308	9.4886
Oxygen..................	0.217	1.43	0.311	9.4928
Nitrogen.................	0.244	1.26	0.306	9.4857
Aqueous vapor............	0.480	0.80	0.387	9.5877

In the test the average temperature of the escaping gases was 275° C.; that of the air entering the grate was 25° C., a rise of temperature of 250° C. As shown by the wet-and-dry-bulb thermometer, the air was 50 per cent saturated with moisture.

The calculation of the heat carried away is then for:

	Cu. M.		C.
Carbon dioxide...............	1.381	×250×0.463=	160.0
Carbonic oxide...............	0.109	× " ×0.308=	8.4
Oxygen......................	0.888	× " ×0.311=	69.1
Nitrogen....................	9.631	× " ×0.306=	737.0
Total..................	12.009		974.5

There is, however, another gas passing up chimney of which we have taken no cognizance, namely, water-

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* Fischer, Tech. d. Brennstoff, p. 267.

vapor; this comes from the moisture in the coal, from the combustion of hydrogen in the coal, and from the air entering the grate; its volume is calculated as follows:

The moisture in the coal as found by chemical analysis was 1.5% = 0.015 kg.; the hydrogen in the coal was 2.5% = 0.025 kg. The amount of water this forms when burned is nine times its weight, 0.025 kg. × 9 = 0.225 kg. The moisture in the air entering the grate would be, if completely saturated, 22.9 grams per cubic meter, as shown by Table I; it was, however, but 50% saturated. The quantity is then, the volume of air used per kilogram of coal × moisture contained in it, or 11.955 × 22.9 × 0.50 = 0.137 kg. The volume of air used is the volume of gases generated 12.009 cu. meters (p. 37) less one-half the carbonic oxide .054 cu. m. The weight of aqueous vapor passing up chimney per kilogram of coal is 0.015 + 0.225 + 0.137 = 0.377 kg.; the quantity of heat that this carries off is 0.377 × 250 × 0.480 = 45.2 C. The total quantity of heat passing up chimney is then 1019.7 C. The heat of combustion of this coal as found by Mahler's calorimetric bomb was 7220 C.; hence the percentage of heat carried off is 1020/7220 = 14.1%.

RAPID METHODS OF CALCULATION.

The preceding calculations though correct are tedious, so much so, as to almost preclude their use for an hourly observation of the firing. They should be employed, however, in making the final calculation of a boiler-test, using the averages obtained.

Shields * has combined the operations in

1. Pounds of Air per Pound of Coal (p. 35), and obtains the following formula:

Pounds of air per pound of coal

$$=2.31\frac{\text{Per cent carbon in coal}}{\text{Per cent } CO_2+\text{per cent } CO}.$$

Similarly, **Per cent heat lost**

$$=\frac{\text{Per cent carbon in coal}}{\text{Heating value of coal}}\times\frac{200+\text{per cent } CO_2}{\text{Per cent } CO_2+\text{per cent } CO}$$
$$\times \text{rise in temperature in } ^\circ\text{ C.}\times 0.2864.$$

The values found by this equation are 0.5 per cent low, as no cognizance has been taken of the water vapor.

In rapid work the following formula will be found more applicable: Let *o* and *n* represent the percentages of oxygen and nitrogen found in the chimney-gas; then the ratio of the air actually used to that theoretically necessary is expressed by the formula

$$\frac{21}{21-\left(\frac{79o}{n}\right)}.$$

Applying it in the case of the flue-gas given, it becomes

$$\frac{21}{21-\left(\frac{79\times 7.4}{80.2}\right)}=\frac{21}{13.7}=1.533 \text{ ratio.}$$

Multiplying this by 11.54, the theoretical number of

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* Power, 30, 1121 (1909).

pounds of air per pound of carbon, we obtain 17.69 as against 19.59 on page 35.

Multiplying 17.69 by 83 (the per cent of carbon in the coal) we obtain 14.15 *pounds of air per pound of coal* as against 15.66 on p. 36.

Bunte * has given a shorter method for the determination of the quantity of heat passing up chimney, and one which does not involve the analysis of the coal.

For every per cent of carbonic acid present 43.43 cal. per cubic meter of flue-gases have been developed $=W$; $C=$specific heat of the flue-gases per cubic meter; then W/C represents the initial temperature (which is never attained) the ratio of which to the actual exit temperature of the flue-gases shows the heat lost. If $T=$this initial temperature and t the rise of temperature of the flue-gases, then t/T represents the heat lost in the chimney-gases.

The table on page 41 gives the data for the calculation for both pure carbon and coal of average value.

Applying these data to the problem on page 35 we find the initial temperature T to be 1762° C., the rise of temperature of the gases was 250° C., the loss is $250/1762=14.2\%$, against 14.1% found by the calculation page 38.

Bunte also employs a partially graphical method for the determination of the loss of heat. In Fig. 12 the extreme left-hand column represents the temperatures which should be obtained by the combustion of the average coal with the formation of a chimney-gas con-

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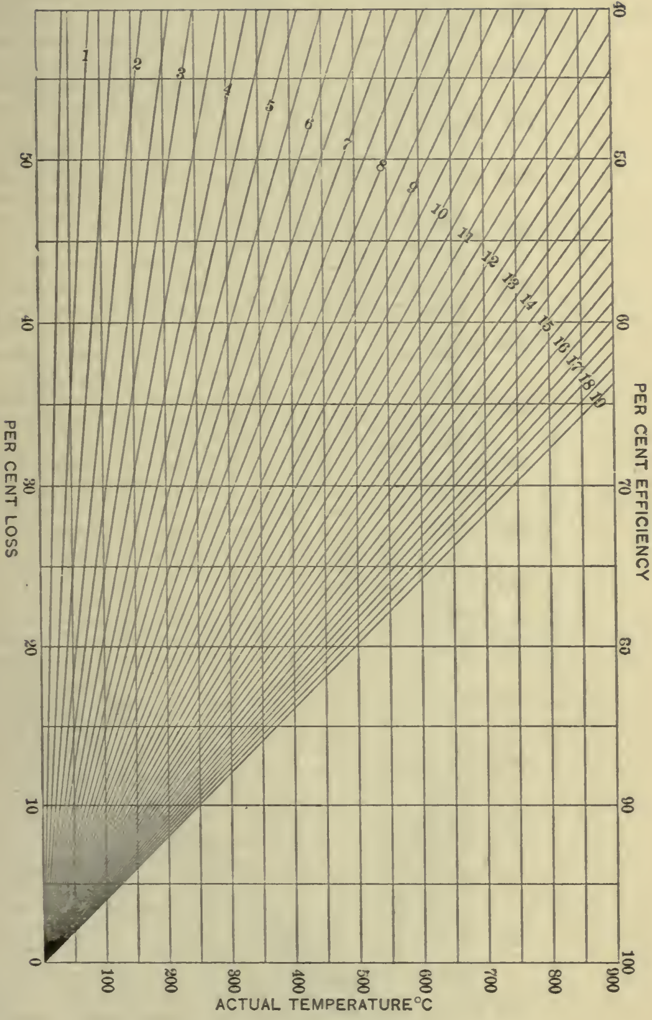
* Jour. f. Gasbeleuchtung, **43**, 637 (1900); Abstr. Jour. Soc. Chem. Industry, **19**, 887.

TABLE XI.


PER CENT LOSS
0
10
20
30
40
50
PER CENT EFFICIENCY
100
90
80
70
60
50
40
ACTUAL TEMPERATURE °C
0
100
200
300
400
500
600
700
800
900
1
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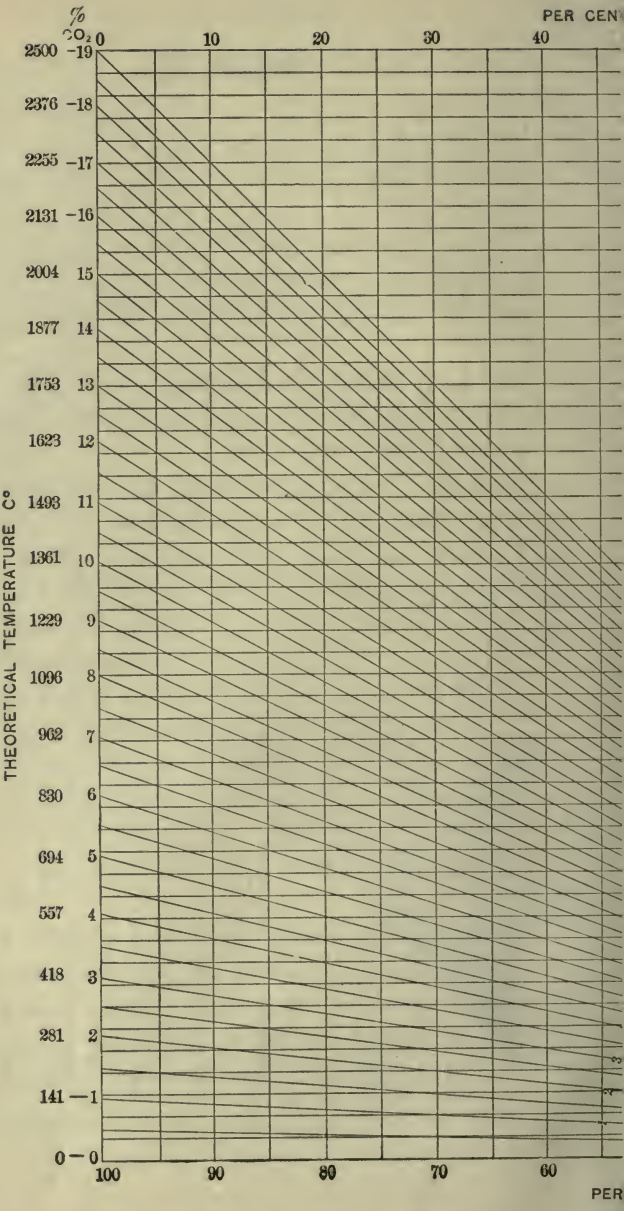
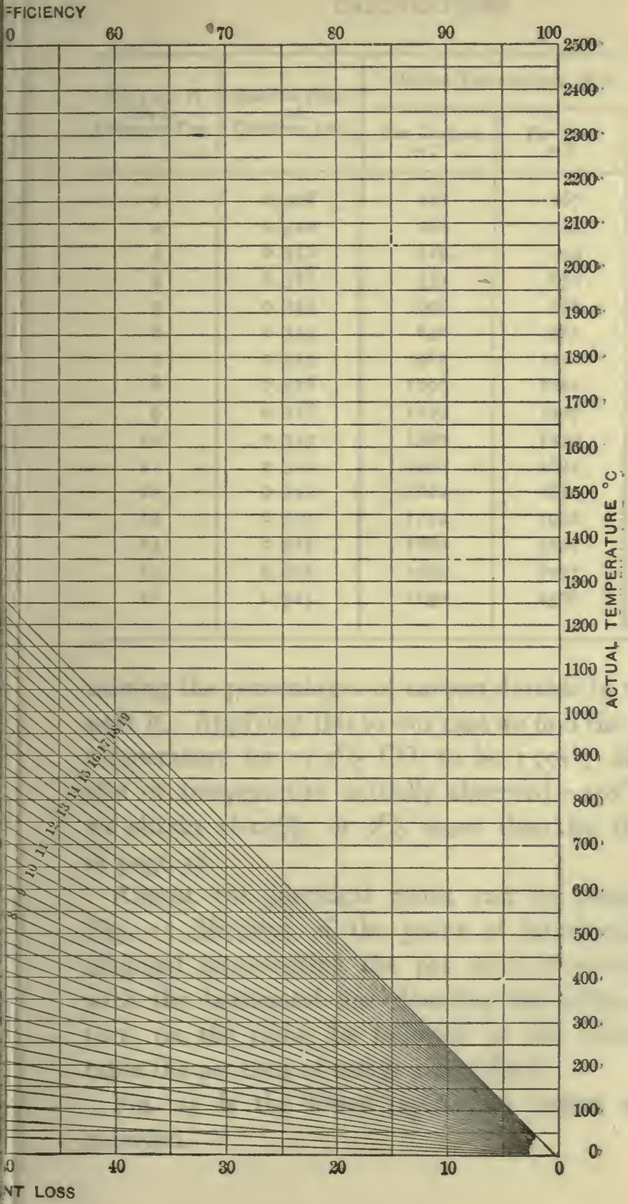


FIG. 12.—BUNTE'S CHART SHOWING HEAT LOST IN CHIM



-GASES FROM THE CARBONIC ACID AND THE TEMPERATURE.

[Between pages 40 and 41.]

Per Cent of CO_2 in Chimney Gas.	Specific Heat of Chimney Gas.	Initial Temperature, *W/C.* Degrees C		
		For Carbon = *T.*	For Coal = *T.*	Diff. for 0.1% CO_2.
1	0.308	141	167	16
2	0.310	280	331	16
3	0.311	419.	493	16
4	0.312	557	652	15
5	0.313	691	808	15
6	0.314	830	961	15
7	0.315	962	1112	15
8	0.316	1096	1261	15
9	0.318	1229	1407	14
10	0.319	1360	1550	14
11	0.320	1490	1692	14
12	0.322	1620	1830	14
13	0.323	1750	1968	13
14	0.324	1880	2102	13
15	0.324	2005	2237	13
16	0.325	2130	2366	

taining the percentages of carbon dioxide in the column next it. Applying this to our case we find the theoretical temperature for 11.5% CO, to be 1558°; dividing the rise of temperature actually observed—250°—by this, we obtain 16.05%, or 2% more than by the method of page 38.

Almost the identical result can be obtained from Fig. 13 directly: if the point of intersection of the diagonal representing the per cent of carbon dioxide with the horizontal line denoting the actual temperature, on the right, be followed to the bottom of the table the per cent of loss is ascertained.

Fig. 13 is the lower right-hand corner of Fig. 12 enlarged.

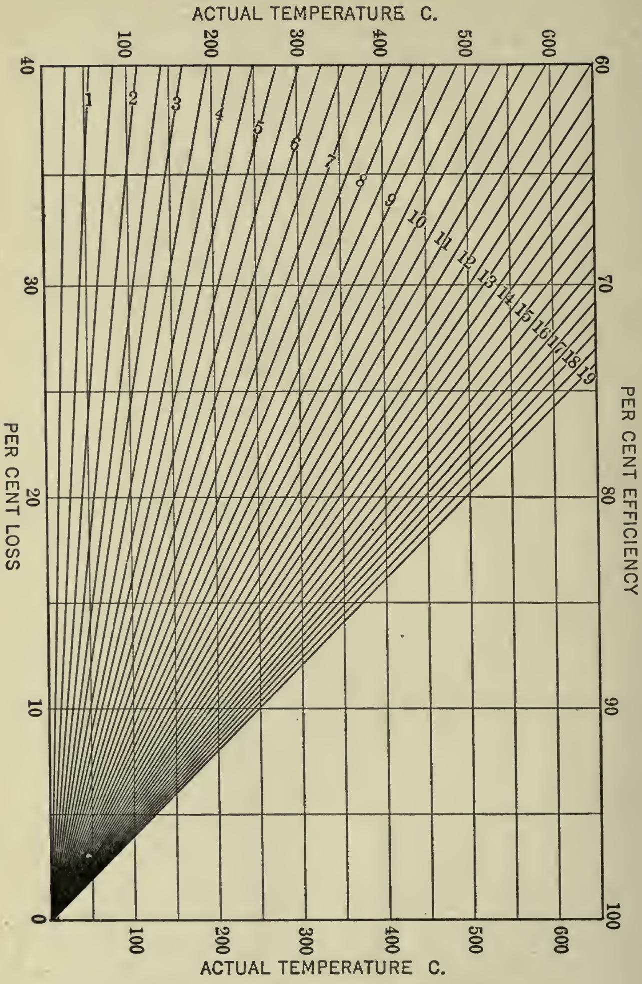


FIG. 13.—BUNTE'S FLUE GAS CHART, ENLARGED.

W. A. Noyes * states that the following formula gives close results and is also independent of the composition of the coal.

$$\text{Percentage loss} = \left(0.011 + \frac{100 - \%CO_2}{\%CO_2} 0.00605\right)(t' - t).$$

Lunge † has also given a shorter method for the calculation of the heat lost.

The following table ‡ shows roughly the excess of air and the per cent of heat lost in the chimney gases:

PER CENT OF CARBONIC ACID.	2	3	4	5	6	7	8	9	10	11	12	13	14	15
VOLUME OF AIR MORE THAN THEORY. (Theory = 1.0).	9.5	6.3	4.7	3.8	3.2	2.7	2.4	2.1	1.9	1.7	1.6	1.5	1.4	1.3
PER CENT LOSS OF HEAT. .Temp. of chimney gases, 518° F	90	60	45	36	30	26	23	20	18	16	15	14	13	12

Notes.—The increase in per cent of nitrogen over that in the air, 79.1, is due to the condensation of the steam formed from the hydrogen in the coal: this, as has been shown, p. 34, amounts to 1.4 of the 20.9 volumes of oxygen, and form 2.8 volumes or mols of water.

The question is often asked "What percentage of carbon dioxide should be obtained?" The table by

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* Am. Chem. Journal, 19, 162

† Zeit. f. angewandte Chemie, 1889, 240.

‡ Arndt's Econometer Circular.

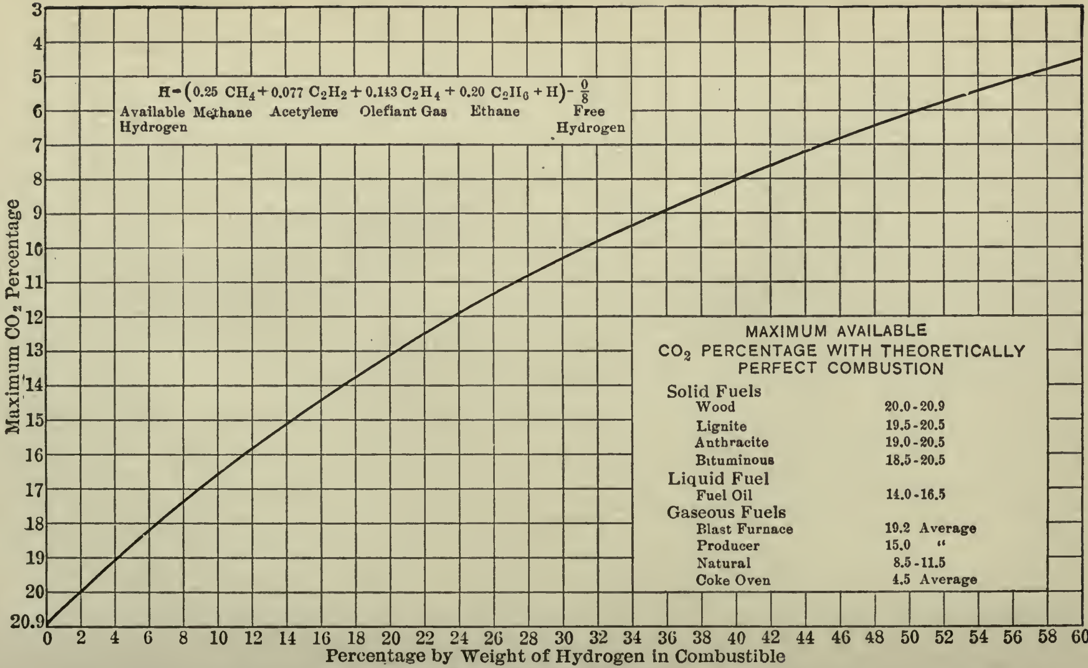

FIG. 14.—AZBE'S CHART.

Curve showing available CO_2 at theoretically perfect combustion with fuels of different hydrogen contents.

Azbe,[*] Fig. 14, shows the available CO_2 with different fuels. With coal, the maximum efficiency is between 14 and 15.5 per cent; an average of from 12 to 14 per cent; with oil, 13 to 14 per cent; with natural gas from 8 to 9 per cent, are all good practice.[†] Carbon monoxide should not exceed 0.5 per cent.

If the per cent of oxygen be 1.5 – 2 (and the draft through the fire high), the fire is too thick; if it be less than 8 per cent the fire is too thin.

The permissible excess of air is with coal from 30–100 per cent; with oil not over 25 per cent; and with natural gas 10 or 15 per cent.

In attempting to obtain good combustion, there is danger in carrying it too far, *i.e.*, in forcing the percentage of CO_2 too high, ensuring a loss, through the formation of carbon monoxide. Care should be taken that the gain in carbon *dioxide* be not more than offset by a loss in carbon *monoxide*.

Determination of Loss Due to Formation of Carbonic Oxide.—*A*. From page 33, seventh column, we see that 10.8 grams carbon of that in 186.1 grams of coal burn to carbon monoxide; this is 58 grams carbon per kilo as in *B*.

B. On page 36 we see that 58 grams of carbon burned to carbonic oxide; for every gram of carbon burned to carbonic oxide there is a loss of 5.66 C., in this case a loss of 328 C. The heating value of the coal is 7220 C., hence the loss is 4.5 per cent. Combustion gases from oil gas fuels should always be tested for carbon monoxide.[‡]

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[*] Azbe, Power, **43**, 543 (1916).

[†] Power, **48**, 956 (1918).

[‡] Wales, Power, **45**, 347 (1917).

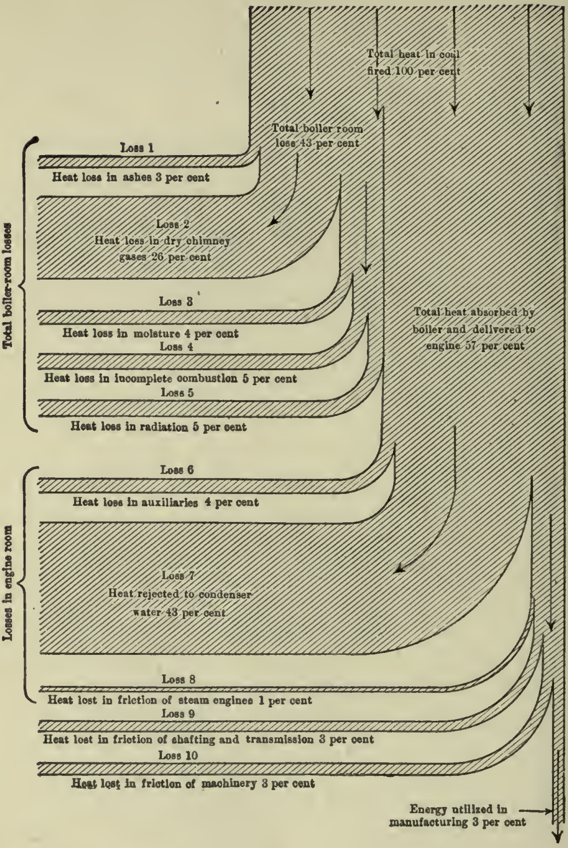

FIG. 15.—LOSSES IN AN AVERAGE INDUSTRIAL PLANT HAVING 1000–2000 H.P. THE BRANCHES TURNING TO THE LEFT REPRESENT THE LOSSES.

Other Losses.—Kreisinger and Ovitz (Bureau Mines Bulletin 97, p. 35), have admirably shown the other sources of loss. This is so important that it is here reproduced, Fig. 14.

REFERENCES.—Hutzel, *Power*, 44, 821 (1916).
O'Neill, *Power*, 47, 52 (1918).
J. W. Richards, "*Metallurgical Calculations.*"

CHAPTER V.

APPARATUS FOR THE ANALYSIS OF FUEL AND ILLUMINATING GASES.

HEMPEL'S APPARATUS.

Description.—The apparatus, Figs. 16 and 17, is very similar in principle to that of Orsat; the burette is longer, admitting of the reading of small quantities of gas, and the pipettes are separate and mounted in brass clamps on iron stands. *P* shows a "simple" pipette * provided with a rubber bag; this form, after ten years of use, can be said to satisfactorily take the place of the cumbersome "compound" pipette.

The pipette for fuming sulphuric acid † is shown at *F*, and differs from the ordinary in that vertical tubes after the manner of those in the Orsat pipettes replace the usual glass beads. This prevents the trapping of any gas by the filling, which was so common with the beads and glass wool. *E* represents the large explosion pipette, ‡ of about 250 cc. capacity, with walls half an inch thick; the explosion wires enter at the top and bottom to prevent short-circuiting; mercury is the confining liquid. The small explosion pipette holds

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* Gill, Am. Chem. J., 14, 231 (1892).

† *Id.*, J. Am. Chem. Soc., 18, 67 (1896).

‡ Gill, J. Am. Chem. Soc., 17, 771 (1895).

about 110 cc. and is of glass, the same thickness as the simple pipettes. Water is here used as the confining liquid, and also usually in the burette.

An induction coil capable of giving a half-inch spark, with a six-cell "Samson" battery, four "simple" pipettes and a mercury burette, complete the outfit.

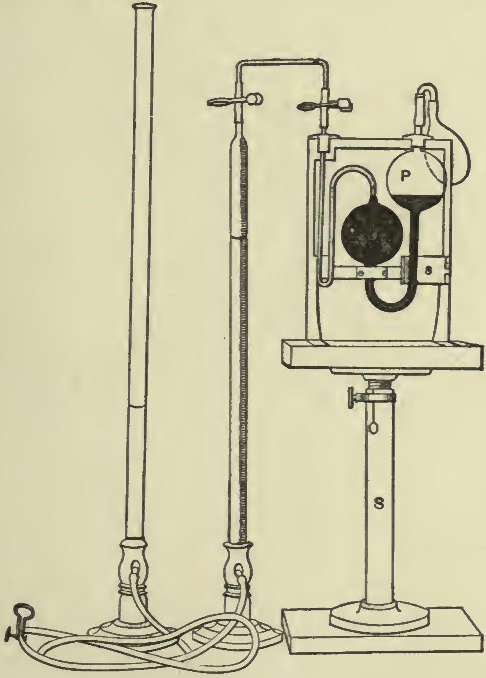

FIG. 16.—SHOWING HEMPEL BURETTE CONNECTED WITH THE SIMPLE PIPETTE ON THE STAND.

The burette should be carefully calibrated and the corrections may very well be etched upon it opposite the 10-cc. divisions.

In working with the apparatus the pipettes are placed upon the adjustable stand *S* and connection made with the doubly bent capillary tube.

Manipulation.—To acquire facility with the use of the apparatus before proceeding to the analysis of illuminating-gas, it is well to make the following determinations, obtaining "check readings" in every case: I. Oxygen in air, by (1) absorption with phosphorus; (2) absorption with potassium (or sodium) pyrogallate; (3) by explosion with hydrogen.

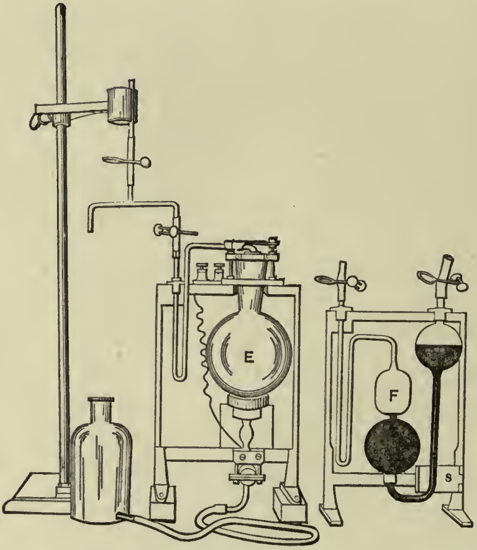

Fig. 17.—Explosion Pipette for Mercury and Sulphuric Acid Pipette.

I. DETERMINATION OF OXYGEN IN AIR.

(1) **By Phosphorus.**—100 cc. of air are measured out as with the Orsat apparatus, the burette being allowed to drain two minutes. The rubber connectors upon the burette and pipette are filled with water, the capillary tube inserted, as far as it will go, by a twisting motion, into the connector upon the burette, thus filling the capillary with water; the free end of the capillary is inserted into the pipette connector, the latter pinched so as to form a channel for the water contained in it to escape, and the capillary twisted and forced down to the pinch-cock. There should be as little free space as possible between the capillaries and the pinch-cock. Before using a pipette, its connector (and rubber bag) should be carefully examined for leaks, especially in the former, and if any found the faulty piece replaced.

The pinch-cocks on the burette and pipette are now opened, the air forced over into the phosphorus, and the pinch-cock on the pipette closed; action immediately ensues, shown by the white fumes; after allowing it to stand for fifteen minutes the residue is drawn back into the burette, the latter allowed to drain and the reading taken. The absorption goes on best at 20° C., not at all at below 15° C.; it is very much retarded by small amounts of ethene and ammonia. No cognizance need be taken of the fog of oxides of phosphorus.

(2) **By Pyrogallate of Potassium.**—100 cc. of air are measured out as before, the carbon dioxide absorbed with potassium hydrate and the oxygen with potassium

pyrogallate, as with the Orsat apparatus; before setting aside the pyrogallate pipette, the number of cubic centimeters of oxygen absorbed should be noted upon the slate *s* on the stand. This must never be omitted with any pipette save possibly that for potassium hydrate, as failure to do this may result in the ruin of an important analysis. The reason for the omission in this case is found in the large absorption capacity—four to five litres of carbon dioxide—of the reagent.

(3) **By Explosion with Hydrogen.**—43 cc. of air and 57 cc. of hydrogen are measured out, passed into the small explosion pipette, the capillary of the pipette filled with water, the pinch-cocks and glass stop-cock all closed, a heavy glass or fine wire gauze screen placed between the pipette and the operator, the spark passed between the spark wires, and the contraction in volume noted. *The screen should never be omitted, as serious accidents may occur thereby.* The oxygen is represented by one third of the contraction. For very accurate work the sum of the combustible gases should be but one sixth that of the non-combustible gases, otherwise some nitrogen will burn and high results will be obtained;* that is, $(H + O) : (N + H) :: 1 : 6$.

II. ANALYSIS OF ILLUMINATING-GAS.

100 cc. of gas are measured from the bottle containing the sample into the burette.

Determination of Carbon Dioxide.—The burette is connected with the pipette containing potassium

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* This is shown in the work of Gill and Hunt, J. Am. Chem. Soc., 17, 987 (1895).

hydrate and the gas passed into it with shaking until no further diminution in volume takes place.

Illuminants, C_nH_{2n}, C_nH_{2n-6} Series.—The rubber connectors are carefully dried out with filter-paper, a dry capillary used, and the gas passed into the pipette containing fuming sulphuric acid and allowed to stand, with occasional passes to and fro, for forty-five minutes. On account of the extremely corrosive nature of the absorbent it is not advisable to shake the pipette, as in case of breakage a serious accident might occur. For Boston gas this is sufficient, although with richer gases check readings to 0.2 cc. should be obtained. It is then passed into potassium hydrate, as in the previous determination, to remove any sulphurous acid which may have been formed and any sulphuric anhydride vapor, these having a higher vapor tension than water. The difference between this last reading and that after the absorption of the carbon dioxide represents the volume of "illuminants" or "heavy hydrocarbons" present.

As has already been stated, page 25, saturated bromine water may replace the fuming sulphuric acid. Fuming nitric acid is not recommended, as it is liable to oxidize carbonic oxide.

Oxygen.—This is absorbed, as in the analysis of air, by potassium or sodium pyrogallate.

Carbonic Oxide.—The gas is now passed into ammoniacal cuprous chloride, until the reading is constant to 0.2 cc.; it is then passed into a second pipette,* which is fresh, and absorption continued until constant readings are obtained.

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* White states this should not have absorbed more than 10 cc.

For very accurate work the gas should be absorbed in a U tube of iodic anhydride heated to 150°. Extreme care must be taken to prevent contact of the gas with sulphur, organic matter, as vaseline and rubber,* as the anhydride is readily reduced. The reaction is

$$5CO+I_2O_5=5CO_2+2I.$$

The diminution in volume represents the carbonic oxide; or the iodine can be determined in the usual way with thiosulphate.

The volume of air contained in the tube should be corrected for as follows: One end of the tube is plugged tightly and the other end connected with the gas burette partly filled with air. A bath of water at 9° C. is placed around the U-tube and the reading of the air in the gas burette recorded when constant; the bath is now heated to 100° and the burette reading again recorded when constant. The increase in reading represents one third the volume of the U-tube, $273:273+(100-9)::3:4$.

Methane and Hydrogen.—(*a*) *Hinman's Method.*† —The gas left from the absorption of carbonic oxide is passed into the large explosion pipette. About half the requisite quantity of oxygen (40 cc.) necessary to burn the gas is now added, mercury introduced through the T in the connector sufficient to seal the capillary of the explosion pipette, all rubber connectors carefully wired, the pinch-cocks closed, and the pipette cautiously shaken. A screen of heavy glass or fine wire gauze is interposed between the operator and the

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* Morgan & McWhorter, J. Am. Chem. Soc., **22**, 14 (1900).

† Gill and Hunt, J. Am. Chem. Soc., **17**, 987 (1895).

apparatus, the explosion wires are connected with the induction coil, a spark passed between them and the pinch-cocks opened, sucking in the remainder of the oxygen. The capillary is again sealed with mercury, the stop-cock opened and closed, to bring the contents of the pipette to atmospheric pressure, and the explosion repeated as before, and the stop-cock opened.

It may be found expedient, to increase the inflammability of the mixture, to introduce 5 cc. of "detonating-gas," the hydrolytic mixture of hydrogen and oxygen. The gas in the pipette containing carbon dioxide, oxygen, and nitrogen is transferred to the mercury burette and accurately measured. The carbon dioxide resulting from the combustion of the marsh-gas is determined by absorption in potassium hydrate; to show the presence of an excess of oxygen, the amount remaining is determined by absorption with potassium pyrogallate.

The calculation is given on page 56. For very accurate work a second analysis should be made, making successive explosions, using the percentages of methane and hydrogen just found as a basis upon which to calculate the quantity of oxygen to be added each time. The explosive mixture should be so proportioned that the ratio of combustible gas (i.e., CH_4, H and O) is to the gases which do not burn (i.e., N and the excess of CH_4 and H) as 100 is to about 50 (from 26 to 64);* otherwise the heat developed is so great as to produce oxides of nitrogen, which, being absorbed

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* Bunsen, Gasometrische Methoden, 2d ed., p. 73 (1877).

in the potassium hydrate, would affect the determination of both the methane and the hydrogen. The oxygen should preferably be pure, although commercial oxygen, the purity of which is known, can be used; the oxygen content of the latter should be tested from time to time, especially with different samples.

(*b*) *Hempel's Method.**—From 12 to 15 cc. of the gas are measured off into the burette (e.g., 13.2 cc.) and the residue is passed into the cuprous chloride pipette for safe keeping. That in the burette is now passed into the small explosion pipette; a volume of air more than sufficient to burn the gas, usually about 85 cc., is accurately measured and also passed into the explosion pipette, and in so doing water from the burette is allowed to partially fill the capillary of the pipette and act as a seal. The rubber connectors upon the capillaries of the burette and pipette are carefully wired on, both pinch-cocks shut, and the stop-cock closed. The pipette is cautiously shaken, the screen interposed, the explosion wires connected with the induction coil, a spark passed between them, and the stop-cock immediately opened. The gas in the pipette, containing carbon dioxide, oxygen, and nitrogen, is transferred to the burette, accurately measured, by reading immediately, to prevent the absorption of carbon dioxide, and carbon dioxide and oxygen determined in the usual way.

Calculation.—(*a*) *Hinman's Method.*—56.2 cc. of gas remained after the absorptions; 77.4 cc. of oxygen were introduced, giving a total volume of 133.6 cc.

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* Hempel, Gas Analytische Methoden, 3d ed., p. 245 (1901).

Residue after explosion	46.9 cc.
Residue after CO_2 absorption	28.2 "
Carbon dioxide formed	18.7 "
Contraction.......133.6 — 46.9 =	86.7 "
Residue after O absorption	25.6 "
Oxygen in excess, 28.2 — 25.6 =	2.6 "

The explosion of marsh-gas or methane is represented by the equation*

$$\boxed{CH_4} + \boxed{O_2}\,\boxed{O_2} = \boxed{CO_2} + \boxed{H_2O} + \boxed{H_2O}.$$

From this it is evident that the volume of carbon dioxide is equal to the volume of methane present; therefore in the above example, in the 56.2 cc. of gas burned there were 18.7 cc. methane.

The total contraction is due (1) to the disappearance of oxygen in combining with the hydrogen of the methane, and (2) to the union of the free hydrogen with oxygen. The volume of the methane having been found, (1) can be ascertained from the equation above, equals twice the volume of the methane; hence

$$86.7 - (2 \times 18.7) = 49.3 \text{ cc.},$$

contraction which is due to the combustion of hydrogen. This takes place according to the following reaction:*

$$\boxed{H_2} + \boxed{H_2} + \boxed{O_2} = \boxed{H_2O} + \boxed{H_2O}.$$

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* H_2O being as steam at 100° C. At ordinary temperatures this is condensed, giving rise to "total contraction."

Hydrogen then requires for its combustion half its volume of oxygen, hence this 49.3 cc. represents a volume of hydrogen with ½ its volume of oxygen, or $\frac{3}{2}$ volumes; hence the volume of hydrogen is 32.9 cc.

(*b*) *Hempel's Method.*—Of the 82 cc. of gas remaining after the absorptions, 13.2 cc. were used for the explosion; 86.4 cc. air introduced giving a total volume of 99.6 cc.

Residue after explosion...........	78.0	cc.
Residue after CO_2 absorption......	73.2	"
Carbon dioxide formed...........	4.8	"
Contraction........99.6 − 78.0 =	21.6	"
Residue after O absorption........	70.2	"
Oxygen in excess. .73.2 − 70.2 =	3.0	"

The carbon dioxide being equal to the methane present, in the 13.2 cc. of gas burned, there were 4.8 cc. of methane. The volume of methane is found by the proportion 13.2 : 82 :: 4.8 : x, whence $x =$ 29.8 cc.

The hydrogen is calculated similarly.

The following method of calculation may be substituted for that on page 55: Let m = methane, h = hydrogen, c = total contraction, and O = oxygen actually used; then

$$2m + \frac{h}{2} = O$$

and

$$2m + \frac{3h}{2} = c,$$

whence

$$m = \frac{3O - c}{4}$$

and

$$h = c - O.$$

The explosion can also be made after the absorption of oxygen and thus the troublesome absorption of carbonic oxide avoided. The calculation is then, if $C =$ carbonic oxide, $K = CO_2$ formed:

$$c = \frac{C}{2} + 2m + \frac{3h}{2}, \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$K = C + m, \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$V = C + m + h; \quad . \quad . \quad . \quad . \quad (3)$$

whence

$$h = V - K,$$

$$C = \frac{K}{3} + V - \frac{2c}{3},$$

$$m = \frac{2K}{3} - V + \frac{2c}{3}.$$

Another method for the estimation of hydrogen is by absorption with palladium sponge;* it, however, must be carefully prepared, and it is the author's experience that one cannot be sure of its efficacy when it is desired to make use of it. A still better absorbent of hydrogen † is a 1 per cent solution of palladous

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* Hempel, Berichte deutsch. ch. Gesell., **12**, 636 and 1006 (1879).

† Campbell and Hart, Am. Chem. J., **18**, 294 (1896).

chloride at 50° C.; when fresh this will absorb 20–50 cc. of hydrogen in ninety minutes. A proportionately longer time is required if more hydrogen be present or the solution nearly saturated. The methane could then be determined by explosion or by mixing with air and passing to and fro over a white-hot platinum spiral in a tubulated pipette called the grisoumeter [*] (grisou = methane).

Nitrogen.—There being no direct and convenient method for its estimation with this apparatus, the percentage is obtained by finding the difference between the sum of all the percentages of the gases determined and 100 per cent.

New [†] determines nitrogen in illuminating-gas directly after the method of Dumas in organic substances; 150 cc. of gas are used, the hydrocarbons partially absorbed by fuming sulphuric acid and the remainder burned in a combustion tube with copper oxide; the carbon dioxide is absorbed and the residual nitrogen collected and measured.

Accuracy and Time Required.—For the absorptions the apparatus is accurate to 0.1 cc.; for explosions by Hinman's method [‡] the methane can be determined within 0.2 per cent, the hydrogen within 0.3 per cent; by Hempel's method within 1 per cent for the methane and 7.5 per cent for the hydrogen. The time required for the analysis of illuminating-gas is from three to three and one-half hours; for air, from fifteen to twenty minutes.

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[*] Winkler, Fres. Zeit., 28, 269 and 288.

[†] J. Soc. Chem. Ind., 11, 415 (1892).

[‡] Gill and Hunt, *loc cit.*

Notes.—The object in filling the capillaries of the explosion pipettes with water or mercury before the explosion is to prevent the bursting of the rubber connectors on them. With mercury this is effected by introducing it through the T joint in the connector. After testing for oxygen with the pyrogallate a small quantity of dilute acetic acid is sucked into the burette to neutralize any alkali which by any chance may have been sucked over into it. The acid is rinsed out with water and this forced out by mercury before the burette is used again.

The water in the burette should be saturated with the gas which is to be analyzed—as illuminating-gas—before beginning an analysis. The reagents in the pipettes should also be saturated with the gases for which they are not the reagent. For example, the fuming sulphuric acid should be saturated with oxygen, carbon monoxide, methane, hydrogen, and nitrogen; this is effected by making a blank analysis using illuminating-gas.

The method of analysis of the residue after the absorptions have been made by explosion is open to two objections: 1st, the danger of burning nitrogen by the violence of the explosion; and 2d, the danger of breakage of the apparatus and possible injury to the operator. These may be obviated by employing the apparatus of Dennis and Hopkins,* which is practically a grisoumeter with mercury as the confining liquid; or that of Jager,† who burns the gases with oxygen in a

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* J. Am. Chem. Soc., **21**, 398 (1899).

† J. f. Gasbeleuchtung, **41**, 764. Abstr. J. Soc. Chem. Ind., **17**, 1190 (1898).

hard-glass tube filled with copper oxide. By heating to 250° C. nothing but hydrogen is burned; higher heating of the residue burns the methane. Or the mixture of oxygen and combustible gases, bearing in mind the ratio mentioned at the bottom of page 55; can be passed to and fro through Drehschmidt's* capillary heated to bright redness. This consists of a platinum tube 20 cm. long, 2 mm. thick, 1.7 mm. bore, filled with three platinum or palladium wires. The ends of the tube are soldered to capillary brass tubes and arranged so that these can be water cooled. It is inserted between the burette and a simple pipette, mercury being the confining liquid in both cases. The air contained in the tube can be determined as in the case of the tube containing iodic anhydride, p. 54.

To the method of explosion by the mixture of an aliquot part of the residue with air, method (*b*), there is the objection that the carbon dioxide formed is measured over water in a moist burette, giving abundant opportunities for its absorption, and that the errors in anylysis are multiplied by about six, in the example by $\frac{820}{132}$.

REFERENCES.—
Dennis, "*Gas Analysis.*"
White, "*Technical Gas and Fuel Analysis.*"

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* Ber. d. deut. chem. Gesell., 21, 3242 (1888).

CHAPTER VI.

REAGENTS AND ARRANGEMENT OF THE LABORATORY.

THE reagents used in gas-analysis are comparatively few and easily prepared.

Hydrochloric Acid, Sp. gr. 1.10.—Dilute "muriatic acid" with an equal volume of water. In addition to its use for preparing cuprous chloride, it finds employment in neutralizing the caustic solutions which are unavoidably more or less spilled during their use.

Fuming Sulphuric Acid.—Saturate "Nordhausen oil of vitriol" with sulphuric anhydride. Ordinary sulphuric acid may be used instead of the Nordhausen; in this case about an equal weight of sulphuric anhydride will be necessary. *Absorption capacity*, 1 cc. absorbs 8 cc. of ethene (ethylene).

Acid Cuprous Chloride.—The directions given in the various text-books being troublesome to execute, the following method, which is simpler, has been found to give equally good results. Cover the bottom of a two-liter bottle with a layer of copper oxide or "scale" $\frac{3}{8}$ in. deep, place in the bottle a number of pieces of rather stout copper wire reaching *from top to bottom*, sufficient to make a bundle an inch in diameter, and fill the bottle with common hydrochloric acid of 1.10 sp. gr. The bottle is occasionally shaken, and when the solution is colorless, or nearly so, it is poured into the half-liter reagent bottles, containing copper wire, ready for use. The space left in the stock bottle should be immediately filled with hydrochloric acid (1.10 sp. gr.).

By thus adding acid or copper wire and copper oxide when either is exhausted, a constant supply of this reagent may be kept on hand.

The absorption capacity of the reagent per cc. is, according to Winkler, 15 cc. CO; according to Hempel 4 cc. The author's experience with Orsat's apparatus gave 1 cc.

Care should be taken that the copper wire does not become entirely dissolved and that it extend from the top to the bottom of the bottle; furthermore the stopper should be kept thoroughly greased the more effectually to keep out the air, which turns the solution brown and weakens it.

Ammoniacal Cuprous Chloride. — The acid cuprous chloride is treated with ammonia until a faint odor of ammonia is perceptible; copper wire should be kept in it similarly to the acid solution. This alkaline solution has the advantage that it can be used when traces of hydrochloric acid vapors might be harmful to the subsequent determinations, as, for example, in the determination of hydrogen by absorption with palladium. It has the further advantage of not soiling mercury as does the acid reagent.

Absorption capacity, 1 cc. absorbs 1 cc. CO.

Cuprous chloride is at best a poor reagent for the absorption of carbonic oxide; to obtain the greatest accuracy where the reagent has been much used, the gas should be passed into a fresh pipette for final absorption, and the operation continued until two consecutive readings agree exactly. The compound formed by the absorption—possibly Cu_2COCl_2—is very unstable, as carbonic oxide may be freed from the solution by boiling or placing it in vacuo; even if it be shaken up with N_2, the gas is given off, as shown by the increase in volume and subsequent diminution when shaken with fresh cuprous chloride.

Hydrogen.—A simple and effective hydrogen generator can be made by joining two six-inch calcium chloride jars by their tubulatures. Pure zinc is filled in as far as the constriction in one, and the mouth closed with a rubber stopper carrying a capillary tube and a pinch-cock. The other jar is filled with sulphuric acid 1 : 5 which has been boiled and cooled out of access of air. The mouth of this jar is closed with a rubber stopper carrying one of the rubber bags used on the simple pipettes.

Mercury.—The mercury used in gas analysis should be of sufficient purity as not to "drag a tail" when poured out from a clean vessel. It may perhaps be most conveniently cleaned by the method of J. M. Crafts, which consists in drawing a moderate stream of air through the mercury contained in a tube about 3 feet long and 1¼ inches internal diameter. The tube is supported in a mercury-tight V-shaped trough, of size sufficient to contain the metal if the tube breaks, one end being about 3 inches higher than the other. Forty-eight hours' passage of air is sufficient to purify any ordinary amalgam. The mercury may very well be kept in a large separatory funnel under a layer of strong sulphuric acid.

Palladous Chloride.—5 grams palladium wire are dissolved in a mixture of 30 cc. hydrochloric and 2 cc. nitric acid, this evaporated just to dryness on a water-bath, redissolved in 5 cc. hydrochloric acid and 25 cc. water, and warmed until solution is complete. It is diluted to 750 cc. and contains about one per cent of palladous chloride. It will absorb about two thirds of its volume of hydrogen.

Phosphorus.—Use the ordinary white phosphorus cast in sticks of a size suitable to pass through the opening of the tubulated pipette.

Potassium Hydrate.—(*a*) For carbon dioxide determination, 500 grams of the commercial hydrate is dissolved in 1 liter of water.

Absorption capacity, 1 cc. absorbs 40 cc. CO_2.

(*b*) For the preparation of potassium pyrogallate for special work, 120 grams of the commercial hydrate is dissolved in 100 cc. of water.

Potassium Pyrogallate.—Except for use with the Orsat or Hempel apparatus, this solution should be prepared only when wanted. The most convenient method is to weigh out 5 grams of the solid acid upon a paper, pour it into a funnel inserted in the reagent bottle, and pour upon it 100 cc. of potassium hydrate (*a*) or (*b*). The acid dissolves at once, and the solution is ready for use.

If the percentage of oxygen in the mixture does not exceed 28, solution (*a*) may be used;* if this amount be exceeded, (*b*) must be employed. Other-

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* Clowes, Jour. Soc. Chem. Industry, **15**, 170. Anderson, J. I. and Eng. Chem., **7**, 595 (1915), recommends a solution of 15 grm. pyrogallol in 100 cc. KOH sp. gr. 1.55.

wise carbonic oxide may be given off even to the extent of 6 per cent.

Attention is called to the fact that the use of potassium hydrate purified by alcohol has given rise to erroneous results.

Absorption capacity, 1 cc. absorbs 2 cc. O.

Sodium Hydrate.—Dissolve the commercial hydrate in three times its weight of water. This may be employed in all cases where solution (*a*) of potassium hydrate is used. The chief advantage in its use is its cheapness. Anderson * states that it is not practicable to use it for pyrogallol; this is at variance with the experiments of Wehl †, Berthelot ‡ and the author. It has been so used in the author's laboratory for more than twenty-five years, the absorption is rapid and complete. Sodium pyrogallate is, however, a trifle slower in action than the corresponding potassium salt.

ARRANGEMENT OF THE LABORATORY.

The room selected for a laboratory for gas-analysis should be well lighted, preferably from the north and east. To prevent changes in temperature it should be provided with double windows, and the method of heating should be that which will give as equable a temperature as possible. In the author's laboratory, instead of the usual tables, shelves are used, 18 inches wide and $1\frac{1}{4}$ inches thick, best of slate or soapstone, firmly fastened to the walls, 30 inches from the floor; the Orsat apparatus, when not in use, may be suspended from these. The reagents are contained in

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* Loc. cit.

† Ber. 14, 2659 (1881).

‡ Ann. chim. phys., 15, 294 (1898).

half-liter bottles fitted with rubber stoppers, placed upon a central table convenient to all. Here are found scales, funnels and graduates for use in making up reagents. Tap water is piped around to each place by ⅛-inch tin pipe and $\frac{3}{16}$-inch rubber tubing from a ¾-inch "main," being supplied at the temperature of the room from bottles placed about six feet above the laboratory shelves. A supply of a gallon per day per student should be provided.

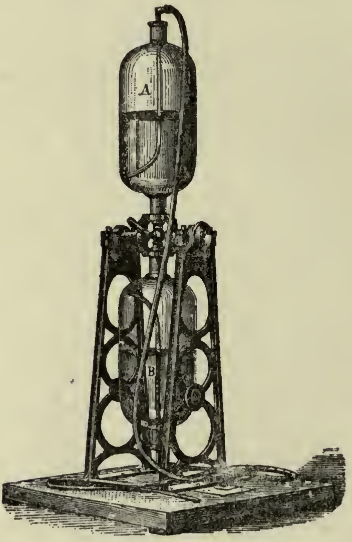

FIG. 18.—MUENCKE'S ASPIRATOR.

At the right of each place is fixed a sand-glass of cylindrical rather than conical form, graduated to minutes for the draining of the burettes. The "egg-timers" found in kitchen-furnishing stores serve the purpose admirably.

"Unknown gases" for analysis are best contained in a Muencke double aspirator, Fig. 18, where they can be thoroughly mixed before distribution and conveyed by a pipe to the central table.

Finally, the laboratory should contain a stone-ware sink provided with an efficient trap of the same material, to prevent mercury from being carried into and corroding the lead waste-pipes.

Drawers should be provided with compartments for various sizes of rubber connectors, pinchcocks, glass tubing, stoppers and fittings, and tools. When working with the Orsat apparatus alone, three feet of shelf space may be allowed to each student; when using this with another, as, for example, the Bunte, another foot should be added.

The course which the writer has been in the habit of giving to the Mechanical and Electrical Engineers embraces two exercises in the laboratory of two hours each, supplemented with six hours of lectures. The students in the laboratory make an analysis of air and an "unknown" furnace-gas, take and analyze an actual sample of chimney-gas, and make the calculation of heat lost and air used. In the lectures, the subject of gas-analysis and its other applications, and of fuels, their origin, description, preparation, application, analysis, and determination of heating value, are described.

CHAPTER VII.

FUELS—SOLID, LIQUID, AND GASEOUS: THEIR DERIVATION AND COMPOSITION.

The substances employed as fuels are:

a. SOLID FUELS.—Wood, peat, brown, bituminous and anthracite coal, charcoal, coke, and oftentimes various waste products, as sawdust, bagasse, straw, and spent tan.

b. LIQUID FUELS.—Crude petroleum and various tarry residues.

c. GASEOUS FUELS.—Natural gas, producer, blast-furnace, water, and illuminating gas.

The essential constituents in all these are carbon and hydrogen; the accessory, oxygen, nitrogen, and ash; and the deleterious, water, sulphur, and phosphorus.

a. SOLID FUELS.

Wood is composed of three substances—*cellulose*, or woody fibre $(C_6H_{10}O_5)_n$; *the components of the sap*, the chief of which is lignine, a resinous substance of identical formula with cellulose; and *water*. The formation of cellulose from carbon dioxide and water may be represented by the equation

$$6CO_2 + 5H_2O = C_6H_{10}O_5 + 6O_2.$$

The amount of water which wood contains determines its value as a fuel. This varies from 29 per cent in ash to 50 per cent in poplar; it varies also with the season at which the wood is cut, being least when the sap is in the roots—in December and January. This difference may amount to 10 per cent in the same kind of wood.

The harder varieties of wood make the best fuel, a cord of seasoned hardwood being about equal to a ton of coal. Yellow pine, however, has but half this value; the usual allowance in a boiler-test is 0.4 the value of an equal weight of coal.

The ash of wood is mainly potassium carbonate, with traces of other commonly occurring substances, as lime, magnesia, iron, silica, and phosphoric acid.

The *percentage composition of wood* may be considered as approximately,

Water.	Carbon.	Hydrogen.	Oxygen.	Ash.	Sp. Gr.
20	39	4.4	35.6	1	0.5.*

When burned it yields about 4000 C. per kilo, and requires 6 times its weight of air or 4.6 cu. m. (74.1 cu. ft. per pound) for its combustion.

Peat finds considerable application in Europe, and is coming into use in this country in the form of briquettes. To this end it is reduced to a dry powder and compressed into small cylindrical blocks; it is claimed to be as efficient as coal at half the price. It is also proposed to gasify peat after the manner of coal. Peat is produced by the slow decay under water of certain swamp plants, more especially the mosses (Sphagnaceæ), evolving methane (CH_4) (marsh-gas) and carbon dioxide (CO_2).

It contains considerable moisture, from 20 to 50 per cent, and 10 per cent even when "thoroughly

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* Mills & Rowan, Fuels, p. 11.

dry." Thirty per cent of its available heat is employed in evaporating this moisture. The high content of ash, from 3 to 30 per cent, averaging 15 per cent, also diminishes its value as a fuel.

The ash of peat differs from that of wood in containing little or no potassium carbonate.

The *percentage composition of peat* may be considered as approximately,

	Water.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ash.	Sp. Gr.
German....	16.4	41.0	4.3	23.8	2.6	11.9	1.05
American...	20.8	40.8	4.4	26.6		7.7	—

Such peat is about equivalent to wood in its heating effect, one pound evaporating from 4.5 to 5 pounds of water.

Coal.—Geologists tell us that coal was probably produced by the decay under fresh water of plants belonging principally to the Conifer, Fern and Palm families; these flourished during the Carboniferous Age to an extent which they never approached before or since. Representatives of the last family, which it is thought produced most of the coal, have been found 2 to 4 feet in diameter and 80 feet in height.

By their decay, carbon dioxide "choke-damp," marsh-gas "fire-damp," and water were evolved. The change might be represented by the equation

$$\underset{\text{Cellulose.}}{6C_6H_{10}O_5} = 7CO_2 + 3CH_4 + 14H_2O + \underset{\text{Bituminous Coal.}}{C_{26}H_{20}O_2}.$$

Some idea of the density of the vegetation and the time required may be obtained from the fact that it has been calculated that 100 tons of vegetable matter —the amount produced per acre per century—if compressed to the specific gravity of coal and spread over an acre would give a layer less than 0.6 of an inch thick. Now four fifths of this is lost in the evolution of the gaseous products, giving as a result an accumulation of *one eighth of an inch per century*, or one foot in 10,000 years.*

Brown Coal or Lignite may be regarded as forming the link between wood and coal; geologically speaking it is of later date than the true coal. Most of the coal west of the Rocky Mountains is of this variety.

As its name denotes, it generally is of brown color —although the western coal is black—and has a conchoidal fracture. It contains a large quantity of water when first mined, as much as 60 per cent, and when " air-dry " from 15 to 20 per cent. The per cent of ash is also high, from 1 to 20 per cent.

The average moisture and ash in American lignites are 12.75 and 6.1 respectively.

The *percentage composition of brown coal* may be considered as approximately,

	Water.	Carbon.	Hydrogen.	Oxygen & Nitrogen.	Ash.	Sp. Gr.
German	18.0	50.9	4.6	16.3	10.2	1.3

Bituminous Coal.—This is the variety from which all the following coals are supposed to have been formed, by a process of natural distillation combined with pressure. According to the completeness of this process we have specimens which contain widely differing quantities of volatile matter. This forms the true basis for the distinguishing of the varieties of coal. In ordinary bituminous coal this volatile matter amounts to 30 or 40 per cent. Three varieties of bituminous coal are ordinarily distinguished, as follows:

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* In case the student desires to follow in a more extended manner the geology of coal, reference may be had to Le Conte's " Elements of Geology," pp. 345–414, 3d ed.

Dry or non-caking.—those which burn freely with but little smoke and—as the name denotes—do not cake together when burned. The coals from Wyoming are an example of this class.

Caking—those which produce some smoke and cake or sinter together in the furnace. An example of these is the New River and Connellsville coal.

Fat or Long-flaming—those producing much flame and smoke and do or do not cake in burning; volatile matter 50 per cent or more. Some of the Nova Scotia coals belong to this class.

Bituminous coal varies much in its composition—is black or brownish black, soft, friable, lustrous, and of specific gravity of 1.25 to 1.5.

Moisture varies from 0.25 to 8 per cent, averaging about 5.

The *percentage composition of bituminous coal* may be considered as approximately,*

Water.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ash.	Sulphur.
0.9	77.1	5.2	6.7	1.6	7.6	1.0

Water.	Volatile Matter.	Fixed Carbon.	Ash.
0.9	27.4	64.1.	7.6

Semi-Bituminous or Semi-Anthracite Coal is upon the border-line between the preceding and the following variety; it is harder or softer than bituminous, contains less volatile matter (15 to 20 per cent), and burns with a shorter flame. An example of this is the Pocahontas coal.

The *percentage composition of semi-bituminous and semi-anthracite coal* may be considered to be approximately,*

Water.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ash.	Sulphur.
0.5	83.0	4.7	4.2	1.3	5.5	0.8

Water.	Volatile Matter.	Fixed Carbon.	Ash.
0.5	16.7	77.3	5.5

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* H. J. Williams.

Anthracite Coal is the hardest, most lustrous, and densest of all the varieties of coal, having a specific gravity of 1.3 to 1.75; it contains the most carbon and least hydrogen and volatile matter (5 to 10 per cent). It has a vitreous fracture and kindles with difficulty, burning with a feeble flame, giving little or no smoke and, with sufficient draft, an intense fire. The Lehigh coal is an excellent example of this class.

The *percentage composition of anthracite coal* may be considered as approximately,*

Water.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ash.	Sulphur.
2.0	83.9	2.7	2.8	0.8	7.2	0.6

Water.	Volatile Matter.	Fixed Carbon.	Ash.
2.0	4.3	86.5	7.2

The ash of coal † varies from 1 to 20 per cent and is mainly clay—silicate of alumina—with lime, magnesia, and iron. When coal is burned it yields from 6100 to 8000 C. and requires about 12 times its weight of air, 9.76 cu. m. per kilo or 156.7 feet per pound. For the greatest economy Scheurer-Kestner ‡ found that this should be increased from 50 to 100 per cent.

Charcoal is prepared by the distillation or smouldering of wood, either in retorts, where the valuable by-products are saved, or in heaps. It should be jet-black, of bright lustre and conchoidal fracture.

When wood is charred in heaps only about 20 per cent of its weight in charcoal is obtained—48 bushels per cord, or about half the percentage of carbon. When retorts or kilns are employed, the yield is increased to 30 per cent, and 40 per cent of pyroligneous

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* H. J. Williams.

† Regarding the fusibility of coal ash, see Fieldner, J. Ind. and Eng. Chem., 7, 829 (1915).

‡ Jour. Soc. Chem. Ind., 7, 616.

acid of 10 per cent strength, with 4 per cent of tar, are obtained.

The *percentage composition of wood-charcoal* may be considered as approximately,

Carbon.	Ash.	Sp. Gr.
97.0	3.0	0.2

Coke is prepared by the distillation of bituminous coal in ovens; these are of two types, those in which the distillation-products are allowed to escape—the "beehive" ovens—and those in which they are carefully saved, as the Otto-Hoffman, Semet-Solvay, Simon-Carvés', and others.

The "beehive" ovens yield from 50 to 65 per cent of the weight of the coal—about 2½ tons. The Otto-Hoffman ovens are long narrow thin-walled retorts 33 by 6 by 1.5 feet,* regeneratively heated by side and bottom flues; the charge is about 6 tons of coal, and the following percentage yields of by-products are obtained: coke 70–75, gas 16 (10 M. cu. ft.), tar 3.3–5.6, ammonia 0.3–1.4.† The Semet-Solvay ovens differ from the above in that they are not regeneratively heated and their walls are thicker, serving to store up the heat; the yield of coke is somewhat higher—about 80 per cent.‡ The by-products obtained alone increase the value of the output about one and one half times. Good coke should possess a cellular structure, a metallic ring, contain practically no impurities, and be capable of bearing a heavy burden in the furnace.

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* Irwin, Eng. Mag., Oct. 1901, abstr. J. Am. Chem. Soc., **24**, 40.

† H. O. Hofman, Tech. Quar., **11**, 212 (1898).

‡ Pennock, J. Am. Chem. Soc., **21**, 678 (1899).

The analysis of Connellsville coke with the coal from which it is prepared is given below.

	Water.	Volatile Matter.	Carbon.	Sulphur.	Ash.
Coal	1.26	30.1	59.62	0.78	8.23
Coke	0.03	1.29	89.15	0.084	9.52
Otto-Hoffman coke:					
			Fixed Carbon.		
	3.7	1.3	86.1		8.9

Heating value.................... 7100 C.

The Minor Solid Fuels.

Sawdust and **Spent Tan-bark** find occasional use, their value depending upon the quantity of moisture they contain. With 57 per cent of moisture 1 pound of tan-bark gave an evaporation of 4 pounds of water.

Wheat Straw finds application as fuel in agricultural districts, 3½ pounds being equal to 1 pound of coal. Upon sugar-plantations the crushed cane or **Bagasse,** partially dried, is extensively used as a fuel. With 16 per cent of moisture an evaporation of 2 pounds of water per pound of fuel has been obtained.

Briquets, "Patent Fuel." *—In Europe coal dust is cemented together with some tarry binding material and baked or compressed into blocks usually about 6×2×1 inches, which form a favorite fuel for domestic purposes. In some cases they take the form and size of a large goose egg, and are called eggettes: these are being made, among other places, at Scranton, Pa., and withstand well the shocks incident to shipment.

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* Condition of the Coal Briquetting Industry in the United States, E. W. Parker, Bull. No. 316 U. S. Geol. Survey, Contributions to Economic Geology, 1906. Part II, Coal Lignite and Peat, pp. 460–485.

Storage of Coal and Spontaneous Combustion.— While authorities differ as to the way and manner in which coal should be stored, as regards height of pile, number, size, and arrangement of ventilating channels, they are practically agreed that it should always be covered. Six months' exposure to the weather may with European coals cause a loss of from 10 to 40 per cent in heating value, while with Illinois coals it varies from 2 to 10 per cent.* The North German Lloyd Steamship Company stores its coal in a covered bin provided with ventilators, and restricts the height of the pile to 8 feet. A large gas company in a western city also uses a covered bin, with ventilators 8 inches square every 20 feet; the height of the pile may be from 10 to 15 feet. An electric company in the same city † has arranged to store 14,000 tons of coal under water in 12 pits, a steam-shovel being used to dig out the coal. Ventilating flues serve the additional purposes of enabling the temperature of the pile to be ascertained before ignition takes place, and as a means of introduction of either steam or carbonic acid to extinguish any fire which may occur. All the supports of the bin in contact with the coal should be of brick, concrete or iron, and if of hollow iron, filled with cement.

The spontaneous combustion of coal is due primarily to the rapid absorption of oxygen by the finely divided coal, and to the oxidation of iron pyrites, "coal brasses," occurring in the coal. The conditions favorable to the process are:

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* Parr and Hamilton, Univ. of Ill., Bulletin 4, No. 33 (1907). See also Bull. 136, Bureau of Mines, Deterioration of Coal during Storage (1917).

† Eng. and Min. Jour., September 15, 1906.

First. A supply af air sufficient to furnish oxygen, but of insufficient volume to carry off the heat generated.

Second. Finely divided coal, presenting a large surface for the absorption of oxygen.

Third. A considerable percentage of volatile matter in the coal.

Fourth. A high external temperature.

A method of extinguishing a fire in a coal pile not provided with ventilators consists in removing and spreading out the coal and flooding the burning part with water. Another method consists in driving a number of iron or steel pipes provided with "driven well points" at the place where combustion is taking place, and forcing water or steam through these upon the fire.

b. LIQUID FUELS.*

These consist of petroleum and its products, and various tarry residues from processes of distillation, as from petroleum, coking-ovens, wood and shale. Liquid fuel possesses the advantage that it contains no ash, is easily manipulated, the fire is of very equable temperature, very hot, and practically free from smoke.

Regarding the origin of petroleum, many theories have been proposed. That of Engler,† that it was formed by the distillation under pressure of animal fats and oils, the nitrogenous portions of the animals previously escaping as amines, seems most probable; it has yielded the best results of any hypothesis when tested upon an industrial scale.

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* For the heating value of liquid fuels, see Table V; for their specification, see p. 144.

† Jour. Soc. Chem. Industry, 14, 648.

Crude Petroleum varies greatly in color according to the locality; it is usually yellowish, greenish, or reddish brown, of benzine-like odor, and sp. gr. of 0.78 to 0.80. It "flashes" at the ordinary temperature; hence great care should be employed in its use and storage. Its *percentage composition* is shown below.

Carbon.	Hydrogen.
84.0–85.0	16.0–15.0

It is more than twice as efficient as the best anthracite coal. In practice 14 to 16 pounds of water per pound of petroleum have been evaporated, and an efficiency of 19,000 B. T. U. was obtained as against 8500 B. T. U. for anthracite. In general 3½ to 4 barrels of oil are equivalent to a ton of good soft coal.*

c. GASEOUS FUELS.

Natural Gas is usually obtained when boring for petroleum and consists mainly of methane and hydrogen, although the percentage varies with the locality. The Findlay, Ohio,† gas is of the following composition:

CH_4	H	N	O	C_2H_4	CO_2	CO	H_2S	Sp Gr.
92.6	2.3	3.5	0.3	0.3	0.3	0.5	0.2	0.57

Blast-furnace, Producer, or Generator Gas is the waste gas issuing from the top of a blast-furnace or obtained by partially burning coal by a current of air (pro-

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* W. B. Phillips, Texas Petroleum (1900), p. 84.

† Orton, Geology of Ohio, vol VI. p. 137.

duced by steam) in a special furnace—a gas-producer or generator. It is mainly carbonic oxide and nitrogen.

	CO	N	CO_2	H	CH_4	O	B.T.U. per Foot.
Blast-furnace gas.....	34 3	63.7	0.6	1.4	—	—	122
Gas from bitumin. coal	24.5	46.8	3.7	17.8	6.8	0.4	223
" " " "	25.0	41.4	4.0	19.4	9.6	0.6	—
" " anthrac. "	27.0	57.3	2.5	12.0	1.2	—	—
" " " "	17.2	53.1	8.6	18.2	2.4	0.4	140
" " " "	26.0	47.0	8.0	18.5	0.5	—	145 *

One ton of coal yields from 160 † to 170 thousand cubic feet of gas of 156 to 138 B.T.U. heating power, or 81 to 86 or even 90 per cent of the value of the coal.

Water-gas.—If, instead of passing simply air over hot coal, water-vapor, or rather steam, be employed, it is decomposed, giving carbonic oxide and hydrogen, according to the equation $H_2O + C = CO + H_2$, and the resulting mixture is called water-gas. The *percentage composition*, which varies according to the apparatus and fuel employed, is about as follows:

	CO	H	CH_4	CO_2	N	O	Illts.	Sp. Gr.
From coke....	45.8	45.7	2.0	4.0	2.0	0.5	—	0.57
From bit. coal	34.0	41.9	7.5	5.4	9.2	1.1	0.9	—

Fischer ‡ states that 1 ton of coke gives about 36 thousand cubic feet of gas, equivalent to 42 per cent of the value of the coal. From 1 ton of bituminous coal about 51 thousand cubic feet of gas of 360 B.T.U. heating power are obtained, or an efficiency of nearly 62 per cent.§

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* Suction gas producer.

† Humphrey, Jour. Soc. Chem. Industry, **20**, 107 (1901); *ibid.*, **16**, 522 (1897 .

‡ Taschenbuch für Feuerungs-Techniker, p. 27.

§ Slocum, J. Soc. Chem. Industry, **16**, 420 (1897).

Coal or Illuminating Gas was formerly produced by the distillation of bituminous coal; it is at present largely made by the enriching of water-gas. "Gas-oil," a crude naphtha, is blown into the water-gas generator and changed to a permanent gas by the heat. It is of the following composition:

	H	CH_4	CO	C_2H_4	CO_2	N	O	Sp. Gr.
Coal gas...........	47.0	40.5	6.0	4.0	0.5	1.5	0.5	0.4
Enriched water-gas	27.9	25.9	25.3	15.0	2.9	3.0	0.0	0.6

One ton of coal gives about 10 thousand cubic feet of gas, or about 20 per cent of the heating value of the coal.

Heating Value of these Gases.

The following table, mainly from Slocum,* gives an idea of the comparative value of the gases:

Name of Gas.	B. T. U. per Cu. Ft.†	Yield.	Air Required for Combustion per Cu. Ft.
Oil..................	1350	77 cu. ft. per gal.	....
Natural.............	980 840–1170	....	9.80
		Thousand Ft. per Ton.	
Enriched water......	700	40 ‡	....
Coke-oven...........	686	5	....
Coal................	600–625	10	5.65
Blue water..........	332–500	5	....
Heating (coke-oven).	367	5	....
Bit. coal water......	342	51	2.97
Mond producer......	156	160	1.25
Siemens producer....	137	170	....
Wood or peat........	140–145	....	....

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* Slocum, J. Soc. Chem. Industry, **16**, 420 (1897).

† Determined with the Junkers calorimeter.

‡ 168–200 gallons of "gas-oil" are also required.

References.—*Report of U. S. "Liquid Fuel" Board*, Dept. of Navy, Bureau of Steam Engineering, Washington, 1904. pp. 450.

Report on the Operations of the Coal-Testing Plant of the U. S. Geological Survey at St. Louis, 1904. Professional Paper, No. 48, Parts I, II, and II. 1906.

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Uehling, "*Chemical and Physical Control of Boiler Operation.*" *Power*, **49**, 32 (1919).

"*Cost of Steam from Coal.*" *Power*, **42**, 456 (1915).

"*Saving Coal in Boiler Plants.*" Bureau of Mines Technical Paper, 205 (1918).

Moore, "*Liquid Fuels for Internal Combustion Engines,*" (1918).

Maujer and Bromley, "*Fuel Economy in Boiler Rooms,*" (1918).

Wadsworth, "*Efficiency in the Use of Oil Fuel,*" Bureau of Mines (1918).

CHAPTER VIII.

METHODS OF ANALYSIS AND DETERMINATION ON THE HEATING VALUE OF FUEL.

SAMPLING.

A FEW representative lumps or shovelfuls are taken from each barrow or from various points in the pile in boiler tests. Shovelfuls of coal should be taken at regular intervals and put into a *tight covered* barrel or some air-tight receptacle, and the latter should be placed where it is protected from the heat of the furnace.* In sampling two conditions must be observed: First, the original sample should be of considerable size and thoroughly representative; and, second, the quartering down to an amount which can be put into a sealed "lightning" jar should be carried out as quickly as possible after the sample is taken. Careful samplings and careful treatment of samples are necessary to obtain reliable results, especially in the determination of moisture. The lumps are coarsely broken, and the whole spread out in a low circular heap. Diameters are drawn at right angles in it and opposite quarters taken, and treated similarly to the whole sample. The operation is continued until a sample of a few pounds † is obtained. This is roughly crushed and samples taken at different points for the moisture determi-

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* Report of Committee on Coal Analysis, J. Am. Chem. Soc., **21**, 1116 *et seq.* (1899).

† If the largest lump be ¼ inch, 9 pounds; a less quantity as the lumps grow smaller.

nation; it is then further quartered down until a sample of 100 grams which passes a 60-mesh sieve is obtained.

The methods employed in the analysis of fuels are largely a matter of convention, various methods giving varied results; for example, it is well-nigh impossible to obtain accurately the percentage of moisture in coal, as when heated sufficiently hot to expel the water some of the hydrocarbons are volatilized.

Moisture.—Dry one gram of coal in an open crucible at 104°–107° C. for one hour. Cool in a desiccator and weigh covered. Where accuracy is required, determinations must also be made on the coarsely ground sample; this latter result is to be regarded as the true amount and corrections applied to all determinations where the powdered sample is used.[*] [†] [‡]

Volatile Combustible Matter and Coke.[*][§]—Place one gram of fresh, undried powdered coal in a platinum crucible having a capsule cover. Heat over the full flame of a Meker burner for seven minutes by the watch. The crucible should be supported on a platinum triangle with the bottom 1 centimeter above the top of the burner. The flame should be not less than 15 cm. high ×25 cm. in diameter when burning free, and the determination should be made in a place free from drafts. The upper surface of the cover should burn clear, but the under surface should remain covered with carbon. To find "Volatile Combustible Matter" subtract the per cent of moisture from the loss found here. The

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[*] Report of Committee on Coal Analysis, J. Ind. and Eng. Chem. **5**, 522 (1913).

[†] See also an article by Hale, Proc. Am. Soc. Mech. Eng., 1896.

[‡] Variation allowed in check analyses 0.2–0.3 per cent.

[§] Sommermeier, J. A. C. S., 28, 1002 (1906).

residue in the crucible minus the ash represents the *Coke or Fixed Carbon.*

Certain non-coking coals suffer mechanical loss from the rapid heating.* Lignites should be heated for five minutes previously by playing the burner on the crucible.

Carbon.—Marks † has shown how to calculate the total per cent of carbon in the coal, from the proximate analysis, *i.e.*, the *coke* and *volatile matter.* This requires the calculation of the per cent of carbon in the volatile matter, and is done as follows: Coke+volatile matter=combustible. % vol. matter in combustible=

$$\frac{\text{\% vol. matter}}{\text{\% combustible (coke + vol. matter)}} \times 100.$$

With this (vol. matter in combustible) as an abscissa (horizontal distance) locate in Fig. 19 the corresponding ordinate, which is the per cent of volatile carbon in the combustible matter. Multiply the latter by the per cent combustible in the coal, divide by 100 and find the per cent of volatile carbon in the coal; *i.e.*, the percentage of carbon in the volatile matter. An illustration will make this clear. Taking the composition of the bituminous coal (p. 74) as volatile matter 27.4, fixed carbon 64.1. Fixed carbon+volatile matter is

$$64.1 + 27.4 = 91.5\%.$$

$$\frac{\text{\% vol. matter } 27.4}{\text{\% combustible } 91.5} \times 100 =$$

30% vol. matter combustible.

The corresponding ordinate, Fig. 19, is 15.5, which is the per cent of volatile carbon in the combustible.

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* Variation allowed in check analyses 0.5–1.0%.

† Power, 37, 55 (1913).

Since the coal is but 91.5 per cent. combustible, the volatile carbon in the coal is 91.5 per cent of this,

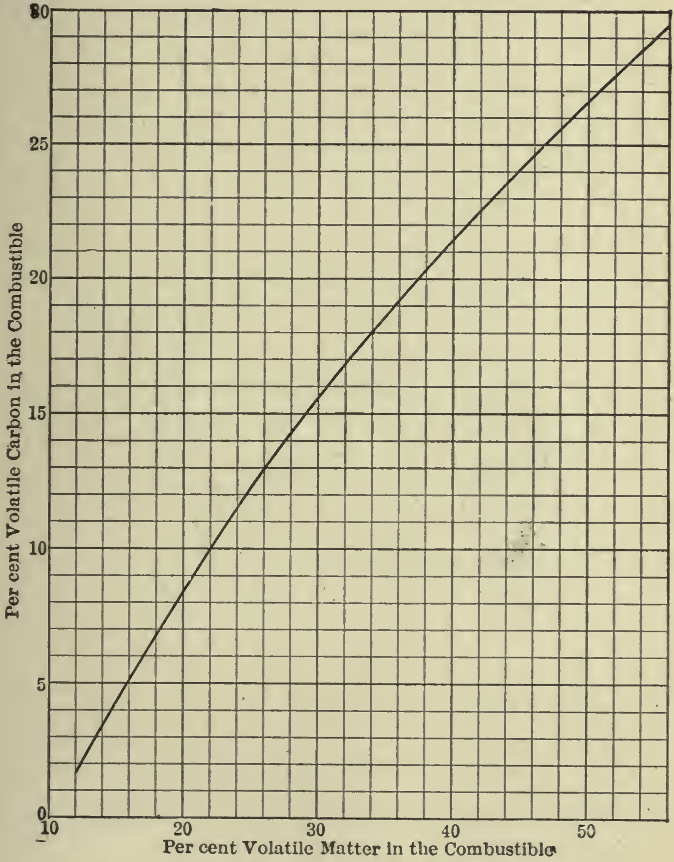

FIG. 19.—MARKS' CHART FOR CARBON IN COAL.

$15.5 \times \frac{91.5}{100.0} = 14.2$. This added to the fixed carbon, $64.1 + 14.2 = 78.3$ per cent, gives the per cent of carbon in the coal; the results of the ultimate analysis showed 77.1 per cent.

Carbon and Hydrogen.—These are determined by burning the coal in a stream of air and finally in oxygen, the products of combustion, carbon dioxide and water, being absorbed in potassium hydrate and calcium chloride.

Apparatus Required.—Combustion-furnace similar to that shown in Fig. 20. Combustion-tube filled.

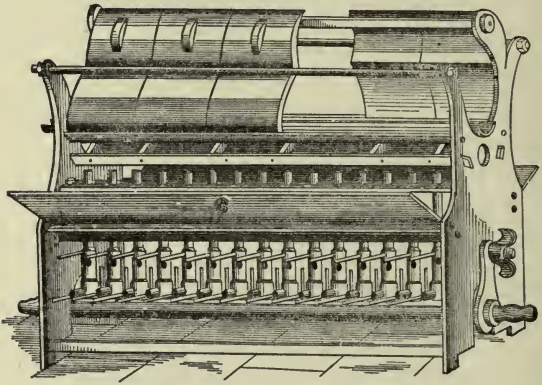

FIG. 20.—COMBUSTION-FURNACE.

Potash-bulbs with straight chloride of calcium tube filled. Chloride of calcium tube filled. Oxygen-holder, drying and purifying apparatus. Porcelain boat, desiccator, tongs, $\frac{1}{8}$-inch rubber tubing. Analytical balance.

The combustion-tube is of hard glass, $\frac{1}{2}$ inch in internal diameter and 36 inches long, closed with perforated rubber stoppers. One end—called the front end—is filled with a layer of copper oxide 12 inches long, held in place by plugs of asbestos coming within 4 inches of the stopper. In coals rich in sulphur the oxide is partially replaced by a layer of chromate of lead 2 inches long. The position of the boat containing the coal is immediately behind this copper oxide; behind the boat is placed an oxidized copper gauze roll, 6 inches long. Before making the combustion, the tube and contents should be heated to a dull red heat in a stream of oxygen freed from moisture and carbon dioxide by the purifying apparatus, to burn any dust and dry the contents; it is then ready for use.

The potash-bulbs are an aggregation of five bulbs, the three lowest filled with potassium hydrate of 1.27 sp. gr., the other two serving as safety-bulbs, preventing the liquid from being carried over into the connectors. They should be connected further with a chloride of calcium tube to absorb any moisture carried away by the dry gas. When not in use they should be closed with connectors carrying glass plugs. Before weighing they should stand at least fifteen minutes in the balance-room to attain its temperature; the weight should be to milligrams and without the connectors.

The chloride of calcium tube is of U form, provided with bulbs for the condensation of the water; the granular calcium chloride is kept in place by cotton plugs, and the stopper neatly sealed in with sealing-wax. As calcium chloride may contain oxide which would absorb the carbon dioxide formed, a current of dry carbon dioxide should be passed through the tube and thoroughly swept out by dry air before use.

The chloride of calcium tube like the potash-bulbs should be placed in the balance-room fifteen minutes before weighing and, if the balance-case be dry, may be weighed without the connectors. It should be weighed to milligrams.

The oxygen-holder may be like the Muencke aspirator, Fig. 18. The oxygen should be purified by passing through potassium hydrate and over calcium chloride.

Operation.—The front stopper of the combustion-tube is slipped carefully upon the stem of the chloride of calcium tube and this connected to the potash-bulbs; 0.2 to 0.3 gram of the coal is carefully weighed into the porcelain boat (to 0.1 mg.), the roll removed, and the boat inserted behind the layer of copper oxide, and the roll and stopper replaced. The tube is now ready to be heated.

The front of the copper oxide is first heated, the heat being gradually extended back; at this time the rear end of the copper roll is heated and a slow current of purified air passed through. This method of gradual heating of the tube is followed until the layer of copper oxide and the rear portion of the roll are at a dull red heat. Heat is now cautiously applied to the coal and the current of air slackened. The volatile matter in the coal distils off, is carried into the layer of copper oxide and burned; the carbon dioxide formed can be seen to be absorbed by the potassium hydrate. When this absorption almost ceases, oxygen is turned on and the coal heated until it glows. The stream of oxygen should be so regulated as to produce but two bubbles of carbon dioxide in the bulbs per second. If the evolution be faster, the gas is not absorbed. When the coal has ceased glowing, oxygen is allowed to pass through the apparatus until a spark held at the exit of the last chloride of calcium tube (on the bulbs) re-inflames; the oxygen is allowed to run for fifteen minutes longer. The current of oxygen is now replaced by purified air, and the heat moderated by turning down the burners and opening the fire-clay tiles; the air is allowed to run through for twenty minutes to thoroughly sweep out all traces of carbon dioxide and moisture. The bulbs and U tube are disconnected, stopped up, allowed to stand in the balance-room, and weighed as before. The increase in weight in the bulbs represents the carbon dioxide formed; this multiplied by the factor 0.2727 gives the carbon. Similarly the increase in the U tube, minus the water due to the moisture in the coal, represents the water formed, one ninth of which is hydrogen.

Notes.—At no time in the combustion should any water appear near the copper roll, as it is an indication that the products of combustion have gone backward into the purifying apparatus and hence are lost. Such analyses should be repeated. Should moisture appear in the front end, it may be *gently* heated to expel it. Both ends of the tube should be frequently touched with the hand during the combustion, and should be no hotter than may be comfortably borne, as the stoppers give off absorbable gases when highly heated. Care should be taken not to heat the tube too hot, fusing the copper oxide into and spoiling it. One tube should serve for a dozen determinations. It should not be placed upon the iron trough of the furnace, but upon asbestos-paper in the trough, to prevent fusion to the latter.

As will be seen, the execution of a combustion is not easy, and should only be intrusted to an experienced chemist. The results are usually 0.1 per cent low for carbon and a similar amount high for hydrogen.

Ash.—This is determined by weighing the residue left in the boat after combustion, or by completely burning 1 gram of the coal contained in a platinum dish.

Nitrogen is determined by Kjeldahl's method, which consists in digesting the coal with strong sulphuric acid, aided by potassium permanganate, until nearly colorless. The nitrogenous bodies are changed to ammonia, forming ammonium sulphate and are determined by rendering alkaline and distilling the solution.

Sulphur is determined by Eschka's method, consisting in heating for an hour one gram of the coal mixed with one gram of magnesium oxide and 0.5 grm. sodium carbonate in a platinum dish without stirring, using an alcohol-lamp, as gas contains sulphur. It is allowed to cool and rubbed up with one gram of ammonium nitrate and heated for 5 to 10 minutes longer. The resulting mass is dissolved in 200 cc. of water evaporated to 150 cc., acidified with hydrochloric acid, filtered, and sulphuric acid determined in the filtrate in the usual way with barium chloride. Or the washings of the bomb calorimeter may be used (see liquid fuels).

Oxygen is determined by difference.

For Coal Specifications see Appendix, p. 133.

For a ready method of calculating cost per million B.t.u., see Blake, J. Ind. and Eng., 10, 627 (1918).

NOTE.—The foregoing methods are technical, but of sufficient accuracy for most purposes. For more accurate and later methods see the Report of the A. C. S. in J. Ind. and Eng. Chem., 5, 517, et seq.

ANALYSIS OF LIQUID FUELS.*

Carbon and Hydrogen.—This determination is made as in the case of the solid fuels, the liquid being contained in a small bulb sealed for weighing to prevent volatilization. The stem is scratched and broken off and the bulb inserted in the combustion tube in place of the boat. Extra care in heating has to be observed to prevent the liquid from passing through unburnt. For thick or tarry oils having a small quantity of volatile matter, the boat may be used as with solid fuels.

Sulphur.—The method consists in burning the oil in a small lamp and collecting the products of combustion. The lamp is a miniature "oil lamp" made from a 3-inch test-tube (weighing tube) by drawing a piece of weighed lamp wicking through a small glass tube contained in the stopper. This lamp is suspended by a wire from the balance and weighed accurately.

It is lighted and hung under a funnel arranged so that the products of combustion are drawn by an air-pump through a series of two washing bottles containing saturated bromine water. After about a gram of oil has been burned (about 1.3 cc.) the wick is carefully removed without losing any oil, the stopper replaced and the tube again weighed. The wick and oil it contains are covered with Eschka's mixture and treated as for the determination of sulphur in coal (p. 92). The hydrochloric acid filtrate is added to the bromine solution, the bromine boiled out, the solution evaporated to about 150 cc., and the sulphuric acid formed determined in the usual way with barium chloride. The oil burned is obviously the weight of the lamp before and after burning less the weight

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* For Fuel Oil Specifications, see Appendix, p. 144.

of the dry wick. This treatment of the wick is necessary, as Conradson * has found sometimes 40 per cent of the sulphur in the wick.

By the Calorimeter.—After oil is burned in the bomb calorimeter (p. 96), it is thoroughly washed out with distilled water, and 6–8 cc. of HCl 1 : 1 with a few drops of bromine water added, the solution heated to boiling and filtered; the filter is washed free of sulphates, the filtrate made just neutral with NaOH or Na_2CO_3, 1 cc. normal HCl added and the sulphates determined in the usual way with barium chloride or with the turbidimeter. If any odor be detected in the gases escaping from the bomb, the determination must be repeated, using a pressure of 25 atmospheres of oxygen with a bomb of 400–600 cc. capacity. The sulphur is usually a trifle low.

Barlow's † method is excellent, but requires considerable experience to carry out.

Nitrogen is determined exactly as in the case of solid fuels.

Water can be shown qualitatively by the eosine test,‡ by rubbing with a little eosine on a glass plate. If water be present the oil will take on a pink color. It is quantitatively determined § by diluting the oil with an equal volume of benzole and whirling it in a centrifuge until the separated layer of water does not appear to increase in volume. The benzole should have been thoroughly shaken with water and centrifuged at the same temperature for the same length of time in order to saturate the benzole with water.

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* J. Ind. and Eng. Chem., 2, 171 (1910).

† J. Am. Chem. Soc., 26, 341 (1904).

‡ Holley and Ladd, Mixed Paints, Color Pigments and Varnishes, p. 36.

§ Charitschkoff, Chem. Zeit., 33, 93 (1906).

Flash and Fire Test.—Determined by heating the oil in the covered New York tester or lubricating oil tester according to Gill, "Short Handbook of Oil Analysis," Chapters I and II.

The analysis of gaseous fuels* has already been described in Chapter V.

DETERMINATION OF CALORIFIC POWER OF SOLID AND LIQUID FUEL

a. Direct Methods.

Many forms of apparatus have been proposed for this purpose; few, however, with the exception of those employing Berthelot's principle—of burning the substance under a high pressure of oxygen—have yielded satisfactory results. The apparatus of William Thomson,† and also that of Barrus, in which the coal is burnt in a bell-jar of oxygen under water, while usually yielding results within 3 per cent of the calculated value, yet they may vary as much as 8 per cent from that value.‡ Unless a crucible lined with magnesia be used, or the sample mixed with bituminous coal, it is inapplicable to certain semi-bituminous and anthracite coals, as the ash formed over the surface prevents the combustion of the coal beneath it.

Fischer's calorimeter § is similar in principle, but is claimed to give very good results.||

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* For the determination of gasolene vapor in gaseous mixtures, see Scott, "Standard Methods of Chemical Analysis," or Bureau of Mines Technical Paper, 115.

† Thomson, Jour. Soc. Chemical Industry, **5**, 581.

‡ Ibid., **8**, 525.

§ Zeit. f. angewandte Chemie, **12**, 351.

|| Bunte, Jour. f. Gasbeleuchtung und Wasserversorgung, **34**, 21, 41.

Lewis Thompson's calorimeter, in which the coal is burnt in a bell-jar by the aid of oxygen furnished by the decomposition of potassium chlorate or nitrate, is open to several objections, the chief of which are: 1. The evolution of heat due to the decomposition of the oxidizing substance used. 2. Loss of heat due to moisture carried off by the gases in bubbling through the water. The results which it gives must be increased by 15 per cent.*

Hempel's apparatus † makes use of the Berthelot principle: the coal must be compressed into a cylinder for combustion—a process to which every coal is not adapted—only applicable to certain varieties of bituminous and brown coal. The mixture with the coal of any cementing or inflammable substance to form these cylinders carries with it the necessity of accurately determining its calorific power beforehand.

Numerous other workers have experimented with the bomb calorimeter, Mahler, Atwater, Kroecker, Williams, Norton, Parr and Emerson; as the last apparatus is now in common use it will be described here.‡

Details of Emerson Apparatus.

Bomb.—The bomb is made of steel, consisting of two cups joined by means of a heavy steel nut. The cups are machined at their contact faces with a tongue and groove, the joint being made tight by means of a lead gasket inserted in the groove. The lining is of sheet

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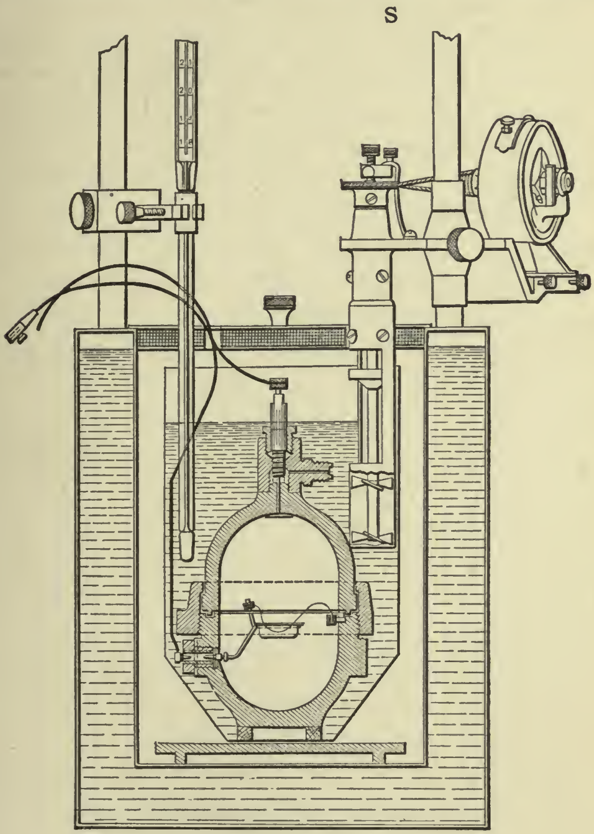
* Scheurer-Kestner, J. Soc. Chem. Industry, 7, 869 (1888).

† Hempel, Gasanalytische Methoden, p. 347.

‡ From the circular accompanying the apparatus.

metal, usually pure nickel, although gold and platinum are sometimes used, spun to fit the interior. The bomb is made up tight with a milled wrench or spanner. The pan holding the combustible is of platinum or nickel, and the supporting wire of nickel. The fuse wire should



EMERSON—FUEL—CALORIMETER

FIG. 21.

be platinum in general fuel testing. In standardizing the calorimeter by means of cane sugar, benzoic acid, etc., it is necessary to use iron fuse wire.

Calorimeter.—The jacket is either a double-walled copper tank, between the walls of which water is inserted, or a vacuum-walled cup. The calorimeter bucket proper, inside this, is made as light as possible of sheet brass.

Stirring Device. S, Fig. 21.—This consists of a paddle-wheel shaft enclosed in a vertical tube to facilitate its action in circulating the water. The stirrer shaft is driven by a belt from a small motor at the other end of the stirrer bracket. The motor is mounted on a sliding plate which permits of varying the tension on the belt. This varying tension serves to regulate the speed of the paddle shaft by thus varying the speed of the motor. The stirrer is mounted on a post on the calorimeter jacket, as is the thermometer holder.

The motor is driven from a 110-volt circuit, and *should be placed in series with a 60-watt lamp.* If so desired, a motor driven by a battery can be specified in ordering the apparatus. The battery motor is driven by a six-volt storage battery. These motors designed for the 110-volt power circuit may be driven on other voltage provided that a proper resistance be placed in series so that the current in the circuit is one-half ampere. The motor may be driven by either direct or a 60-cycle alternating current.

Oxygen Piping. Fig. 22.—The piping for the insertion of oxygen under pressure is made especially strong and durable. The piping of small internal bore is made of heavy brass. The system is fitted with a hand nipple at one end to make the connection with the bomb, and the other end has a special fitting to grasp the oxygen supply tank.* Commercially pure oxygen, free from all traces of combustible gases, should be used.

Iron Plate Holder.—The plate holder or vise is to be used when tightening the nut of the bomb with the spanner.

Swivel Table.—The table with the rotating top is to hold the bomb when the same is connected to the oxygen piping. (See Fig. 22.) This swivel table is not included with the double outlet bomb.

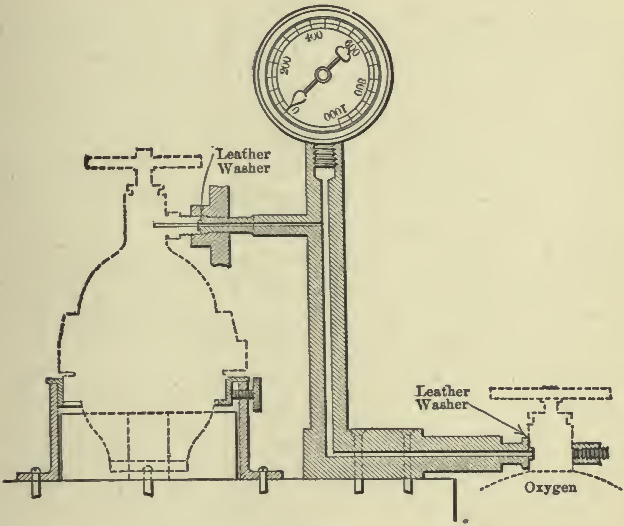


FIG. 22.

Spanner.—The spanner or wrench is a forging with 30-inch handle and is used to make bomb up with gas-tight joint.

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* Furnished by the S. S. White Dental Manufacturing Company. Piping to fit other tanks can be furnished to order.

Thermometer Telescope.—Hand telescope to enable operator to read thermometer to $\frac{1}{1000}$ or $\frac{2}{1000}$ of a degree.

Determination of Heat of Combustion of Fuels and Other Combustibles.

COAL.

Manipulation.—Place the lower half of the bomb in the iron plate holder and adjust the fuel pan support in proper position. This support is held by a taper pin which fits into the inner end of the insulation plug, which plug is at the side of the lower cup of the bomb. The taper pin holding the fuel pan support should be entered firmly into the porcelain plug in order that the support will not permit of tipping, which would likely result in the upsetting of the charge of fuel at the time of ignition. To enter the taper pin in place, use the small steel spanner which fits into the recess of the taper pin. This spanner will also be found suitable for removing the taper pin from the plug. *Care should be taken on the interior of the bomb that the linings do not touch the metal part of the insulation taper pin which holds the fuel pan support.*

The fuse wire is connected to the binding post on the fuel pan support and extends across the bomb to the binding post at the opposite side of the bomb, sufficient length being allowed that the wire will dip down sufficiently to be in contact with the fuel which is afterwards placed in the pan. Care must be taken that the wire does not touch the fuel pan.

The fuel used is sampled, crushed, and powdered according to directions given on page 84.

Fill a test-tube or convenient weighing vial with the prepared sample and weigh it accurately to one-tenth of a milligram. Pour from this into the pan in the bomb until the pan is approximately half full. Weigh the vial again and the difference of the above weighings gives us the net quantity of fuel in the bomb. This weight should be greater than five-tenths of a gram, and not more than one and two-tenths grams. For hard coal the maximum charge should be not greater than one gram. Hard coal should not be as finely divided as soft coal. (Through an 80-mesh sieve is sufficient.)

The upper half of the bomb is placed in position and the nut screwed down as far as may be by hand, *care being taken not to cross the threads.* The shoulder on the upper half of the bomb over which the nut makes bearing contact should be thoroughly lubricated with oil. Extreme care should be taken that no oil or grease is deposited on the lead gasket, as the bomb, when working properly, closes without the upper half turning on the gasket on account of the contact friction of the nut. Any oil on the lead gasket would tend to hinder the proper action in this respect.

The large wrench is used to make the joint tight, and operator should apply the same very nearly to his full strength. (If the thread of the large nut is kept free from dirt, it will turn into place freely by hand.)

The bomb is now ready to be filled with oxygen, and this is accomplished by means of the spindle valve at the top of the bomb. The nipple is coupled to the oxygen piping by means of the attached hand union, the bomb resting on the swivel table. (The oxygen piping should be properly located and screwed fast to the bench.) The screw holes in the feet of the swivel table are left large and are made for round-head screws so as to allow for adjustment relative to the oxygen piping. Both should be fixed in position. *In handling the bomb, care should be taken not to tip or jar it, as fuel may be thrown from the pan.*

The spindle valve on the bomb need only be opened one turn, and then the valve on the oxygen supply cylinder is very cautiously opened. The pressure gauge should be carefully watched and the cylinder valve so regulated that the pressure in the system *shall rise very gradually.* When the pressure reaches 300 pounds per square inch, the cylinder valve is closed, and then the spindle valve on the bomb immediately after.

The bomb should be immersed in water immediately to detect any possible leakages. (Preferably a glass jar, as slight leaks are detected by looking from all sides.)

The bomb is now ready for the calorimeter, which is prepared as follows:

Nineteen hundred grams of water are placed in the calorimeter can at a temperature about 1½° below the jacket temperature (which temperature should be in the proximity of the room temperature.) The bomb is then placed in the can; care should be taken that the outer surface of this can is thoroughly dry; the stirrer and thermometer are lowered into position as indicated by the illustration. The thermometer is immersed about 3 inches in the water and the thermometer bulb should be at least ½ inch from the bomb. Care should be taken that the bomb does not touch the sides of the can or that the *stirrer does not touch the bomb.*

Ignition Wiring.—One terminal of the electric circuit for igniting the charge is connected to the bomb by means of the taper binding post which fits into the spindle at the top, and the other is connected to the outer end of the insulation plug on the lower cup of the bomb. A short length of insulated wire, which is connected to a small taper pin fitting into the outer end of the insulation plug, is included with the apparatus. The other end of this piece of insulated wire is fitted with a connector for one terminal from the switchboard. This last-mentioned taper pin is fitted into the plug before the bomb is lowered into the calorimeter bucket. Two 100-watt lamps in parallel are placed in series with the fuse wire when 110-volt circuit is used for firing.

The Run.—The stirrer is started, and allowed to run three or four minutes to equalize the temperature throughout the calorimeter.*

Readings of the thermometer are taken for five minutes (reading to the $\frac{1}{1000}$ or $\frac{2}{1000}$ of a degree every minute), at the end of which time the switch is turned on for an instant only, which will be found sufficient to fire the charge. In course of a few seconds the temperature begins to rise rapidly and readings are taken every half minute from the time of firing. After a maximum temperature is reached and the rate of change of temperature is evi-

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* If the stirrer gives trouble by refusing to run at sufficient speed or by stopping completely, the difficulty is usually due to the accumulation of oil on the commutator The operator can readily remove the oil with chamois cloth and by using care, this removal of the oil from the commutator can be accomplished when the stirrer is running. Draw the chamois tightly over the forefinger and press gently on the surface of the commutator, taking care not to injure the brushes.

If the stirrer runs at too high speed causing the water in the calorimeter can to be thrown about, a rheostat placed in series with the motor will serve to regulate and modify the speed.

dently due only to the radiation to or from the calorimeter, the readings are continued for an additional five minutes, reading every minute. These readings before the firing and after the maximum temperatures are necessary in the computation of the cooling correction. The time elapsed from the time of firing to the maximum temperature should be in no case more than six minutes.

When through with run, replace bomb in the holder and allow the products of combustion from within to escape through the valve at the top of the bomb. Unscrew the large nut and clean the interior of the bomb. The inside of the nut should be kept oiled; and also the threaded part at the top of the lower cup.

Immediately after each run the inside of the bomb should be dried out with a cloth. The lining of the lower cup is removed by withdrawing the fuse-wire binding post which is held in place with a taper fit and is easily removed. The lining to the upper cup is held in place by the small screw at the top which holds the deflector.

After each day's run the linings should be removed and the inner surface of the bomb under the linings should be coated slightly with oil. (This oil must positively be removed when the bomb is in operation.)

The pan may be cleaned by boiling in dilute hydrochloric acid. Any further slag clinging to the pan may be fused with sodium carbonate. The fused mass dissolves in hot water.

Computation.—The data obtained during the run are used as follows:

To the temperature in the calorimeter at firing and the maximum temperature is applied the correction for the errors on the thermometer, which are obtained from the table of corrections supplied with the thermometer when it is standardized at the Bureau of Standards. The difference between these corrected temperatures at maximum and firing gives the true rise of temperature in the calorimeter, and to which must be added a cooling correction, which is computed as follows:

The change in temperature during the preliminary five minutes of reading, divided by the time (five minutes), gives the rate of change of temperature per minute, due to radiation to or from the calorimeter, and also any heating due to stirring, etc. Call this factor R_1, and in like manner the readings taken after the maximum temperature give R_2. The rates of change of temperature give the existing conditions in the calorimeter at the start and at the finish of the run. The radiation to and from the calorimeter when the same is at room temperature is 0. Therefore:

$$\frac{R_1+0}{2}\times(\text{time from firing temperature to room temperature})$$

expresses the exchange of heat to and from the calorimeter in that part of the run from firing temperature to room temperature. In the same manner the expression

$$\frac{0+R_2}{2}\times(\text{time from room temp. to maximum temp.})$$

gives a close approximation of the exchange of heat to and from the calorimeter during the latter part of the run.

In the first factor above mentioned, as the time from firing temperature to room temperature is invariably close to one minute, the expression for cooling can be written as follows:

$$\frac{R_1}{2}+\left[\frac{R_2}{2}\times(\text{time from room temp. to maximum temp.})\right].^{*}$$

This latter quantity is either added to or subtracted from the above corrected rise in temperature, accordingly as the balance of heat radiation is *to* the surroundings or *from* the surroundings. This is at once determined from an inspection of the data. This rise of temperature, corrected for thermometer calibration errors, and with the cooling correction applied, is divided by the weight of fuel used, thus giving directly the rise in temperature per gram of fuel.

This rise per gram, times the weight of water, plus "water equivalent" (see "standardization,") will give immediately the calories per gram of fuel, which is the result to be obtained. The result in calories per *gram* of fuel multiplied by the factor 1.8 gives B.T.U. per *pound* of fuel.

HEAVY OILS, COKE, HARD COAL, ETC.

The determination of the heat of combustion of heavy oils such as crude petroleum, and also of coke and extremely hard coals, is best made by burning them mixed

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[*] If due to unusual atmospheric temperatures the run is made with temperatures all below or temperatures all above room temperature, then the expression $\left[\frac{R_1+R_2}{2}\right]\times$(time from firing temperature to maximum temperature) gives a close approximation for the cooling correction. For an even closer approximation of the radiation correction, the Regnault-Pfaundler formula is recommended.

with a ready-burning combustible, such as a high-grade bituminous coal. This auxiliary combustible facilitates the complete combustion of the whole mixture in case of coke and hard coal, and with the heavy oil it acts as a holder and prevents rapid evaporation of the oil.

A known weight of the auxiliary combustible should be placed at the bottom of the pan and the coke, coal or oil sprinkled over it. The auxiliary combustible should be dried and carefully standardized as to its rise in temperature per gram in the calorimeter when the same is completely burned.

Weighing of Fuel Oils.—In the handling of fuel oil, the most suitable method of preventing evaporation in weighing the sample is to hold it in a small weighing bottle with a dropper arranged in the stopper for the purpose of conveying the liquid fuel to the sample of standard combustible in the fuel pan; and after a few drops have been placed here, the stopper is put again in the weighing bottle and the whole is reweighed. The difference between this weight and the weight previous to the taking out of the sample gives the net weight of fuel oil in the bomb. The upper half of the bomb should be immediately placed in position to prevent as much as possible the vaporization of the sample.

Light Fuel Oils, Gasoline, Alcohol, etc.

Because of the rapid evaporation of the lighter fuel oils it is not advisable to pour it directly into the fuel pan. Small gelatine capsules can be obtained which may be filled with ignited asbestos into which the light oils may be poured and absorbed by the asbestos. The filled capsule is sealed, placed in the fuel pan and burned in the usual manner, using iron wire for ignition. The dry weight of the capsule and asbestos must be known and after filling capsule with charge and sealing it, the weight of the whole is taken. Care should be used that no air bubbles are enclosed with the charge in the capsule, as the fuel will otherwise ignite with explosive violence.

THERMOMETERS.

The accuracy of the calorimeter depends largely on the accuracy of the thermometer used in connection with the same. A good grade calorimetric thermometer, graduated in $\frac{1}{100}$ or $\frac{1}{50}$ of a degree, ranging from about 15° to 28° C., is a desirable type. *This thermometer should have a Bureau of Standards calibration certificate.*

A Beckman type of thermometer with Bureau of Standards certificate is satisfactory.

STANDARDIZATION OF CALORIMETER.

In the measurement of the heat of combustion of a fuel or a combustible in a bomb calorimeter, the immersed parts of the calorimeter including the bomb, can, stirrer, etc., are carried through the same rise in temperature as the water. The amount of heat absorbed by these immersed parts for one degree rise in temperature is known as the "Water Equivalent" factor of the apparatus.

A bomb calorimeter when operated properly will give the true heat value of a given combustible if as a water equivalent factor we use that obtained from the weights and specific heats of the immersed parts, i.e., the sum of the products of the weight of each part times its specific heat. The work of such physicists as Berthelot and Mahler has conclusively proven that this above method is correct. It is sometimes desirable to check this value by burning a combustible of known calorific value. Extreme care should be taken that such standardizing substances should be of 100 per cent purity and absolutely free from chemically or physically combined water.

The value of such a standard substance in calories per gram is divided by the rise in temperature in the calorimeter per gram of sample, and the result is the water plus the water equivalent of the apparatus. The water being known, the water equivalent is thus determined.

With a combustible of absolute purity this determination will check the value of the water equivalent as figured from the weights and specific heat of the material included in the immersed parts of the calorimeter.

The chemically pure cane sugar, benzoic acid and naphthaline obtained at the Bureau of Standards, Washington, D. C., are the only suitable materials to be used for the purpose of standardization of bomb calorimeters. These materials are prepared by the Bureau specifically for laboratories and users of combustion apparatus. The sample as received from the Bureau is in a finely divided condition suitable to be used for the work of standardization. With naphthaline, the sample should be briquetted or fused into a solid mass.

To standardize the calorimeter with one of the above materials, the bomb, fuel pan and fuse wires are prepared in the same manner as in the testing of a fuel, except that the fuse wire should be of iron instead of platinum. The iron wire at the point where it touches the combustible should be wound in a narrow helix. The pan should be about three-quarters filled with a known weight of the standard substance used, the iron fuse wire resting on its surface. One or two flakes of chemically pure naphthaline should be sprinkled on the coil where it is in contact with the material when cane sugar is used. These small pieces of naphthaline act as an igniter. For different diameters of iron fuse wire it will be necessary to change somewhat the resistance placed in series with the same. With wire about three- or four-thousandths of an inch in diameter, two 100-watt lamps should be placed in the firing circuit in parallel and in series with the iron fuse wire. Wires larger than this latter diameter should have three or four lamps in parallel according to the size of the same.

In making a run the weight of combustible is recorded, the weight of the naphthaline used as an igniter, and the weight of the iron fuse wire burned. The latter quantity is obtained by weighing the entire piece of fuse wire originally connected in the bomb, and subtracting from that weight of the unburned ends if any are found after the run. The following corrections must be made:

1. The heat generated by the burning of the small quantity of naphthaline used as an igniter.
2. The heat generated by the burning of the iron fuse wire.
3. The heat input of the electrical current used in bringing the fuse wire to incandescence.
4. The heat of formation of nitric acid.

With reference to the above:

The heat of combustion of naphthaline is 9610 calories per gram.

The heat of combustion of iron wire is 1600 calories per gram.

The correction for electrical input can be best determined by a blank run in which wire of the same diameter as that to be used in the test is burned in the bomb without the presence of a charge of combustible. This blank run is made with the temperature in the calorimeter bucket exactly the same as the surrounding conditions, in order that a cooling correction will be avoided. When the temperatures within and without the calorimeter are exactly equalized, the current is turned on and the iron wire ignited. The current is turned on for an exact period of time, i.e., either of one or two seconds' duration. This continuation of the flow of current should be exactly duplicated when the standardization run is being made and the standard combustible is being burned. From the total calories developed in the blank run should be subtracted the heat developed due to the burning of the known weight of iron wire. The remainder gives the amount due to the flow of current.

In supplying the correction for the formation of nitric acid, an arbitrary correction of about ten calories is satisfactory.

These above corrections are all subtractive and are deducted from the results as obtained from the calorimeter test.

The mean value for the heat of combustion of cane sugar is 3950 calories per gram. The heat of combustion of benzoic acid is 6320 calories per gram.

For further detailed information regarding the standardization of bomb calorimeters, Circular No. 11 of the Bureau of Standards is recommended.

The water equivalent factor of the Emerson Fuel Calorimeter, as computed from the immersed parts and their specific heats, is furnished with the outfit.

Specific heat of steel = 0.116; of nickel = 0.109; of brass = 0.094; of vulcanite = 0.331; of copper = 0.092; of platinum = 0.032.

Heat of Combustion.

SAMPLE RUN.

November 20, 1912.

Sample No. 128 (air dried.) Run No. 2.
Thermometer used, No. 2295.
Weight of tube and coal = 7.9379 Room Temp. = 22° C.
Weight of tube and coal = 7.0713

Weight of fuel	.8666 gram
Weight of water	1900 grams

READINGS OF THERMOMETER.

Time	Temp.	Time	Temp.	Time	Temp.
0	20.348	6	22.600	10	23.194
1	20.352	30	22.900	11	23.182
2	20.358	7	23.100	12	23.174
3	20.362	30	23.150	13	23.166
4	20.368	8	23.194	14	23.158
5	20.376 Firing Temp.	30	23.196 Max. Temp.	15	23.150
30	21.000	9	23.196		
		30	23.194		

(Calibration Correction)

Temperature at firing = 20.376 + (−.011) = 20.365
Temperature at max. = 23.196 + (+.002) = 23.198
Rise in temperature corrected for errors in thermometer = 2.833
Rate of change of temperature before firing = 0.0056 = R_1
Rate of change of temperature after maximum temperature = 0.0088 = R_2*

$$\text{Total cooling corr.} = \frac{(-.0056)}{2} \times (1) + \frac{(+.0088)}{2} \times (2.5) = .008 \text{ (additive)}$$

Total corrected rise in temperature = 2.841.
Rise per gram of sample = 3.278
The water equivalent of bomb, calorimeter can, stirrer, etc. = 490
Gram calories per gram of coal = (1900 + 490) × 3.278 = 7834
British Thermal Units per pound of coal = 7834 × 1.8 = 14,100

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* Rate for last five minutes.

Berthier's Method.—Another method of direct determination was proposed by Berthier in 1835.* It uses as a measure of the heating value the amount of lead which a fuel would reduce from the oxide; in other words it is proportional to the amount of oxygen absorbed.

The method is as follows †: Mix one gram of the finely powdered dry coal with 60 grams of oxide of lead (litharge) and 10 grams of ground glass. This mixing can be done with a palette-knife on a sheet of glazed paper; the mixture is transferred to a fire-clay crucible (Battersea C size), covered with salt, the crucible covered and heated to redness in a hot gas-furnace—or the hottest part of the boiler-furnace—for 15–20 minutes. After cooling, the crucible is broken and the lead button carefully cleaned and weighed. Multiply the weight of the lead button obtained by 268.3 calories (or 483 B. T. U.) and divide the product by the weight of coal taken. The result is the number of calories per gram or B. T. U. per pound. One gram of lead is theoretically equivalent to 234 calories (C); owing to the hydrogen present this factor gives results about 2 per cent too low. The results obtained by the author using "horn-pan" scales in one case by this method were within 2.8 per cent of those yielded by the bomb calorimeter, which are as close as those obtained by any calorimeter save Parr's. The method would seem worthy of more attention than it has received.

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* Dingler's Polytechnisches Journal, 58, 391.

† Noyes, McTaggart and Craver, J. Am. Chem. Soc., 17, 847 (1895).

b. Determination of Heating Value by Calculation.

The method of determination of the heating value first described, though exact, has the disadvantages that the apparatus is costly and the compressed oxygen is not easily obtained. To obviate these, it has been sought to obtain the heating value by calculation from the chemical analysis, the heating value of the constituents being known. This has the disadvantage that we have no absolute knowledge—nay, not even an approximate idea—as to how the carbon, hydrogen, water, and sulphur exist in the coal, so that any formula must of necessity be quite removed from the truth. Dulong was the first to propose the method by calculations, and his formula as modified by Bunte * is

$$\frac{8080c + 28800\left(h - \frac{o}{8}\right) + 2500s - 600w}{100}.$$

c, h, o, s and w representing the percentages of carbon, hydrogen, oxygen, sulphur and water in the coal. It gives results varying from +2.8 to −3.7 per cent; it would scarcely seem that the sulphur would be worth considering unless high, 1 per cent affecting the result but 0.3 per cent. The hydrogen is considered as burned to aqueous vapor.

The results obtained by these formulæ for anthracite coal are as a rule considerably too low.

The heating value can also be determined from the proximate analysis—the percentage of fixed carbon and

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* Jour. für Gasbeleuchtung, **34**, 21–26 and 41–47.

volatile matter; this has been well shown by Maujer.* The chart, Fig. 23, was constructed from over 300 analyses of representative coal made by the Bureau of Mines; the curve is most accurate for coals having from 64–90 per cent of fixed carbon in the combustible matter; where this is less than 64 per cent the error may be as much as 7 per cent. To determine the heating value of the coal from the chart, the percentage of fixed carbon is divided by the sum of the fixed carbon and of the volatile combustible matter and multiplied by 100; this gives the percentage of fixed carbon in the combustible matter. Let us suppose a coal of this composition; moisture, 5.12,

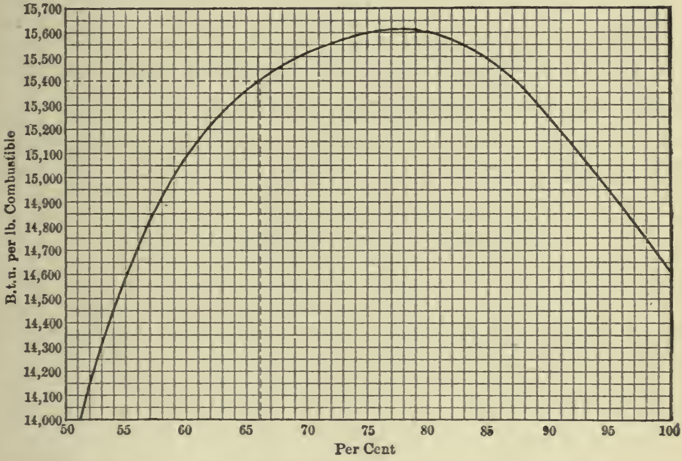

FIG. 23.—CHART FOR DETERMINING HEAT VALUE OF COMBUSTIBLE WITH DIFFERENT PERCENTAGES OF FIXED CARBON.

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* Power, **37**, 836 (1913), also in "Fuel Economy and CO_2 Recorders," (1916), pp. 45–47. A similar curve is given by Kowalke, Power, **35**, 559 (1912).

volatile combustible matter 27.25, fixed carbon 53.38, and ash 14.25 per cent. The sum of the volatile matter and fixed carbon is $(27.25+53.38)=80.63$ divided into the fixed carbon $\frac{53.38}{80.63}\times 100=66.2$ per cent.

That is, there are 66.2 per cent fixed carbon in the total combustible matter; using this as an abscissa (horizontal distance), in Fig. 23 we find 15,400 B. T. U. as the corresponding ordinate; this is the heating value of the combustible matter in the coal; since by the above calculation but 80.63 per cent of the coal is combustible, the heating value of the coal is $80.63\times 15,400$ or 12,420 B. T. U.

CALORIFIC POWER OF GASEOUS FUEL.

a. Direct Determination.

Perhaps the best apparatus for the determination of the heating value of gases is the Junkers calorimeter, Figs. 24 and 25. The following description is taken from an article by Kühne in the Journal of the Society of Chemical Industry, vol. 14, p. 631.* As will be seen from Fig. 24, this consists of a combustion-chamber, 28, surrounded by a water-jacket, 15 and 16, this being traversed by a great many tubes. To prevent loss by radiation this water-jacket is surrounded by a closed annular air-space, 13, in which the air cannot circulate. The whole apparatus is constructed of copper as thin as is compatible with strength. The water enters the jacket

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* See also Industrial Gas Calorimetry, Tech. Paper No. 36, Bur. Standards; Standard Methods of Gas Testing, Circular No. 48, Bur. Standards.

at 1, passes down through 3, 6, and 7, and leaves it at 21, while the hot combustion-gases enter at 30 and pass down, leaving at 31. There is therefore not only a very large surface of thin copper between the gases and the water, but the two move in opposite directions, during which process all the heat generated by the flame is transferred to the water, and the waste gases leave the apparatus approximately at atmospheric temperature. The gas to be burned is first passed through a meter,

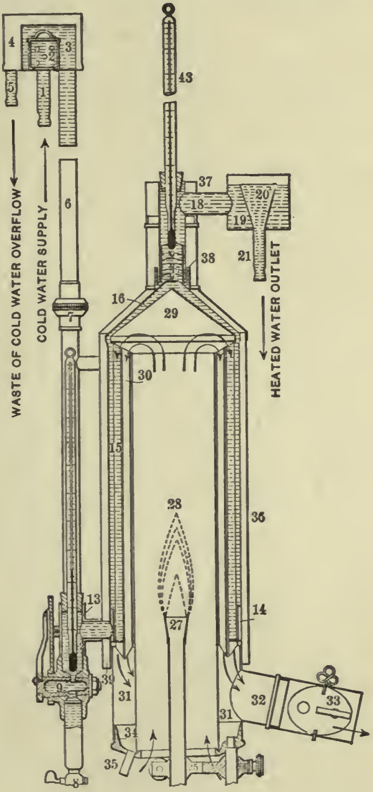

FIG. 24.—JUNKERS GAS-CALORIMETER (SECTION).

Fig. 25, and then, to insure constant pressure, through a pressure regulator. The source of heat in relation to the unit of heat is thus rendered stationary; and in

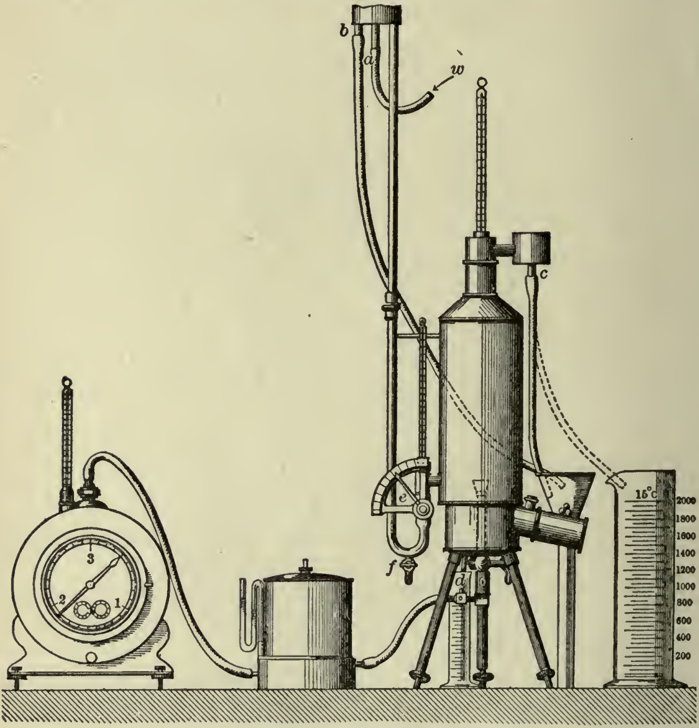

Fig. 25.—Junkers Gas-calorimeter.

order to make the absorbing quantity of heat also stationary, two overflows are provided at the calorimeter, making the head of water and overflow constant. The temperatures of the water entering and leaving the apparatus can be read by 12 and 43; as shown before, the quantities of heat and water passed through the apparatus are constant. As soon as the flame is lighted, 43 will rise to a certain point and will remain nearly constant.

Manipulation.—The calorimeter is placed as shown in Fig. 25, so that one operator can simultaneously observe the two thermometers of the entering and escaping water, the index of the gas-meter, and the measuring-glasses.

No draft of air must be permitted to strike the exhaust of the spent gas.

The water-supply tube *w* is connected with the nipple *a* in the centre of the upper container; the other nipple, *b*, is provided with a waste-tube to carry away the overflow, which latter must be kept running while the readings are taken.

The nipple *c* through which the heated water leaves the calorimeter is connected by a rubber tube with the large graduate. *d* empties the condensed water into the small graduate.

The thermometers being held in position by rubber stoppers and the water turned on by *e* until it discharges at *c*, no water must issue from *d* or from 39, Fig. 24, as this would indicate a leak in the calorimeter.

The cock *e* is now set to allow about two liters of water to pass in a minute and a half, and the gas issuing from the burner ignited. Sufficient time is allowed until the temperature of the inlet-water becomes constant and the outlet approximately so; the temperature of the inlet-water is noted, the reading of the gas-meter taken, and at this same time the outlet-tube changed from the funnel to the graduate.

Ten successive readings of the outflowing water are taken while the graduate (2-liter) is being filled and the gas shut off.

A better procedure is to allow the water to run into tared 8-liter bottles, three being used for a test, and weighing the water. The thermometer in the outlet can then be read every half-minute.

EXAMPLE.—Temp. of incoming water, 17.2°
" " outgoing " 43.8°

Increase, 26.6°
Gas burned, 0.35 cu. ft.

$$\text{Heat} = \frac{\text{liters water} \times \text{increase of temp.}}{\text{cu. ft. gas}} = \frac{2 \times 26.6}{0.35}$$
$$= 152\ 3\text{C.}$$

From burning one cubic foot of gas 27.25 cc. of water were condensed. This gives off on an average 0.6 C. per cc.

$27.25 \times 0.6 = 16.3$ C.; $152.3 - 16.3 = 136$ C. per cubic foot; $136 \times 3.96823 = 540$ B.T.U.

NOTES.—After setting up the apparatus the *first* thing to be done is to turn on the *water*—(*not the gas*). Similarly, the *water* should be shut off *last*. All connections and the meter should be tested for leaks before each test. The water level in the meter should be checked daily. Slight drafts caused by moving suddenly near the apparatus will vary outlet readings and vitiate the test. The instrument should not be set up near a window or heating apparatus where radiant heat might affect the readings.

If 0.2 cu. ft. of gas are burned, then an error of 0.1° F. in temperature of water means an error of 4 B.T.U.; an error of 0.01 lb. water, 0.9 B.T.U.; 1° F. in gas temperature, 1.8 B.T.U.; 0.1 inch (barometer), 2 B.T.U.; 1 inch water pressure of gas, 1.5 B.T.U.*

The calorific power obtained without subtracting the heat given off by the condensation of the water represents the *total* heating value of the gas. This is the heat given off when the gas is used for heating water or in any operation where the products of combustion pass off below 100° C., and is the one which should be reported. It should, however, be corrected,† as shown on page 124, to the legal cubic foot, that is, measured at 30 inches barometric pressure, and 60° F. saturated with moisture.

The *net heating value* represents the conditions in which by far the greater quantity of gas is consumed, for cooking, heating and gas engines.

The apparatus has been tested for three months in the German Physical Technical Institute with hydrogen, with but a deviation of 0.3 per cent from Thomson's value. This value may vary nearly that amount from the real value owing to the method which he employed.

b. By Calculation.

Oftentimes it may be impracticable to determine the heating value of gases directly; in such cases recourse must be had to the calculation of its calorific power from volumetric analysis of the gas.

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* Rept. Joint Committee on Calorimetry Public Service Commission and Gas Corporations in the Second Public Service District of New York State (1910), p. 81.

† A difference of 1° C. or of 3 mm. pressure makes a change of 0.3 per cent in the volume. Pfeiffe, J. Gasbeleucht., 50, 67 (1870).

To this end multiply the percentage of each constituent by its number as given in Table IV, and the sum of the products will represent the British Thermal Units evolved by the combustion of one cubic foot of the gas.* It is assumed that the temperature of the gas burned and the air for combustion is 60° F., and that of the escaping gases is 328° F., that corresponding to the temperature of steam at 100 pounds absolute pressure.

As has been already stated, column 3 in Table IV is based upon the assumption that the gas, and air for its combustion, enter at 60° F., and the products of combustion leave at 328° F.; in column 4 it is assumed that the entering temperature of both gas and air is 32° F., and the combustion-gases are cooled to 32° F. In case these conditions are varied, the amount of heat which the gas and air bring in must be determined; this is found in the usual way by multiplying the proportionate parts of 1 cubic foot, as shown by the analysis, by the specific heat of the gas, and this by the rise in temperature (difference between observed temperature and 32° F.). The quantity of air necessary for combustion is found by multiplying the percentage composition of the gas by the number of cubic feet necessary for the combustion of each constituent.

An example will serve to make this clear. The analysis of Boston gas is as follows: †

CO_2	"Illuminants."	O	CO	CH_4	H	N
2.9	15.0	0.0	25.3	25.9	27.9	3.0

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* H. L. Payne, Jour. Analytical and Applied Chem., 7, 230.

† Jenkins, Annual Report Inspector of Gas Meters and Illuminating Gas, 1896, p. 11.

Or in one cubic foot there are

.029 CO_2......................
.150 "illuminants".........
.253 CO......................
.259 CH_4
.279 H
.030 N

Let us assume that the gases, instead of passing out at a temperature of 328° F., leave at the same temperature as that of the chimney-gases, p. 29, 250° C or 482° F.

The calculation of the heat carried away is similar to that there given.

0.15 cu. ft. of "illuminants" produces, Table III, 0.3 cu. ft. CO_2 and 0.3 cu. ft. steam;
0.253 cu. ft. of carbonic oxide produces .253 cu. ft. CO_2;
0.259 cu. ft. methane produces 0.259 cu. ft. CO_2 and .518 cu ft. steam;
0.279 cu. ft. hydrogen produces .279 cu. ft. steam.

From the combustion of the gas there results .812 cu. ft. CO_2, 1.097 cu. ft. steam, and 5.90 × 79.08 or 4.665 cu. ft. N.

The quantity of heat they carry off is as follows:

	Vol.	Vol. Sp. Ht.	Rise.	B.T.U.
CO_2...........	.812 ×	.027 ×	450 =	9.9
N.............	4.66 ×	.019 ×	450 =	39.9
Excess of air..	1.2 ×	.019 ×	450 =	10.2
Steam.........	1.097 ×	.0502 ×	1229 =	67.7
Total heat lost................ =				127.7

The loss due to the steam is found by multiplying the weight of steam found by the "Total Heat of

Steam," as found from Steam Tables.* The tables, however, do not extend beyond 428° F.; it can be calculated by the formula

$$\text{Total heat} = \lambda = 1091.7 + 0.305(t - 32).$$

One cubic foot of hydrogen when burned yields .0502 lbs. of water.

The heat generated by the combustion of the gas is found by multiplying its volume by its calorific power, Table IV.

"Illuminants"	0.15	× 2000.0 =	300.0	B.T.U.
CO................	0 253	× 341.2 =	86.3	
CH_4...............	0.259	× 1065.4 =	276.0	
H.................	0.279	× 345.4 =	96.3	
Heat generated by the gas...........			758.6	B.T.U.
Total heat lost (p. 109)......			127.7	
			630.9	B.T.U.

This figure, 630.9 B.T.U., represents the heating power of one cubic foot of the gas measured at 62° F., and is consequently too small; its heating value at 32° F. is represented by

$$\frac{492 + 30}{492} \times 630.9, \text{ or } 669.1 \text{ B.T.U.}$$

The above calculation, like all giving accurate results, is somewhat tedious; a shorter and less correct one is as follows: Divide the figures found in the last column of Table IV of the Appendix by 100, the result gives the heating value of these gases in B.T.U. per cubic centi-

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* Peabody's Steam Tables.

meter.* According to the volumetric analysis of the gas there are in 100 cc. the following:

15.0 cc. illuminants,
25.3 cc. carbonic oxide,
25.9 cc. methane,
27.9 cc. hydrogen.

The heating value is

$$\begin{aligned}
15.0 \times 20.0 &= 300.0 \text{ B.T.U.}\\
25.3 \times 3.41 &= 86.3\\
25.9 \times 10.65 &= 276.0\\
27.9 \times 3.45 &= \underline{96.3}\\
& 758.6 \text{ B.T.U.}
\end{aligned}$$

the same as the gross heating value obtained by the other method. No correction is applied for the heat lost.

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* Method followed in Prof. Paper, No. 48, U. S. Geol. Survey, Part III, p. 1005.

APPENDIX.

TABLE I.

TABLE SHOWING THE TENSION OF AQUEOUS VAPOR AND ALSO THE WEIGHT IN GRAMS CONTAINED IN A CUBIC METER OF AIR WHEN SATURATED.

From 5° to 30° C.

Temp.	Tension, mm.	Grams.	Temp.	Tension, mm.	Grams.	Temp.	Tension, mm.	Grams.
5	6.5	6.8	14	11.9	12.0	23	20.9	20.4
6	7.0	7.3	15	12.7	12.8	24	22.2	21.5
7	7.5	7.7	16	13.5	13.6	25	23.6	22.9
8	8.0	8.1	17	14.4	14.5	26	25.0	24.2
9	8.5	8.8	18	15.4	15.1	27	26.5	25.6
10	9.1	9.4	19	16.3	16.2	28	28.1	27.0
11	9.8	10.0	20	17.4	17.2	29	29.8	28.6
12	10.4	10.6	21	18.5	18.2	30	31.5	29.2
13	11.1	11.3	22	19.7	19.3			

TABLE II.

"VOLUMETRIC" SPECIFIC HEATS OF GASES.*

Air	0.019	"Illuminants"	0.040
Carbon dioxide	0.027	Methane	0.027
Carbonic oxide	0.019	Nitrogen	0.019
Hydrogen	0.019	Oxygen	0.019

The "volumetric" specific heat is the quantity of heat necessary to raise the temperature of one cubic foot of gas from 32° F. to 33° F.

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* H. L. Payne, *Jour. Anal. and Applied Chem.*, 7, 233.

TABLE III.

THE VOLUME OF OXYGEN AND AIR NECESSARY TO BURN ONE CUBIC FOOT OF CERTAIN GASES, TOGETHER WITH THE VOLUME OF THE PRODUCTS OF COMBUSTION.

Name.	Formula.	Volume of Oxygen.	Volume* of Air.	Volume of Steam.	Volume of Carbon Dioxide.	Ignition Point Deg. F.
Hydrogen....	H_2	0.5	2.39	1	0	1085 ‖
Carbonic oxide	CO	0.5	2.39	0	1	1200 ‖
Methane.....	CH_4	2.0	9.56	2	1	1230
Ethane......	C_2H_6	3.5	16.73	3	2	1140
Propane......	C_3H_8	5.0	23.90	4	3	1015
Butane......	C_4H_{10}	6.5	31.07	5	4	....
Pentane......	C_5H_{12}	8.0	38.24	6	5	....
Hexane......	C_6H_{14}	9.5	45.41	7	6	1400
Ethylene†....	C_2H_4	3.0	14.34	2	2	1010 ‖
Propylene‡...	C_3H_6	4.5	21.51	3	3	940
Benzene§.....	C_6H_6	7.5	35.85	3	6	....
Acetylene....	C_2H_2	2.5	11.95	1	2	788 ‖

* Air being 20.92% by volume, 4.78 vols. contain 1 vol. of oxygen.

† The chief constituent of "illuminants," new name "ethene."

‡ New name "propene."

§ Often called benzol, not to be confounded with benz*i*ne.

‖ Dixon & Coward, Proc. Chem., Soc., 26, 67.

TABLE IV.

SPECIFIC HEATS OF VARIOUS OILS USED AS FUEL.

Alcohol, absolute	0.700
Benzol	0.430
Ether	0.503
Gasoline	0.525 0.700
Kerosene	0.500
Machine oil	0.400
Paraffin oil	0.520
Paraffin solid	0.600
Crude oils, Pa	0.500
Crude oils, Cal	0.398
Crude oils, Russia	0.435

LATENT HEAT OF VAPORIZATION * B.T.U. PER POUND.

Gasoline	130
Gas oil	200–250

*Cross, "Oil and Gas News," 2, 13 (1917).

TABLE V.

CALORIFIC POWER OF VARIOUS GASES [*] IN BRITISH THERMAL UNITS PER CUBIC FOOT.

Name.	Symbol.	60° initial. 328° final.[§]	32° initial. 32° final.
Hydrogen	H	263.2	345.4
Carbonic oxide	CO	306.9	341.2
Methane	CH_4	853.0	1065.0
Illuminants[†]	....	1700.0	2000.0
Ethane	C_2H_6	....	1861.0
Propane	C_3H_8	....	2657.0
Butane	C_4H_{10}	....	3441.0
Pentane	C_5H_{12}	....	4255.0
Hexane[‡]	C_6H_{14}	....	5017.0
Ethylene	C_2H_4	....	1674.0
Propylene	C_3H_6	....	2509.0
Benzene	C_6H_6	....	4012.0
Acetylene	C_2H_2	....	1477.0

[*] H. L. Payne, *loc. cit.*

[†] Where the "illuminants" are derived chiefly from the decomposition of mineral oil.

[‡] The chief constituent of the "gasolene" used in the gas machines for *carburetting* air.

[§] The temperature of steam at 100 lbs. absolute pressure.

TABLE VI.

CALORIFIC POWER OF VARIOUS LIQUIDS IN BRITISH THERMAL UNITS PER POUND.

Name.	B. T. U.	Pounds of Air for Combustion.
Crude petroleum, Lima, Ohio	20,890	
Crude petroleum, Oil Creek, Pa	21,600	
Crude petroleum, heavy, W. Va	18,180	
63° Bé. gasolene	19,162–20,448	14.96[*]
114° F. flash kerosene	18,643–19,892	14.89[*]
150° fire-test kerosene	18,290	
Mineral sperm	20,065	
Ethyl alcohol, 95 per cent	10,504	
Methyl alcohol	9,565	
Denatured alcohol	10,512–11,616	8.13[*]
Benzole	17,260–18,000	

[*] Bull. 43 Bureau of Mines, 1912, pp. 18–21. "Fuel Values of Gasolene and Denatured Alcohol in Internal Combustion Engines."

TABLE VII.

CALORIFIC POWER OF CERTAIN SOLID FUELS IN BRITISH THERMAL UNITS PER POUND, FIGURED ON THE PURE DRY COMBUSTIBLE.

Anthracite	13,740–15,620
Bituminous coal:	
Cumberland	16,320
Georges Creek	15,140
Pocahontas	15,700
West Virginia	13,700
Brown coal	9,060–14,240
Coke	13,880–14,560
Peat	7,400–10,625
Tanbark	6,100
Wheat straw	10,380
Wood, hard	8,500
Wood, pine	9,150

TABLE VIII.

SHOWING THE MOLECULAR WEIGHT, THE WEIGHT OF A LITER AND SPECIFIC GRAVITY, REFERRED TO AIR, OF CERTAIN GASES AT 0° C. AND 760 MM.

Name of Gas.	Molecular Weight, 22.4 L.	Weight, Grams.	Specific Gravity.
Carbonic oxide	28	1.251	0.967
Carbon dioxide	44	1.966	1.519
Hydrogen	2	0.0896	0.069
Methane	16	0.715	0.553
Nitrogen	28	1.255	0.970
Oxygen	32	1.430	1.105
Air	28.95	1.294	1.000
Steam	18	0.803	0.621

13.14 cu. ft. air at 62° F., and 30 in., weighs 1 lb.

12.40 cu. ft. air at 32° F., and 30 in., weighs 1 lb.

359 cu. ft. of a gas is a pound mol. (molecular weight in pounds).

TABLE IX.

SOLUBILITY OF VARIOUS GASES IN WATER.

One volume of water at 20° C. absorbs the following volumes of gas reduced to 0° C., and 760 mm. pressure.

Name of Gas.	Symbol.	Volumes.
Carbonic oxide	CO	0.023
Carbon dioxide	CO_2	0.901
Hydrogen	H_2	0.019
Methane	CH_4	0.035
Nitrogen	N_2	0.014
Oxygen	O_2	0.028
Air	......	0.017
Ethylene	C_2H_4	0.150

TABLE X.

MELTING-POINTS OF VARIOUS METALS AND SALTS, FOR USE WITH APPARATUS FIG. 11.

Alphabetically.		By Temperatures.	
Aluminium	658° C.	Tin	232° C.*
Antimony	630	Bismuth	270*
†Barium chloride	950	Cadmium	302*
Bismuth	270	Lead	327*
Calcium fluoride	902	Zinc	419*
Cadmium	302	Cadmium chloride	541‡
†Cadmium chloride	541	Antimony	630*
Copper	1083	Aluminium	658*
Lead	327	Potassium bromide	740*
†Potassium bromide	740	Sodium bromide	748*
†Potassium chloride	780	Potassium chloride	780*
†Sodium bromide	748	Sodium carbonate	853*
†Sodium carbonate	853	Calcium fluoride	902§
Tin	232	Barium chloride	950*
Zinc	419	Copper	1083*

* Burgess-Le Chatelier, Measurement of High Temperatures, 1912.

† These salts must be dried at 105° C. to a constant weight.

‡ Carnelley, Melting- and Boiling-point Tables.

§ Meyer, Riddle and Lamb, Ber. d. deut. Chem. Gesellsch., **27**, 3140 (1894).

TABLE XI.

GIVING THE NUMBER OF TIMES THE THEORETICAL QUANTITY OF AIR SUPPLIED, WITH VARIOUS GAS ANALYSES.*

CO_2 + CO.	N = 79. $CO_2+O+CO=21$	N = 80. $CO_2+O+CO=20$.	N = 81. $CO_2+O+CO=19$.	N = 82. $CO_2+O+CO=18$.
21	1.00	....	....	....
20	1.05	1.00	....	....
19	1.10	1.05	1.00	....
18	1.17	1.10	1.05	1.00
17	1.23	1.16	1.10	1.05
16	1.31	1.23	1.16	1.10
15	1.40	1.31	1.23	1.16
14	1.50	1.39	1.30	1.22
13	1.61	1.49	1.39	1.30
12	1.75	1.60	1.48	1.38
11	1.91	1.73	1.59	1.47
10	2.10	1.89	1.72	1.58
9	2.33	2.07	1.87	1.70
8	2.62	2.29	2.04	1.85
7	3.00	2.57	2.26	2.02
6	3.50	2.92	2.52	2.23
5	4.20	3.39	2.86	2.48
4	5.25	4.05	3.30	2.79
3	7.00	5.00	3.89	3.20
2	10.50	6.53	4.76	3.76
1	21.00	9.43	6.10	4.54

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* Coxe, Proc. N. E. Cotton Manufacturers' Assoc., 1895.

TABLE XII.

COMPARISON OF METRIC AND ENGLISH SYSTEMS.

1 cubic inch = 16.39 c.c.
1 cubic foot = 28.315 liters.
1 cubic meter = 35.32 cu. ft.
1 Imperial gallon = 4.543 liters.

1 lb. avoirdupois = 453.593 grams.
1 calorie = 3.969 B.T.U. (Röntgen).

COAL AND FUEL OIL SPECIFICATIONS.

COAL SPECIFICATIONS.*

The following, from Bulletin 339, U. S. Geological Survey (1908), by D. T. Randall, will give an idea of some coal specifications:

SPECIFICATIONS FOR THE U. S. GOVERNMENT FUEL SUPPLY AS APPROVED BY THE NATIONAL ADVISORY BOARD ON FUELS AND STRUCTURAL MATERIALS, MARCH, 1907.

Specifications and Proposals for Supplying Coal.

United States.............

.........., 190.....

PROPOSAL.

Sealed proposals will be received at this office until 2 o'clock P.M.,..... 190.., for supplying coal to the United States.............building at.................... as follows:

....

....

....

The quantity of coal stated above is based upon the previous annual consumption, and proposals must be made upon the basis of a delivery of 10 per cent more or less than this amount, subject to the actual requirements of the service.

Proposals must be made on this form, and include all expenses incident to the delivery and stowage of the coal, which must be delivered in such quantities and at such times within the fiscal year ending June 30, 190.., as may be required.

Proposals must be accompanied by a deposit (certified check, when practicable, in favor of..................) amounting to 10 per cent of the aggregate amount of the bid submitted, as a guaranty that it is bona fide. Deposits will be returned to unsuccessful bidders immediately after award has been made, but the deposit of the successful bidder will be retained until after the coal shall have been delivered and final settlement made therefor, as security for the faithful performance of the terms of the contract, with the understanding that the whole or a part thereof may be used to liquidate the value of any

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* See also Bulletin 63, Bureau of Mines (1913), Sampling Coal Deliveries.

deficiencies in quality or delivery that may arise under the terms of the contract.

When the amount of the contract exceeds $10,000, a bond may be executed in the sum of 25 per cent of the contract amount, and in this case the deposit or certified check submitted with the proposal will be returned after approval of the bond.

The bids will be opened in the presence of the bidders, their representatives, or such of them as may attend, at the time and place above specified.

In determining the award of the contract, consideration will be given to the quality of the coal offered by the bidder, as well as the price per ton, and should it appear to the best interests of the Government to award the contract for supplying coal at a price higher than that named in lower bid or bids received, the award will be so made.

The right to reject any or all bids and to waive defects is expressly reserved by the Government.

DESCRIPTION OF COAL DESIRED.*

Bids are desired on coal described as follows:

....

....

....

Coals containing more than the following percentages, based upon dry coal, will not be considered:

Ash.................................... ...per cent
Volatile matter.......................... ...per cent
Sulphur................................ ...per cent
Dust and fine coal as delivered at point of
consumption †........................ ...per cent

DELIVERY

The coal shall be delivered in such quantities and at such times as the Government may direct.

In this connection it may be stated that all the available storage capacity of the coal bunkers will be placed at the disposal of the contractor to facilitate delivery of coal under favorable conditions.

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* This information will be given by the Government as may be determined by boiler and furnace equipment, operating conditions, and the local market.

† All coal which will pass through a ¼-inch round-hole screen.

After verbal or written notice has been given to deliver coal under this contract, a further notice may be served in writing upon the contractor to make delivery of the coal so ordered within twenty-four hours after receipt of said second notice.

Should the contractor, for any reason, fail to comply with the second request, the Government will be at liberty to buy coal in the open market, and to charge against the contractor any excess in price of coal so purchased over the contract price.

SAMPLING.

Samples of the coal delivered will be taken by a representative of the Government.

In all cases where it is practicable, the coal will be sampled at the time it is being delivered to the building. In case of small deliveries, it may be necessary to take these samples from the yards or bins. The sample taken will in no case be less than the total of 100 lbs., to be selected proportionally from the lumps and fine coal, in order that it will in every respect truly represent the quantity of coal under consideration.

In order to minimize the loss in the original moisture content the gross sample will be pulverized as rapidly as possible until none of the fragments exceed one-half inch in diameter. The fine coal will then be mixed thoroughly and divided into four equal parts. Opposite quarters will be thrown out, and the remaining portions thoroughly mixed and again quartered, throwing out opposite quarters as before. This process will be continued as rapidly as possible until the final sample is reduced to such amount that all of the final sample thus obtained will be contained in the shipping can or jar and sealed air-tight.

The sample will then be forwarded to.....................,

If desired by the coal contractor, permission will be given to him, or his representative, to be present and witness the quartering and preparation of the final sample to be forwarded to the Government laboratories.

Immediately on receipt of the sample, it will be analyzed and tested by the Government, following the method adopted by the American Chemical Society, and using a bomb calorimeter. A copy of the result will be mailed to the contractor upon the completion thereof.

CAUSES FOR REJECTION.

A contract entered into under the terms of this specification shall not be binding if, as the result of a practical service test of reasonable duration, the coal fails to give satisfactory results owing to excessive clinkering or to a prohibitive amount of smoke.

It is understood that the coal delivered during the year will be of the same character as that specified by the contractor. It should, therefore, be supplied, as nearly as possible, from the same mine or group of mines.

Coal containing percentages of volatile matter, sulphur, and dust higher than the limits indicated on page 2 and coal containing a percentage of ash in excess of the maximum limits indicated in the following table will be subject to rejection.

In the case of coal which has been delivered and used for trial, or which has been consumed or remains on the premises at the time of the determination of its quality, payment will be made therefor at a reduced price, computed under the terms of this specification.

Occasional deliveries containing ash up to the precentage indicated in the column of "Maximum limits for ash," on page 4, may be accepted. Frequent or continued failure to maintain the standard established by the contractor, however, will be considered sufficient cause for cancellation of the contract.

PRICE AND PAYMENT.*

Payment will be made on the basis of the price named in the proposal for the coal specified therein, corrected for variations in heating value and ash, as shown by analysis, above and below the standard established by contractor in this proposal. For example, if the coal contains 2 per cent, more or less, British thermal units than the established standard, the price will be increased or decreased 2 per cent accordingly.

The price will also be further corrected for the percentages of ash. For all coal which by analysis contains less ash than that established

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* The economic value of a fuel is affected by the actual amount of combustible matter it contains, as determined by its heating value shown in British thermal units per pound of fuel, and also by other factors, among which is its ash content. The ash content not only lowers the heating value and decreases the capacity of the furnace, but also materially increases the cost of handling the coal, the labor of firing, and the cost of removal of ashes, etc.

in this proposal a premium of 1 per cent per ton for each whole per cent less ash will be paid. An increase in the ash content of 2 per cent over the standard established by contractor will be tolerated without exacting a penalty for the excess of ash. When such excess exceeds 2 per cent above the standard established, deductions will be made from the price paid per ton in accordance with following table:

Ash as Established in Proposal (Per Cent).	No Deduction for Limits Below.	Cents per Ton to be Deducted.							Maximum Limits for Ash.
		2	4	7	12	18	25	35	
		Percentages of Ash in Dry Coal.							
5	7	7–8	8–9	9–10	10–11	11–12	12–13	13–14	12
6	8	8–9	9–10	10–11	11–12	12–13	13–14	14–15	13
7	9	9–10	10–11	11–12	12–13	13–14	14–15	15–16	14
8	10	10–11	11–12	12–13	13–14	14–15	15–16	16–17	14
9	11	11–12	12–13	13–14	14–15	15–16	16–17	17–18	15
10	12	12–13	13–14	14–15	15–16	16–17	17–18	......	16
11	13	13–14	14–15	15–16	16–17	17–18	18–19	......	16
12	14	14–15	15–16	16–17	17–18	18–19	19–20	......	17
13	15	15–16	16–17	17–18	18–19	19–20	20–21	......	18
14	16	16–17	17–18	18–19	19–20	20–21	21–22	......	19
15	17	17–18	18–19	19–20	20–21	21–22	......	......	19
16	18	18–19	19–20	20–21	21–22	22–23	......	......	20
17	19	19–20	20–21	21–22	22–23	......	......	......	21
18	20	20–21	21–22	22–23	......	......	......	......	22

Proposals to receive consideration must be submitted upon this form and contain all of the information requested.

....

............, 190..

The undersigned hereby agree to furnish to the U. S............... building at ...., the coal described, in tons of 2,240 lbs. each and in quantity 10 per cent more or less than that stated on page 1, as may be required during the fiscal year ending June 30, 190.., in strict accordance with this specification; the coal to be delivered in such quantities and at such times as the Government may direct.

	Item No...	Item No...	Item No...
Description.			
Commercial name........	....	....	....
Name of mine......	....	....	....
Location of mine.........	....	....	....
Name of coal bed........	....	....	....
Size of coal (if coal is screened):			
Coal to pass through openings............	.inches } round	..inches } round	..inches } round
	} square	} square	} square
Coal to pass over openings................	.inches } bar	..inches } bar	..inches } bar
Data to establish a basis for payment.			
Per cent of ash in dry coal (method of American Chemical Society)......	....	....	....
British thermal units in coal as delivered.......	....	....	....
Price per ton (2,240 lbs.) ..	....	....	....

It is important that the above information does not establish a higher standard than can be actually maintained under the terms of the contract; and in this connection it should be noted that the small samples taken from the mine are invariably of higher quality than the coal actually delivered therefrom. It is evident, therefore, that it will be to the best interests of the contractor to furnish a correct description with average values of the coal offered, as a failure to maintain the standard established by contractor will result in deductions from the contract price, and may cause a cancellation of the contract, while deliveries of a coal of higher grade than quoted will be paid for at an increased price.

Signature.................
Address..................

Name of corporation........................
Name of president.........................
Name of secretary.........................
Under what law (State) corporation is organized...............

As will be seen from the foregoing specification, the bidder is not required to submit a sample of his coal, but is expected to name a standard of British thermal units in the coal as it is to be delivered. This value is made the basis for purchase, because a correction is thus made for the amount of moisture in the coal. It should be noted that this value will in all cases be lower than the British thermal units in the dry coal, which is usually given in connection with the coal analysis. The percentage of ash is also specified, as it is a factor in the successful burning of the coal on the grate and as it involves an expense for removal from the premises.

The following are the essential features of the contracts on which a Chicago company is said to purchase and inspect nearly 1,000,000 tons of coal for its clients in Chicago, Indianapolis, Minneapolis, St. Louis, and other cities:

I. The company agrees to furnish and deliver to the consumer...... .... at such times and in such quantities as ordered by the consumer for consumption at said premises during the term hereof, at the consumer's option, either or all of the kinds of coal described below; said coals to average the following assays:

Kind of coal........................	....	....	....
Of size passing through screen having circular perforations in diameter...........	....inches	....inches	....inches
Of size passing over a screen having circular perforations in diameter..............	....inches	....inches	....inches
Per cent of moisture in coal as delivered ..	....	....	....
Per cent of ash in coal as delivered.......	....	....	....
British thermal units per pound of dry coal.	....	....	....
From following county.................	....	....	....
From following State..................	....	....	....

Coal of the above respective descriptions and specified assays (not average assays) to be hereinafter known as the contract grade of the respective kinds.

II. The consumer agrees to purchase from the company all the coal required for consumption at said premises during the term of said contract, except as set forth in Paragraph III below, and to pay the company for each ton of 2000 lbs. avoirdupois of coal delivered and accepted in accordance with all the terms of this contract at the following contract rate per ton for coal of each respective contract grade, at which rates the company will deliver the following respective numbers of British thermal units for 1 cent, the contract guaranty:

Kind of Coal.	Contract Rate per Ton.	Contract Guaranty.
....	$.......	equal to..........net B.T.U. for 1 cent
....	$.......	equal to..........net B.T.U. for 1 cent
....	$.......	equal to..........net B.T.U. for 1 cent

Said net British thermal units for 1 cent being in each case determined as follows: Multiply the number of British thermal units per pound of dry coal by the per cent of moisture (expressed in decimals), subtract the product so found from the number of British thermal units per pound of dry coal, multiply the remainder by 2000, and divide this product by the contract rate per ton (expressed in cents) plus one-half of the ash percentage (expressed as cents).

III. It is provided that the consumer may purchase for consumption at said premises coal other than herein contracted for, for test purposes, it being understood that the total of such coal so purchased shall not exceed 5 per cent of the total consumption during the term of this contract.

IV. It is understood that the company may deliver coal hereunder containing as high as 3 per cent more ash and as high as 3 per cent more moisture and as low as 500 fewer British thermal units per pound dry than specified above for contract grades.

V. Should any coal delivered hereunder contain more than the per cent of ash or moisture or fewer than the number of British thermal units per pound dry allowed under Paragraph IV hereof, the consumer may, at its option, either accept or reject same.

VI. All coal accepted hereunder shall be paid for monthly at a price per ton determined by taking the average of the delivered values obtained from the analyses of all the samples taken during that month, said delivered value in each case being obtained as follows: Multiply the number of British thermal units delivered per pound of dry coal by the per cent of moisture delivered (expressed in decimals), subtract the product so found from the number of British thermal units delivered per pound of dry coal, multiply the remainder by 2000, divide this product by the contract guaranty, and from this quotient (expressed as dollars and cents) subtract one-half of the ash percentage delivered (expressed as cents).

The following are the essential features of the specifications used by the Interborough Rapid Transit Company of New York in purchasing about 30,000 tons of coal each month for use in its plants, which are among the largest in the United States:

Preliminary Specifications for Bituminous Coal for the Interborough Rapid Transit Company.

Coal must be a good steam, caking, run-of-mine, bituminous coal free from all dirt and excessive dust, a dry sample of which will approximate the company's standard in heat value and analysis as follows: Carbon, 71; volatile matter, 20; ash, 9; B.T.U., 14,100; sulphur, 1.50.

A small quantity of coal will be taken from each weighing hopper just before the hopper is dumped while the lighter is being unloaded. These quantities will be thrown into a receptacle provided for the purpose, and when the lighter is empty the contents of the receptacle will be thoroughly mixed, and a sample of this mixture will be taken for chemical analysis. This average sample of coal will be labeled and held for one week after the unloading of the lighter. The sample taken from the mixture for test will be analyzed as soon as possible after being taken. No other sample will be recognized.

Tests of sample taken from average sample will be made by the company's chemist under the supervision of the superintendent. Should the contractor question the results of the company's test (a copy of which will be mailed to him), the company will, if requested by the contractor within three days after copy of test has been mailed to him, forward sufficient quantity of the average sample taken from each weighing hopper to any laboratory in the city of New York which may be agreed upon by the superintendent and the contractor, and have said sample analyzed by it, and the results obtained from this second test will be considered as final and conclusive. In case the disputed values, as obtained in the company's test, shall be found by the second test to be 2 per cent or less in error, then the cost of said second test shall be borne by the contractor; but if the disputed values shall be found to be more than 2 per cent in error, then the cost of said second test shall be borne by the company.

Should there be no question raised by the contractor within the three days specified, as to the values of the first analysis, the average sample of coal will be destroyed at the end of seven days from date of discharge of coal from lighter. Should a second test be made of coal taken from any lighter as herein provided, then any penalties to be made as set forth in paragraph under "Penalties" will be based on the results as obtained from the second test.

The price to be paid by the company per ton per lighter of coal will be based on a table of heat values for excess or deficiency of its standard, but subject to deductions as given in the section under "Penalized coal," including excess of ash, volatile matter, sulphur, or dust, or less than the minimum amount required to be contained in any lighter, for coal which shows results less than the company's standard.

Premiums or deductions are based on a rate of 1 cent per ton for a variation of 50 B.T.U. per pound of coal, as indicated in a table a few items of which are given below:

Table for B.T.U. Values.

For coal in any lighter which is found by test to contain, per pound of dry coal, from

15,501 and above	28 cents per ton above standard
15,101 to 15,150, both inclusive	20 cents per ton above standard
14,601 to 14,650, both inclusive	10 cents per ton above standard
14,101 to 14,150, both inclusive	Standard
13,601 to 13,650, both inclusive	10 cents per ton below standard
13,101 to 13,150, both inclusive	20 cents per ton below standard
12,101 to 12,150, both inclusive	40 cents per ton below standard

No lighter of coal will be accepted which, by trial, in the judgment of the superintendent, contains an excessive amount of dry coal dust. The decision of the superintendent will be final in this respect. Coal taken from such lighter for trial will be subject to the special deduction set forth under "Penalized coal," but paid for in all other respects as herein provided.

Coal which is shown by analysis to contain less than 20 per cent of volatile matter, 9 per cent of ash, or 1.50 per cent of sulphur, will be accepted, without a deduction from the bidder's price, plus or minus an amount for excess or deficiency of British thermal unit value, as herein provided. Where the analysis gives amounts for any or all elements in excess of these quantites, deductions will be made from the bidder's price in accordance with the tables of values of volatile matter, ash, and sulphur below given, plus or minus the amount for excess or deficiency of the standard British thermal unit value, in addition to any other deductions which may be made as herein provided.

Table of Deductions for Volatile Matter.

For coal in any lighter which is found by test to contain, per pound of dry coal

Over 20 per cent and less than 21 per cent	2 cents per ton
* * * * *	* * * *
Over 22.5 per cent and less than 23 per cent	12 cents per ton
* * * * *	* * * *
24 per cent and over	18 cents per ton

This table is made for the difference of each one-half of 1 per cent and the deductions are at the rate of 4 cents for each 1 per cent of volatile matter.

Table of Deductions for Ash.

For coal in any lighter which is found by test to contain, per pound of dry coal

Over 9 per cent and less than 9.5 per cent..... 2 cents per ton

* * * * * * * * *

Over 11.5 per cent and less than 12........... 12 cents per ton

* * * * * * * * *

13.5 per cent and over....................... 23 cents per ton

This table is made for each difference of one-half of 1 per cent and at the rate of 4 cents for each 1 per cent increase in the ash.

Table of Deductions for Sulphur.

For coal in any lighter which is found by test to contain, per pound of dry coal

Over 1.50 per cent and less than 1.75 per cent .. 6 cents per ton

* * * * * * * * *

Over 2 per cent and less than 2.25 per cent..... 10 cents per ton

* * * * * * * * *

2.50 and over............................ 20 cents per ton

This table is made out for each difference of one-fourth of 1 per cent and at a diminishing rate.

Should any lighter of coal delivered at the company's docks contain less than 700 tons, a deduction of 7 cents per ton will be made from the price as determined by the British thermal unit value and analysis, in addition to any other penalty provided for herein. Should any lighter of coal delivered at the company's docks be rejected by the superintendent on account of excessive amount of coal dust, then a reduction of 25 cents per ton will be made from the price as determined by the British thermal unit value and analysis, for the coal taken from said lighter, in addition to any other penalty which may be made as herein provided. Should any lighter of coal be delivered in other than self-trimming lighters as herein provided, a deduction of 7 cents per ton will be made from the price as determined by the British thermal unit value and analysis, exclusive of any other penalty which may be made as herein provided.

The contractor's bill of lading will be checked by the company's scales. Should there be a deficiency of 1 per cent or more between the bill of lading and the company's weights, then the company's weights will be taken as correct.

When the contractor has been notified by the company to deliver coal under this contract, a further notice may be given requiring the contractor to make delivery of the coal so ordered within twelve hours after the receipt of said second notice. Should the contractor, for any reason, fail to deliver the coal so ordered within twelve hours after the receipt of said second notice and in accordance with the requirements therein as to place of delivery, the company shall be at liberty to buy coal in the open market, and the contractor will make good to the company any difference there may be between the price paid by the company for said coal in open market and the price the company would have paid to the contractor had the coal been delivered by it in accordance with the requirements of said notices from the company, or said difference may be deducted from any money then due or thereafter to become due to the contractor under the contract to be entered into.

FUEL OIL SPECIFICATIONS.

The Specifications of the U. S. Government are as follows*:

GENERAL SPECIFICATIONS.

(1) In determining the award of a contract, consideration will be given to the quality of the fuel offered by the bidders, as well as the price, and should it appear to be to the best interest of the Government to award a contract at a higher price than that named in the lowest bid or bids received, the contract will be so awarded.

(2) Fuel oil should be either a natural homogeneous oil or a homogeneous residue from a natural oil; if the latter, all constituents having a low flash-point should have been removed by distillation; it should not be composed of a light oil and a heavy residue mixed in such proportions as to give the density desired.

(3) It should not have been distilled at a temperature high enough to burn it, nor at a temperature so high that flecks of carbonaceous matter began to separate.

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* J. C. Allen, J. Ind. and Eng. Chem., 3, 730 (1911).

(4) It should not flash below 60° C. (140° F.) in a closed Abel-Pensky or Pensky-Martens tester.

(5) Its specific gravity should range from 0.85 to 0.96 at 15° C. (59° F.); the oil should be rejected if its specific gravity is above 0.97 at that temperature.

(6) It should be mobile, free from solid or semi-solid bodies, and should flow readily, at ordinary atmospheric temperatures and under a head of 1 foot of oil, through a 4-inch pipe 10 feet in length.

(7) It should not congeal nor become too sluggish to flow at 0° C. (32° F.).

(8) It should have a calorific value of not less than 10,000 calories per gram * (18,000 B.T.U. per pound), 10,250 calories to be the standard. A bonus is to be paid or a penalty deducted according to the method stated under Section 21, as the fuel oil delivered is above or below this standard.†

(9) It should be rejected if it contains more than 2 per cent water.

(10) It should be rejected if it contains more than 1 per cent sulphur.

(11) It should not contain more than a trace of sand, clay, or dirt.

(12) Each bidder must submit an accurate statement regarding the fuel oil he proposes to furnish. This statement should show:

(*a*) The commercial name of the oil.

(*b*) The name or designation of the field from which the oil is obtained.

(*c*) Whether the oil is a crude oil, a refinery residue, or a distillate.

(*d*) The name and location of the refinery, if the oil has been refined at all.

(13) The fuel oil is to be delivered f.o.b. cars or vessel, according to the manner of shipment, at such places, at such times, and in such quantities as may be required, during the fiscal year ending..........

(14) Should the contractor, for any reason, fail to comply with a written order to make delivery, the Government is to be at liberty to buy oil in the open market, and charge against the contractor any excess of price, above the contract price, of the fuel oil so purchased.

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* Calories × 1.8 = B.T.U. per pound.

† It is important that the standard fixed should not be higher than can be maintained under the terms of the contract. In the absence of information as to the heating value of the oil, the Bureau of Mines will analyze samples taken from the deliveries to establish the standard heating value, expressed in calories or B.T.U. It will be to the best interests of the contractor to specify a fair standard for the fuel oil he offers, since failure to maintain that standard will cause deduction from the contract price and possibly the cancellation of the contract, while deliveries of higher quality than the standard will result in the contractor receiving premiums.

SAMPLING.

(15) Deliveries of fuel oil will be sampled by a representative of the Government. Whenever such action is practicable, the oil will be sampled as it is being delivered. The final sample will be made from samples taken from as large a proportion of the delivery as practicable, in order that the final sample may truly represent the delivery.

(16) The final sample will be sealed and forwarded to the Federal Bureau of Mines, Pittsburgh, Pa., for analysis.

(17) If the contractor so desires, permission will be given him, or his representative, to witness the sampling of the delivery and the preparation of the final sample.

(18) The final sample will be analyzed and tested immediately after its receipt in Pittsburgh.

CAUSES FOR REJECTION.

(19) A contract entered into under the terms of these specifications shall not be binding if, as the result of a practical service test of reasonable duration, the fuel oil fails to give satisfactory results.

(20) It is understood that the fuel oil delivered during the terms of the contract shall be of the quality specified. The frequent or continued failure of the contractor to deliver oil of the specified quality will be considered sufficient cause for the cancellation of the contract.

PRICE AND PAYMENT.

(21) Payment for deliveries will be made on the basis of the price named in the proposal for the fuel oil corrected for variations in heating value,* as shown by analysis, above or below the standard fixed by the contractor. This correction is a *pro rata* one and the price is to be determined by the following formulæ:

$$\frac{\text{Delivered calories per gram (or B.T.U. per lb.)} \times \text{contract price}}{\text{Standard calories per gram (or B.T.U. per lb.)}} = \text{price to be paid.}$$

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* The value of an oil as fuel is in proportion to the total combustible matter it contains as shown by its heating value. This value may be expressed in small calories per gram of B.T.U. per pound. Sulphur, moisture, and earthy matter lower the heating value of an oil and decrease the furnace capacity; they also may have a deleterious effect on boiler and furnace, and may impair the operation of burners.

Water that accumulates in the receiving tank will be drawn off and measured periodically. Proper deduction will be made by subtracting the weight of the water from the weight of the oil deliveries.

DETERMINATION OF WEIGHT FROM VOLUME.

The specifications given on the preceding pages provide for the purchase of fuel oil by weight. As such oil is frequently delivered by volume, it is important to note the temperature of a delivery and to allow for the expansion due to this temperature when computing the weight of the delivery from the volume. From the volume of the oil at the temperature of delivery, the volume at standard temperature (15° C.) should be computed in the manner given below.

The coefficient of expansion of ordinary fuel oil residues of asphaltic base is approximately 0.0006 per 1° C.

Hence if the temperature (N° C.) of the delivery is above 15° C., then $(N^\circ\,\text{C.} - 15^\circ\,\text{C.}) \times 0.0006 =$ correction.

This correction is to be added to the specific gravity at N° C. to give the standard specific gravity, that at 15° C.

If the temperature (N° C.) of the oil delivered is below 15° C., the correction $((15^\circ\,\text{C.} - N^\circ\,\text{C.}) \times 0.0006)$ is to be subtracted from the specific gravity at 15° C.

Since a gallon of water at a temperature of 15° C. weighs 8.3316 lbs., the weight in pounds of a gallon of oil at 15° C. is 8.3316 times the specific gravity of the oil at that temperature.

Similarly, since a cubic foot of water at 15° C. weighs 62.3425 lbs., the weight in pounds of a cubic foot of oil at 15° C. is 62.3425 times its specific gravity at that temperature.

REPORTING ANALYSES OF FUEL OIL.

The following form is used by the Bureau of Mines in reporting the results of an analysis of a sample of fuel oil:

DEPARTMENT OF THE INTERIOR.
BUREAU OF MINES.

WASHINGTON, D. C., ... 191—.

SIR:

In reference to the .... sample of fuel petroleum representing
(Quantity.)
.... of petroleum delivered at a temperature of ....° C. by
(Quantity.)
the .... as a .... product, from the ......
(Company delivering.) (Crude, residue, or distillate.) (Lease.)

.........., ..., ..., to the ....,
(Field or district.) (County.) (State.) (Department receiving.)
at .... on ...., I have the honor to report as
(City.) (Date of delivery.)
follows:

Specific gravity at 15° C. ....
(Baumé at 59° F.) ....
Calorie per gram............................ ......
(B.T.U. per pound)......................... ......
Water, per cent............................. ......
Sulphur, per cent........................... ......
Earthy matter, sand, etc., per cent............ ......
Flash-point, ° C. (Abel-Pensky, or Pensky-Martens, closed tester)..................... ......
Burning point, ° C. (same tester, opened)...... ......
Remarks:

....

....

The above information is for the use of the Government and the dealer or operator furnishing the oil. It is to be considered confidential until it is published by the United States Government.

Respectfully,

....
Chief Clerk.

Certified:

....
Petroleum Chemist.

SAMPLING PETROLEUM OR FUEL OIL.

GENERAL STATEMENT.

The accuracy of the sampling and, in turn, the value of the analysis must necessarily depend on the integrity, alertness, and ability of the person who does the sampling. No matter how honest the sampler may be, if he lacks alertness and sampling ability, he may easily make errors that will vitiate all subsequent work and render the results of tests and analyses utterly misleading. A sampler must be always on the alert for sand, water, and foreign matter. He should note any circumstances that appear suspicious, and should submit a critical report on them, together with samples of the questioned oil.

SAMPLING WAGON DELIVERIES.

SAMPLING WITH A DIPPER.

Immediately after the oil begins to flow from the wagon to the receiving tank, a small dipper holding any definite quantity, say, 0.5 liter (about 1 pint), is filled from the stream of oil. Similar samples are taken at equal intervals of time from the beginning to the end of the flow—a dozen or more dipperfuls in all. These samples are poured into a clean drum and well shaken. If the oil is heavy, the dipperfuls of oil may be poured into a clean pail and thoroughly stirred. For a complete analysis the final sample should contain at least 4 liters (about 1 gallon). This sample should be poured into a clean can, soldered tight and forwarded to the laboratory.

It is important that the dipper be filled with oil at uniform intervals of time and that the dipper be always filled to the same level. The total quantity of oil taken should represent a definite quantity of oil delivered and the relation of the sample to the delivery should be always be stated, for instance: "1 gallon sample representing 1 wagon-load of 20 barrels."

CONTINUOUS SAMPLING.

Instead of taking samples with a dipper, it may be more convenient to take a continuous sample. This may be taken by allowing the oil to flow at a constant and uninterrupted rate from a ½-inch cock on the under side of the delivery pipe during the entire time of discharge. The continuous sample should be thoroughly mixed in a clean drum or pail, and at least 4 liters (about 1 gallon) of it forwarded for analysis. A careful examination should be made for water, and if the first dipperful shows water this dipperful should be thrown into the receiving tank and not mixed with the sample for analysis.

MIXED SAMPLES.

If the oil delivered during any definite period of time, say one month, be from the same source and of uniform quality (but only in case it is of uniform quality), it may suffice to pour definite proportional quantities of the dipper and the continuous samples taken during this period into a tinned can or drum having a tight screw cap or bung. An iron drum should not be used, since even a clean iron surface will absorb sulphur by long contact with a sulphur-containing oil, and this sulphur will be lost to the analyst. At the end of the month a number of round, clean stones should be put into the drum and the drum should be rolled to insure intimate mixing. Then 4 liters (about 1 gallon) of the gross sample should be taken for analysis. The drum should be drained, rinsed clean with gasoline, dried, and made ready for a second sampling.

The all-important point is that the gross sample, whatever the manner of sampling, shall be made up of equivalent portions of oil taken at regular intervals of time, so that the sample finally forwarded for analysis will truly represent the entire shipment.

SAMPLING A LARGE TANK OR RESERVOIR.

Water or earthy matter settles on standing. Hence, before a large stationary tank or reservoir is sampled the character of the contents at the bottom should be ascertained by dredging with a long-handled dipper, and the content of the dipper should be examined critically. If a considerable quantity of sediment is brought up, it should be cause for rejecting the oil.

The sampling of a large stationary tank or reservoir of oil, particularly if the oil has stood so long that it has begun to stratify, or form layers of different density, may be done as follows:

The sampler should procure an ordinary iron pipe, or preferably a tinned tube, 1 inch in diameter and long enough to reach from above the manhole, where he can grasp it, to the bottom of the tank. The lower end of the pipe should be reamed out with a round file. A conical plug of cork, wood, or other suitable material should be fitted to this end, and a strong, stiff wire, such as the ordinary telegraph wire, run through this plug and up through the pipe to a point where it can be grasped firmly by the sampler. A pull on the wire will close the bottom of the pipe, and a rap against the bottom of the tank will drive the plug home and make an oil-tight seal or valve.

To operate this sampling device, the sampler should remove the plug, allow it to drop some three inches below the bottom of the pipe, and let it hang there by the wire extending above the pipe. Then holding the pipe, open at top and bottom, in a vertical position, the sampler should allow it to sink slowly through the oil to the bottom of the tank. He should do this slowly and with care, so that the pipe will penetrate the oil without agitating it and will thus cut a representative core of oil from the surface to the bottom. When the pipe touches the bottom, the sampler should draw up the slack of the wire and pull the plug into place; then he should strike the plug smartly against the bottom of the tank, thereby driving it home and sealing the pipe. He can then withdraw the pipe and pour the oil into the sampling can. If it seems desirable, he should "core" or "sample" a reservoir at regularly spaced points, unite these samples, mix them thoroughly, and take 4 liters (about 1 gallon) of the gross sample for analysis.

Instead of a pipe sampler, a bottle holding half a liter (about 1 pint) may be used. It should be securely fastened to a long pole and have a loosely-fitted stopper tied to a strong cord. The bottle, corked and empty, is immersed to any desired point within the mass of oil, and the stopper is pulled out. The bottleful of oil is poured into a suitable receiving vessel, and the bottle thoroughly drained is made ready for a second filling. Bottlefuls of oil taken in this way from points symmetrically placed throughout the mass of oil, will, if properly mixed, provide an excellent gross sample from which to take the 4-liter (1 gallon) sample for analysis.

SAMPLING A SINGLE DRUM.

A single drum may be sampled with a glass tube. This tube, open at both ends, should be grasped at the top, held vertically, inserted in the drum without agitating the oil, and allowed to cut its way slowly to the bottom of the drum. The upper end should then be closed with the thumb or forefinger of the hand holding it, the tube withdrawn, and the oil on the outside wiped off with the fingers of the other hand. The sample in the tube can then be transferred to a small can, and forwarded for analysis.

FORWARDING SAMPLES.

The sample should be forwarded in a glass bottle or carboy or in a tin can, preferably in the latter, because less liable to breakage. If a tin can is used the cap should be soldered tight. The can should not be filled completely; about an eighth of an inch of space should be left to allow for possible expansion of the oil.

The can should be sealed as soon as it is filled to avoid loss by volatilization of the lighter constituents of the sample. After the can has been filled and tightly soldered, it should be wiped clean and carefully examined for pinholes or small leaks. All leaks should be soldered before the can is packed for shipment.

The bottle or can should be carefully labeled. The following form of label,* used by the Bureau of Mines, should be placed on samples shipped to the bureau:

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* These labels will be furnished on request.

DEPARTMENT OF THE INTERIOR.

BUREAU OF MINES.

Information to Accompany Each Sample of Fuel Petroleum Submitted for Analysis.

Sample number................ Sampled by...................
Oil delivered to...
(Department receiving.)
Place of delivery..
(City.) (State.)
Quantity of oil delivered......................................
Date of delivery...
Temperature of oil as delivered .... ° C.......................
Name of contractor...
Nature of oil..
(Crude, residue, or distillate.)
If refined to any degree, state name and location of refinery..........
....
Source of oil..
(Lease.) (Field or district.) (County.) (State.)
Remarks..
....
....
....
Date of forwarding sample......................................
Forwarded by..................................via............
(Express or fast freight.) (Transportation line.)
....

Date of receipt of sample by Bureau of Mines...................
....
Condition of sample when received by Bureau of Mines............
....

The label should be carefully written with a hard lead pencil on a strong mailing tag, and this tag should be securely tied to the can. The lead pencil should be pressed firmly against the tag so as to indent its surface. An inscription thus written is legible even after the paper has been wet with oil. Gummed labels should not be used; they are easily detached if slightly moistened, and may be lost. A duplicate copy of the record on the label should be mailed to the engineer in charge, Bureau of Mines, Pittsburgh, Pa.

SAMPLING GAS FROM A WELL.

Since the gas associated with oil is an ideal fuel and illuminant, and the literature dealing with the composition of natural gas is scanty, a description of the method of sampling such gas for analysis is here given.

For taking a sample of gas under pressure from an oil well a cloth funnel should be made by folding and sewing any strong, closely-woven cloth into the form of a cornucopia. The larger end of this funnel should be large enough to encompass the gas pipe from which the sample is to be taken. The smaller end, or apex, of the funnel should should be securely tied about one end of a flexible rubber tube 1 or 2 feet long and one-fourth to one-half inch in diameter. If there is a gas jet at the well, one end of the rubber tube may be attached directly to the jet.

A gas-sampling bottle should be procured, if practicable, from the Bureau of Mines, Pittsburgh, Pa. If such a bottle is not at hand, a 1- or 2-liter (1- or 2-quart) bottle with a well-ground, tight-fitting glass stopper may be used. The bottle should be thoroughly cleansed and dried. A large perfume bottle or an acid bottle, such as may be obtained from a drug store, will usually answer. A glass stopper is essential, for a cork or rubber stopper may leak even though it appears to be hermetically sealed with wax; moreover, a cork or rubber stopper may contaminate the gas.

To collect a sample, the funnel should be tied firmly about the end of the gas pipe. The funnel and the rubber tube should then be thoroughly flushed with the gas to rid them of air. The free end of the tube should go to the bottom of the sample bottle. The bottle should be fastened bottom up and the gas allowed to blow strongly into it for at least a quarter of an hour to insure complete expulsion of air. If the gas pressure is low, the gas should be allowed to blow longer, or until it is certain that all air has been expelled from the bottle. Meanwhile the stopper of the bottle should have been well greased with vaseline.

While the gas is still blowing through the tube the tube should be slowly withdrawn. The stopper should be put in just as soon as the tube is withdrawn and should be turned firmly into place. Then the bottle should be turned up and a spoonful of melted paraffin poured over the stopper. The stopper should be secured with elastic band.

A strong tag should be tied to the bottle by a stout cord. This tag should be labeled as follows:

Gas Sample.

Sampled by..
Date..
Well........................ Lease.........................
Number.
Section..............Township...........Range.............
District...............County............State...............
Remarks...
....
....

The bottle should be packed securely in a box and forwarded to the Bureau of Mines, Pittsburgh, Pa. A duplicate copy of the label should be sent to the same address.

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