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Gaseous Fuels

PERFORMANC

TEST

CODES

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
United Engineering Center
345 East 47th Street New York, N.Y. 10017

Gaseous Fuels

PERFORMANCE TEST CODES

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FOREWORD

The edition of the ASME Performance Test Codes issued in 1915 did not contain a Test Code for Fuels. When, however, it was decided to revise this series of test codes, the standing Committee on Performance Test Codes was organized. It, in turn, assigned to a committee of experts the task of formulating Test Codes for Solid Fuels, Liquid Fuels, and Gaseous Fuels.

When the Test Code for Gaseous Fuels had passed through the preliminary stages in the procedure prescribed by the standing committee, notification of this fact appeared in the March, 1941 issue of *Mechanical Engineering*. The standing committee at its December 3, 1943 meeting approved the Test Code for Gaseous Fuels in its finally revised form. It was then approved and adopted by the Council as a standard practice of the Society on April 24, 1944.

In 1958, PTC Committee No. 3.3 on Fuels was reorganized and instructed by the standing committee to revise the 1944 version of the Test Code for Gaseous Fuels. In the preparation of this revision PTC Committee No. 3.3 has worked in close cooperation with ASTM Committees D-2 on Petroleum Products and Lubricants and D-3 on Gaseous Fuels. It should be noted that certain of the ASTM procedures have been adopted as standards in the new Test Code for Gaseous Fuels.

This Code was approved by the Performance Test Codes Committee on June 14, 1968. It was approved and adopted by the ASME Council as a standard practice of the Society by action of the Policy Board, Codes and Standards, on September 25, 1968.

The members of PTC Committee No. 3.3 wish to record with sincere appreciation the important service rendered in the development of this revised Code by their late Chairman, Mr. Martin A. Mayers. A member of the Committee since 1945, he served as its Chairman from 1958 until his untimely death on March 5, 1964.

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ASME PERFORMANCE TEST CODE FOR GASEOUS FUELS

Object and Scope

The Test Code for Gaseous Fuels is intended primarily to specify standard methods for determining those chemical and physical properties of gaseous fuels that are required in tests of equipment using such fuels as a source of energy for generating heat or power.

Insofar as possible, appropriate standard methods published by The American Society for Testing and Materials are specified for the determination of these properties, and the essential information from these methods is reproduced in this Code. When such ASTM methods are not available, the Code outlines suitable methods. Generally, the methods and procedures specified may be applied at the location of the power or heat generating equipment to be tested. In exceptional cases, however, the necessity of using fixed, specialized apparatus in the methods specified herein, may dictate the necessity of transporting samples to the location of that apparatus.

The methods and procedures included in the Code are limited to the following general areas: (a) sampling, (b) chemical composition, (c) moisture content, (d) dust content, (e) calorific values, (f) specific gravity, (g) calculation of physical properties from chemical composition, and (h) stoichiometric calculations from chemical composition.

For purposes of this Code, gaseous fuels are classified as follows:

(a) Gases in which hydrocarbons are the only *fuel* components. Such gases include natural gas, liquefied petroleum gases, and mixtures of these with air or inert components.

(b) Gas mixtures containing significant concentrations of combustible constituents other than, or in addition to hydrocarbons, as well as inerts in concentrations less than 50 per cent by volume. Such gases include coke oven or oil gas.

(c) High-inert gases containing 50 per cent or more by volume of inert constitutents. Such gases include blast furnace gas and producer gas.

Definitions

Gaseous Fuel is a mixture of combustibles with or without inerts in which each component is present as a superheated or saturated vapor under the conditions of handling and use.

(a) *Dry Gas* is a gas containing no water vapor.

(b) *Moist Gas* is gas containing water vapor. The gas is said to be "saturated" when the water vapor in the mixture exerts a partial pressure equal to the absolute pressure of saturated water vapor at the specified temperature. This condition exists at the water dew point of the gas.

(c) *Wet Gas* is a gas containing concentrations of the more readily condensable hydrocarbons high enough so that condensation occurs under the conditions of handling and use.

(d) *Sour Gas* is a gas containing relatively high concentration of hydrogen sulfide.

(e) *Natural Gas* is a combustible gas found in natural underground reservoirs. Methane is usually the major constituent, with ethane, propane, and higher molecular-weight hydrocarbons present in concentrations decreasing as the molecular weight increases. Some natural gases also contain small quantities of nitrogen, carbon dioxide, hydrogen sulfide and other sulfur compounds, and helium.

(f) *Liquefied Petroleum Gas* (*LPG*) is a fuel which is liquid under conditions of storage at elevated pressure, and is vaporized for use as a fuel. It usually is a propane-propylene mixture or a butane-propylene mixture, and sometimes is a mixture of all these hydrocarbons.

(g) *Manufactured Gas* is a gaseous fuel resulting as either the principal product or one of the important products from the processing of solid or liquid fuels at gasification temperatures. The common manufactured gases are:

    (1) Coke Oven Gas, a mixture of gases produced in the carbonization of coal.

    (2) Producer Gas, a high-inert gas of low calorific value resulting from the incomplete combustion of coal or coke by air, or by air and steam, at high temperature in the gas producer.

    (3) Blue Gas or Water Gas, the

fuel gas obtained by the endothermic reaction of steam in one portion of a cyclic process, with coke heated during the other portion of the process by its combustion with air.

(4) Carbureted Water Gas, water gas enriched with gaseous products of higher calorific value resulting from the thermal cracking of liquid hydrocarbon fuels.

(5) Oil Gas, a high Btu fuel gas obtained by the thermal cracking of liquid hydrocarbon fuels, used as a substitute for natural gas.

(6) Reformed Gas or Catalytic Gas, a gas produced to desired specifications by the treatment of hydrocarbon fuels passed through a fuel bed or a catalytic bed.

(7) Blast Furnace Gas, a high-inert gas of low calorific value produced as a by-product of the reduction of iron ore in the blast furnace.

(8) Refinery Gas, is a mixture of gases produced as a by-product in the refining ot petroleum. Refinery gas may consist predominantly of hydrocarbons or it may contain substantial proportions of hydrogen. When the crude being refined has high sulfur content, hydrogen sulfide may be a significant constituent.

(h) *Cubic Foot of Gas* is the usual measure of gas quantity. It is, of course, definite only when the conditions of measurement are established. When these conditions are standardized, a cubic foot of gas, measured under the standard conditions, may be referred to as a *Standard Cubic Foot.*

(i) *Standard Conditions* are variously defined by different organizations.

(a) The American Society of Mechanical Engineers has adopted[1] a pressure of 29.921 in. Hg (at 32°F) and a temperature of 68°F, with the gas saturated at that temperature with water vapor. *When not otherwise qualified,* the term Standard Conditions will be considered to refer to these.

(b) Other code making and commercial agencies frequently use other standard conditions for reporting gas quantities. In reporting quantities of gaseous fuel used by power equipment, it will usually be found advantageous to quote the results under the standard conditions defined for sale of the gas used. Accordingly, several other sets of commonly used conditions are defined in Table 1. The last column of the tabulation gives the factor by which the results measured under the defined conditions must be multiplied to reduce them to the ASME Standard.

(c) Of special interest are the conditions adopted by the American Society for Testing and Materials, because the procedures given in this Code are, for the most part, adopted from the methods standardized by that Society.

(d) When gas measurements are reported under conditions other than those standardized by the ASME, the particular conditions used shall be clearly stated.

Sampling Gaseous Fuels

Procedures in sampling gases vary depending on the class of gas to be sampled and the conditions under which it is supplied. In general, *hydrocarbon gases* are to be sampled by the Standard Method of Sampling Natural Gases, ASTM Designation D 1145-53, or by the Standard Method of Sampling Liquified Petroleum Gases, ASTM Designation D 1265-55. Gas Mixtures containing combustibles other than hydrocarbon gases and *high-inert* gases are usually to be sampled by the Standard Method of Sampling Manufactured Gas, ASTM Designation D 1247-54.

CAUTION: An important precaution to be observed in tests of fuel gases is the proper disposition of the gas flowing from the sampling or analytical equipment. It is essential that such off-gas be properly flared or otherwise safely vented, to eliminate any danger of fire, explosion, or poisonous concentrations.

TABLE 1. STANDARD CONDITIONS USED FOR MEASUREMENT OF GASES

Defining Agency	Absolute Pressure	Temperature	Moisture Content	Multiplying Factor to Convert Volume to ASME Conditions
ASME	29.921 in. Hg*	68°F	Saturated	1.0000
ASTM D 1071-55	30. in. Hg*	60°F	Saturated	1.0240
Scientific Laboratories	760 mm Hg*	0°C	Dry	1.0985
Gas Industry	30. in. Hg*	60°F	Dry	1.0418

* Mercury at 32°F, under standard gravity of 32.2 ft/sec²

NOTE: The general equation for converting gas volume from Condition (1) to Condition (2) of temperature, pressure, and vapor content is:

$$V_2 = V_1 \times \frac{T_2}{T_1} \times \frac{(P_1 - p_1)}{(P_2 - p_2)}$$

where V = Volume of gas mixture, including water vapor if present .... cu ft
P = Absolute total pressure = (barometer + gage) .... in. Hg
T = Absolute temperature (460 + t) .... R
t = Fahrenheit temperature .... F
p = Partial pressure of water vapor (See Fig. 59) .... in. Hg
For dry gas p = 0

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[1] ASME Performance Test Code on Definitions and Values, PTC 2-1945.

Scope and General Considerations

In the three ASTM Standard Methods mentioned above, some of the introductory comments are common to two or more of them. These are, therefore, stated separately in the following and are omitted from the text of the Standard Methods subsequently reproduced.

Scope. These mehods cover the procedures for securing representative samples of gas and correlate the size or type of sample with the analysis to be done subsequently on that sample.

General Considerations. In collecting samples of gas, consideration must be given to the purposes for which the samples are to be used and the conditions under which they must be secured. Consideration must also be given to the volume of sample required for the purpose intended; to the size, design, and material of containers; and to the size, length, and material of which the sampling line and auxiliary equipment are constructed to convey gas from the source of supply into the container and subsequently from the container to the point of use. Account must be taken of the possible constituents in the gas, whether it may contain only hydrocarbons and inert gases such as nitrogen and carbon dioxide or whether hydrogen sulfide, mercaptans, or other sulfur contaminants may be present. Consideration must be given to the effect of changes of temperature and pressure on the components of the fuel gas. Should suspensoids, such as oil, fog, or dust be present, the gas flow pattern in the gas main relative to the sampling connection and the gas sampling rate become important. The object is to obtain a representative gas sample because any subsequent analysis, regardless of the care and accuracy in making any such analytical test, is useless unless a representative sample has been obtained.

Volume of Sample Required. Volume of sample required depends both upon the analyses to be made and the apparatus to be used. In general, the following minimum volumes of samples, including volume needed for purging the apparatus, are recommended. These quantities will normally suffice for two tests, an original and a check:

For chemical analysis	1000 cu cm
For specific gravity with balance type instruments	1.0 cu ft
For heating value determination	3 to 5 cu ft
For superexpansibility tests	10 cu ft, approximately

Terminology

(a) *Sampling Probe.* The sampling probe is that portion of the sampling line attached to and possibly extending into the pipe or vessel containing the gas to be sampled.

(b) *Sampling Line.* The sampling line is that portion of a flexible or semirigid tubing or piping used for conducting the sample from the sampling probe to the sampling container.

(c) *Sample Container.* The sample container is the vessel in which the gas sample is collected, stored, retained, and transported to the analytical equipment.

Standard Method of
SAMPLING NATURAL GAS

ASTM Designation: D 1145–53

Approved as USA Standard Z77.4–1955

(Minor changes made. Omitted sampling at wells to determine gasoline and condensibles. Revised section for collecting average samples in portable containers.)

Scope

1. (*a*) This method of sampling covers the procedures for the sampling of natural gas, containing different gases as contaminants such as: (*1*) natural gases containing primarily hydrocarbons and nitrogen, (*2*) natural gases containing hydrogen sulfide, or organic sulfur compounds, or other sulfur contaminants, (*3*) natural gas containing carbon dioxide. These are treated separately and special precautions stated when necessary. The differences in procedure are mainly in degree, rather than in kind. *(ASTM Sections 1(b) through 5 not included.)*

Outline of Method

6. (*a*) The method in its broadest sense is a means of suitably conducting a flow of gas from the sampling source into a properly purged container (or containers) and obtaining thereby a representative sample of natural gas. To do so may require the taking of grab, spot, or snap samples. A series of grab samples, taken consecutively, may be considered as an average sample. Average samples also may be obtained by a continuous collection method. This may be done by continuous sampling direct to a recording or indicating analytical instrument or collecting a continuous sample in a portable container over a 24-hr. period (or other desired time).

(*b*) The purging of sampling probe, sampling line, and sample container may be done either by the gas to be sampled (air displacement) or by water displacement, or by application of vacuum.

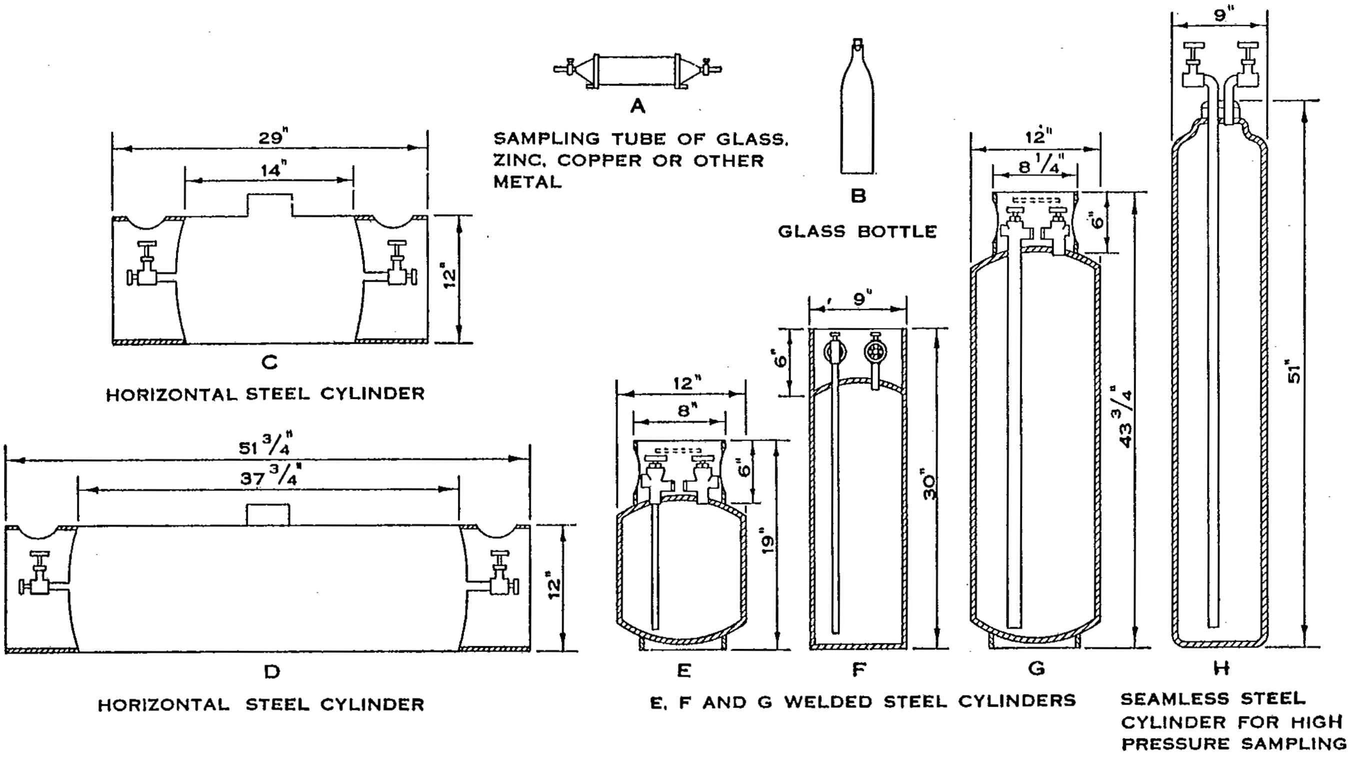

FIG. 1.—Gas Sample Containers.

(*c*) Generally, natural gas is under sufficient pressure to purge and fill the container without the use of additional means; however, in instances where this is not the case, some mechanical means must be provided (see Section 7 (*d*))

(*d*) The choice of the type of sample ("spot" or "continuous"), the method of purging, the type of container, and the choice of any auxiliary pressure equipment, if necessary, will be dictated by the analysis or analyses to be run on the sample, by the type of gas to be sampled, and by the existing equipment available.

Apparatus

7. (*a*) *Sampling Connection.*—Threaded or welded pipe connections of ⅛ or ¼-in. diameter pipe to the side of the vessel containing the gas are satisfactory. If wall condensation may be present, the sampling probe should be extended some distance into the vessel. A distance of one sixth of the diameter of the vessel has been found satisfactory. For unusual conditions, water-cooled probes of special construction may be required.[3]

(*b*) *Sampling Lines* may be made of ⅛ or ¼-in. iron pipe; 3/32 to ⅜-in. outside diameter copper, brass, or aluminum tubing; or ¼-in. high-pressure hose (Note 1). Larger sizes may be used if conditions require them. Regardless of the size and length of the sampling line, flow and time of purge should be sufficiently rapid to ensure that an accurate and fresh sample is obtained from the supply source. In general, sampling lines should be as short and as small in diameter as practicable to decrease purging time and contained volume. In the case of a continuous sampling line direct from the source of supply to analytical apparatus, the above characteristics are especially desirable to permit a rapid change of sample so that the test instrument may follow closely any change in composition of the supply. Glass, quartz, or porcelain tubing may be used for sampling lines when the gas pressure is low. (For special sampling of gases containing sulfur compounds, see Section 10.)

NOTE 1.—If rubber is used, it should be used to a minimum extent and should be a product that will not react with the sample and that has low permeability characteristics. Various types of flexible plastic tubing may be superior to rubber for this service. Rubber should not be considered for anything but low-pressure conditions.

(*c*) *Sample Containers* shall be gastight and easily handled for sampling and delivering the sample to the test apparatus. They shall be of adequate size and shall be made of material that will not react with the sample (Note 2). The size of the container may vary from 250 cu. cm. to several cubic feet. It is usually made of iron, steel, or glass, but it may be made of any metal or alloy sufficiently strong and gastight. (For special sampling of gases containing hydrogen sulfide and organic sulfur, see Section 10.) The design and type

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[3] V. J. Altieri, "Gas Analysis and Testing of Gaseous Materials," Am. Gas Assn., pp. 76–79.

of container may take any number of forms, such as bottles, cans, tubes, cylinders, or tanks which may be sealed with stopcocks, valves, corks, or rubber clips. If the sample is to be shipped under pressure, the vessel must comply with the requirements of, and be approved by, the Interstate Commerce Commission. Except for small samples for gas analysis, it is preferable to sample natural gas without the use of confining liquids, such as water or water solutions of various chemicals. Water or mercury may be used to force the sample out of the container into the test apparatus. Types of sample containers are illustrated in Fig. 1.

NOTE 2.—The confining fluid should not react with the container or the sample.

(*d*) *Auxiliary Pressure Equipment.*—In instances where the pressure of the natural gas is not sufficient to purge and fill the container the following equipment is generally employed: (*1*) a rubber bulb equipped with valves at each end—one for suction and one for pressure, (*2*) a hand pump equipped with double-acting valves, or (*3*) displacing of a confining liquid in two containers such as water or mercury. These items are shown in Fig. 2.

(*e*) *Shipping Tags or Stickers.*—To properly identify and describe all samples they should be marked for identification and proper handling by the analyst. A sticker or a shipping tag attached to the container should include the following information:

Sample taken where,
Sample taken from what line,
Sample taken by,
Date of sampling,
Time of sampling,
Kind of gas, and
Remarks.

Procedures for Sampling Natural Gases Containing Primarily Hydrocarbons and Nitrogen

8. (*a*) For collecting small samples in low-pressure sample containers for analysis of chemical constituents the following procedures are recommended:

(*1*) In the cases where glass bottles are used as sample containers, blow out the gas line thoroughly until no

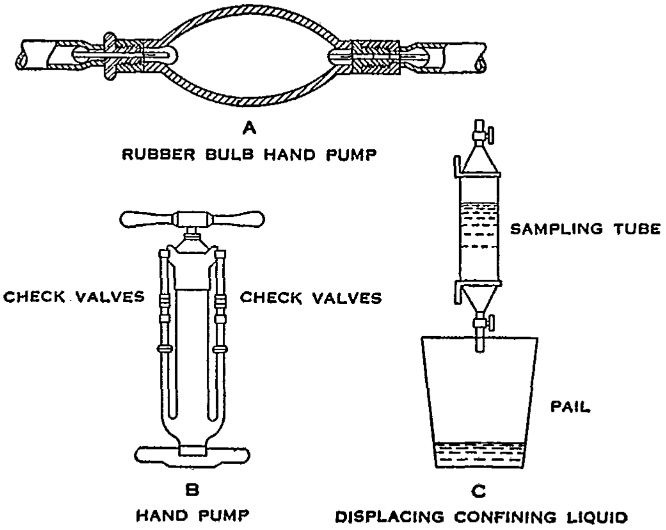

FIG. 2.—Apparatus for Inducing or Forcing Gas Flow.

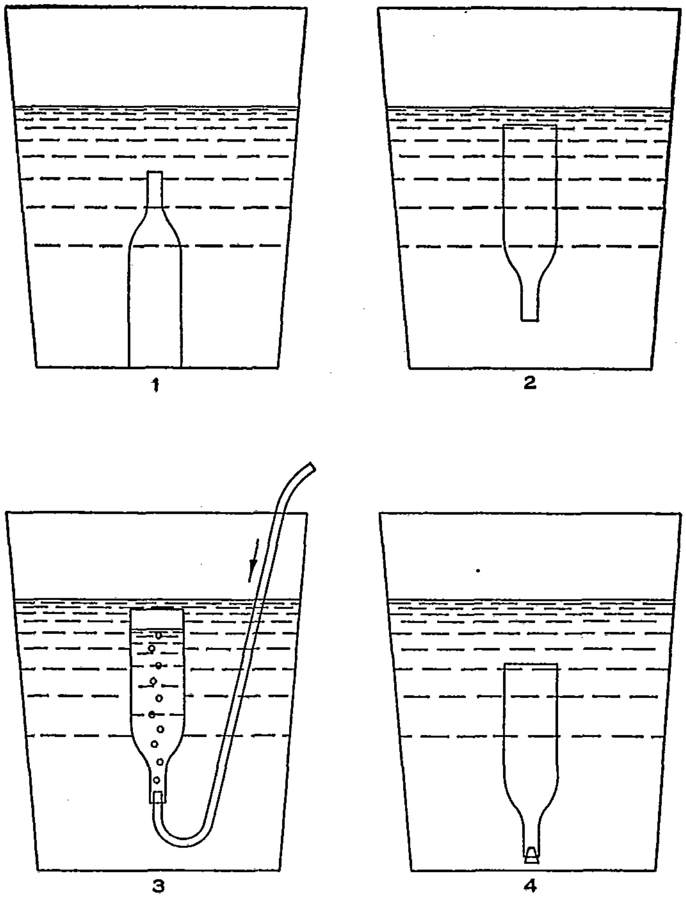

FIG. 3.—Steps in Taking a Sample by Water Displacement from a Glass Bottle.

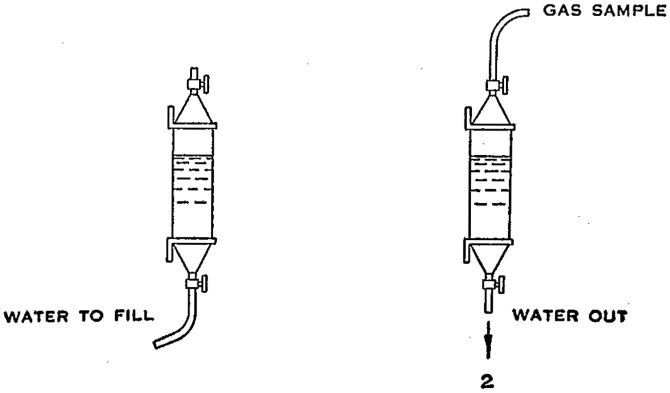

Fig. 4.—Steps in Taking a Sample by Water Displacement in a Sample Container.

dead gas remains. Stretch rubber tubing over a $\frac{1}{4}$ or $\frac{1}{8}$-in. pipe connection made at this place, and leave a small stream of gas flowing through the tubing in order to make certain that no air will get into the sample from an outside source. Displace the air in the small-necked quart glass bottle by immersing it in a bucket of water. This can best be done by standing the bottle on the bottom of the bucket in an upright position and allowing the water to flow into the mouth of the bottle until it is entirely filled (Fig. 3 (*1*)). Then, without taking the bottle out of the water, invert it so that the mouth will be towards the bottom of the bucket (Fig. 3 (*2*)). Do not remove the bottle from under the water until the sample of gas has been collected and it has been firmly stoppered.

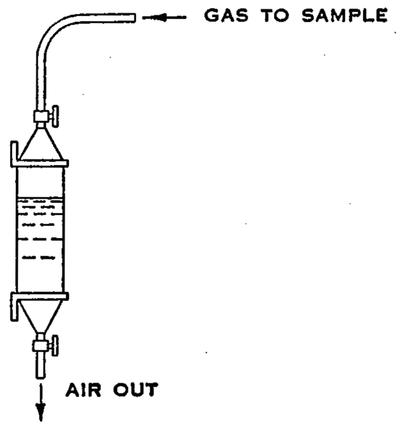

Fig. 5.—Collection of a Sample by Air Displacement from a Sample Container.

(*2*) If no bubble of air can be seen in the bottle after having inverted it, allow the gas to bubble slowly from the rubber hose into it while in this position (Fig. 3 (*3*)). The rate of flow should be such that it will take about 1 min. to displace all of the water in the bottle. Allow the gas to bubble into the bottle 2 min. longer.

(*3*) After the gas has displaced all water, have a nonporous, high quality cork stopper ready as the flexible tubing is withdrawn. As the tubing leaves the mouth, the bottle should be immediately and tightly closed. Wire or clamp the cork in place and if not to be used immediately seal with paraffin or wax. Dry the bottle and attach at once the identification tag, properly filled out.

(*4*) When using the method employing sampling containers with valves or stopcocks on each end (displacement of water or air), blow out the line thoroughly until no dead gas remains. Stretch rubber tubing over a $\frac{1}{4}$ or $\frac{1}{8}$-in. pipe connection made at this place, and leave a small stream of gas flowing through the tubing in order to make certain that no air will get into the sample from an outside source. Completely fill the sampling container with water by holding it vertically and allowing water to flow in through the bottom valve until it overflows from the top valve, making sure that all air has been displaced and close both valves (Fig. 4 (*1*)). Attach the rubber hose through which gas is slowly flowing to the top valve, open the valve, and then open the bottom valve, emptying the water into a bucket or on the ground as it flows from the container (Fig. 4 (*2*)). Regulate the flow so that it takes about 1 min. to displace all water, close the bottom valve, and then close the top valve.

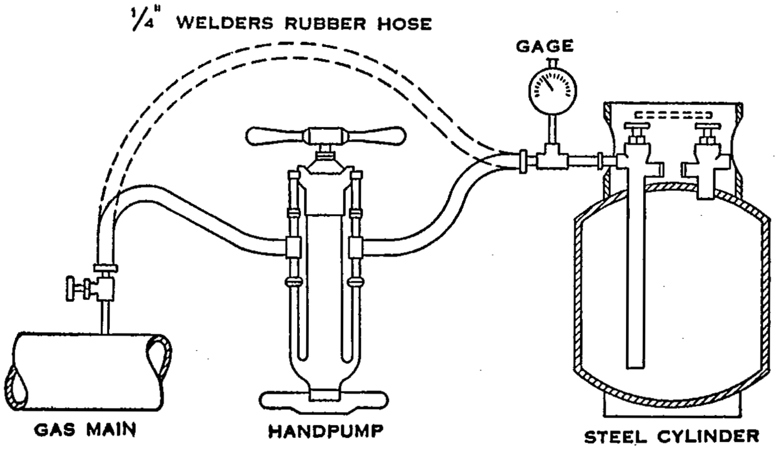

Fig. 6.—Apparatus for Collecting a Sample in a Steel Container Under Pressure, Either Direct from Gas Main or Using a Hand Pump.

(*5*) For air displacement follow the procedure outlined above up to the point of actually filling the cylinder. While holding the sample container vertically, attach the rubber tube through which the gas is flowing to the top valve (Fig. 5), open this

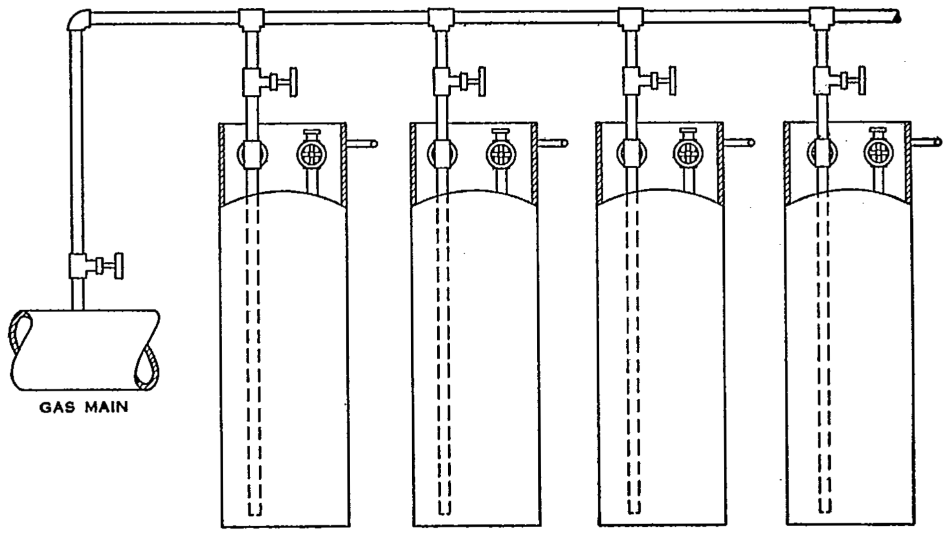

FIG. 7.—Apparatus for Collecting a Gas Sample Under Pressure in Several Steel Containers.

valve, and then open the bottom valve. Allow the gas to flow down through the sampling container at a rapid rate displacing all air. Continue to let the gas flow at least 2 min., or until it is certain that all air has been displaced. A flow of gas equivalent to ten times the volume of the sampling container will usually suffice.

(*b*) For collecting relatively large samples in high pressure sample containers for the determination of heating value, specific gravity, and analysis the following procedure is recommended:

(*1*) Attach $\frac{1}{4}$-in. high-pressure hose, copper tubing, or iron pipe to the point of sampling. Blow the gas through this sampling line until no dead gas remains. Attach the outlet end of the sampling line to the sample container, as shown in Fig. 6, if gas pressure is sufficient to fill the tank to the desired pressure, or to the suction side of the hand pump and with another line from pressure side of pump to container if the pressure is too low—also shown in Fig. 6. Open inlet and outlet valves on the container. Open the valve on the sample line, controlling rate of flow as desired. Fill the container to the desired pressure by closing the outlet valve and regulating the valve on the sample line. Empty the tank to about atmospheric pressure. Repeat the filling and emptying of the container eight to ten times. Then fill the tank to the desired pressure, close both valves and the regulating valve, disconnect the fitting, and mark the container.

(*2*) If it is necessary to collect large samples such as for the determination of gas law deviations or for analysis by fractionation, several sample containers may have to be filled. This can best be accomplished by a manifolding system that will permit taking the several samples simultaneously (Fig. 7). This ensures the same composition of gas at the same pressure and temperature in all tanks, and the several tanks give an adequate supply of gas at a high pressure for each test run. Satisfactory samples are best ensured by filling the sample containers slowly. After several (eight to ten) fillings at low pressure, say to 100 psi., to ensure purged tanks, the tanks should be brought up to pressure slowly.

(*c*) Samples from gas lines shall be taken from a vertical connection over the center of the line, if possible, so that trapped condensables are not drawn into the sample line. To ensure the removal of any condensables, the connection should be blown at full flow for 30 sec. The temperature of the gas in the line should be determined. Ground temperatures at line level will serve if the gas pressure has not been compressed or reduced nearby.

(*d*) After the samples have been shut in and the valves plugged, the containers should be checked for leaks and moved to the laboratory promptly. To minimize condensation within the sample container, the tanks should be kept as warm at all times as the line temperature at which they were filled. This precaution can be neglected if the weather and laboratory temperatures are above the temperature of the gas supply from which the samples were taken.

Procedures for Obtaining Representative Average Samples

9. Average samples consist of samples taken over a designated period of time, from a few minutes to several hours, representing the average composition of the gas over a given time at a particular place. Where the gas composition may vary and a sufficient number of grab samples cannot be obtained for use as an average sample for a given period of time, the following procedures are recommended for securing a representative sample:

(*a*) For continuous sampling direct to a recording or indicating analytical instrument, small-diameter copper, iron, or aluminum sampling lines as short as possible are most satisfactory. The line should be of such size as to permit a complete change of sample in the sampling line in 15 min. or less. If this cannot be done, a portion of the gas should be bled from the line and burned or returned to another line, or a circulating pump should be installed in the sampling line to ensure rapid change of gas in it.

(ASTM Section 9(b) replaced by the following.)

(*b*) For collecting average samples in portable containers three procedures using apparatus as shown in Figs. 8, 9, and 10 are recommended: (1) A method for collecting an average sample, dry, under pressure, is illustrated in Fig. 8.

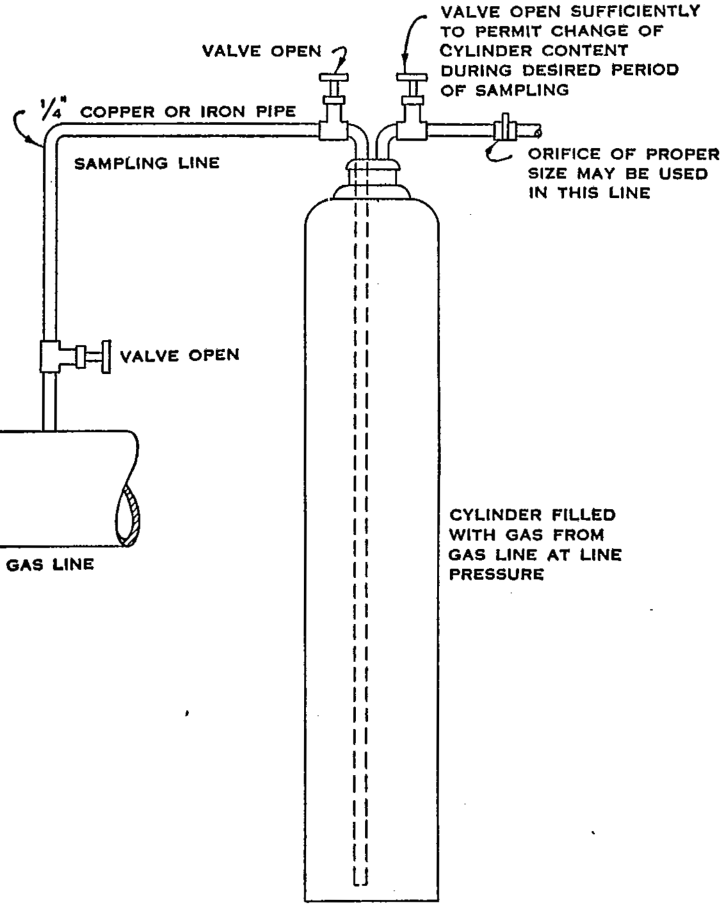

Fig. 8.—Arrangement of Apparatus for Collecting an Average Sample, Dry, Under Pressure.

The cylinder is first filled with gas from the supply line under pressure and the rate of sampling controlled by a valve or orifice in the outlet line. (2) A method of collecting an average sample over water is shown in Fig. 9. When starting with a sample container, such as the gas holder illustrated, it is necessary to adjust the pressure regulator and orifice size to permit continuous flow of gas into the holder to completely fill it in the time desired. Purge the sample line and holder thoroughly with the gas being sampled, then start the sampling period with the holder either completely filled with water, or with the small section of the holder crown sheet, which may extend above the water, filled with the same gas as it is intended to sample. (3) A method for collecting an average sample by water displacement is shown in Fig. 10. The sampling is started with the container filled with water and with the rate of sampling controlled by the rate of discharge of water from the tank. A constant rate of gas collection is obtained as the water in passing through the float valve controlled chamber is maintained at a fixed head upstream of the needle valve or if desired a fixed orifice.

Sampling Natural Gas Containing Hydrogen Sulfide, or Organic Sulfur Compounds or Other Sulfur Contaminants

10. It is advisable to sample natural gas containing hydrogen sulfide, or organic sulfur, or both, directly from the source, such as a natural gas well head or gas line, into the test apparatus through a minimum length of either aluminum or glass tubing joined with rubber sleeves with the ends of the tubing butted together so that no rubber is exposed to the flowing gas. If this cannot be done, dry glass containers and the displacement of air method may be used to collect the samples. Sampling lines and sample containers made of iron, steel, copper, or brass must not be used as the sulfur will combine with these materials, causing a decrease in the sulfur content of the sample. Water must not be used as a confining liquid in the container as it will dissolve a portion of the gaseous sulfides and possibly other sulfur com-

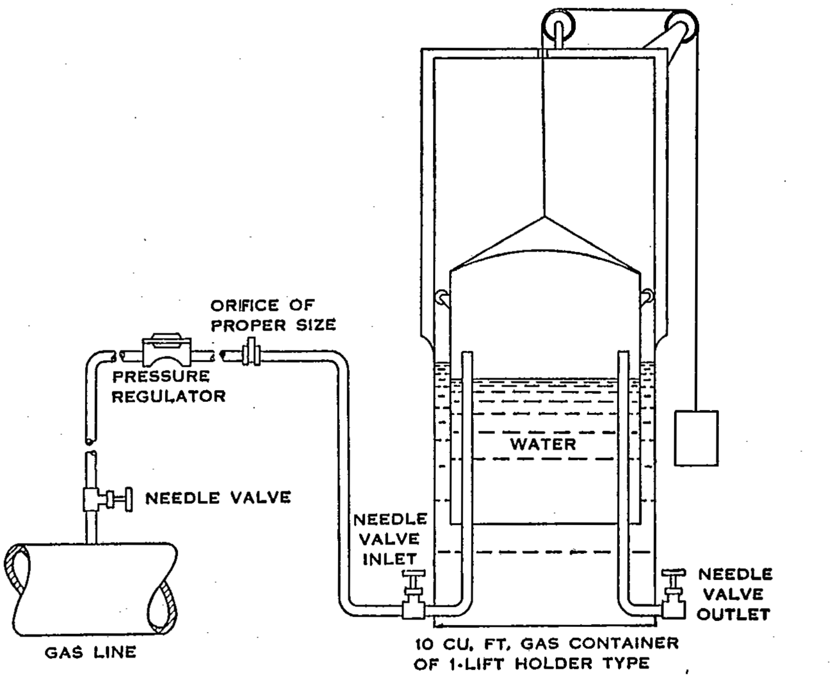

Fig. 9.—Arrangement of Apparatus Employing a Gas Holder for Collecting an Average Sample Over Water.

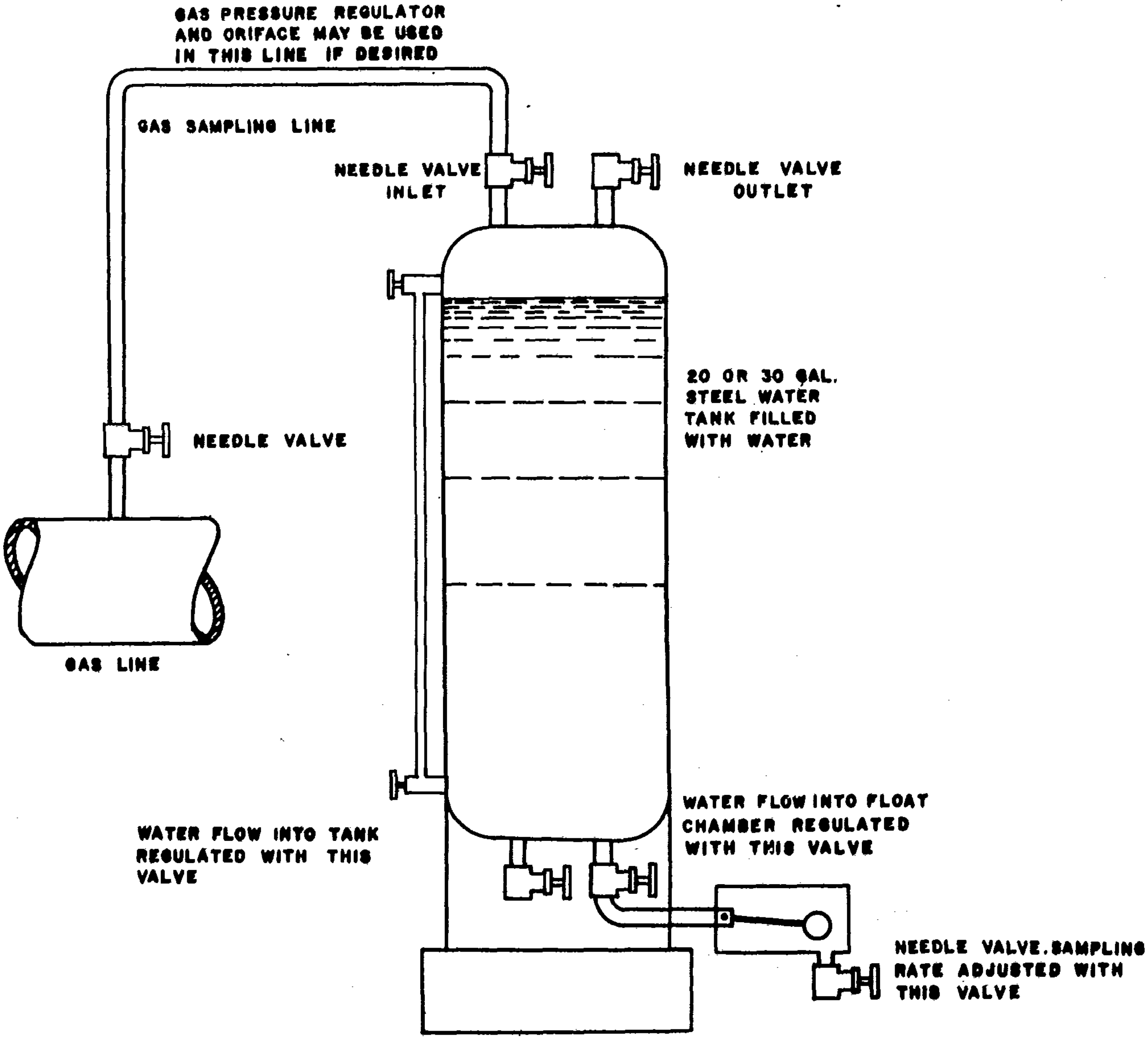

Fig. 10.—Collecting an Average Sample ot Water Displacement.

pounds. To collect a sample of the natural gas containing sulfides, use a clean, dry, glass bottle and sampling tube. For a large sample, an aluminum tank of ample size for the sample required may be employed. The temperature of the air in the container should be about the same as the temperature of the sample to be introduced. Connect a flexible tube to the vessel from which the sample is to be taken and allow gas to flow through this tube to replace the air therein. Insert the free end of the tube into the open mouth of the glass sample bottle (or connect it to one end of the glass sampling container) and extend it to the bottom of the bottle. The gas to be sampled should now be passed briskly through the tube and glass bottle for a period of not less than 10 min. If the gas to be sampled is lighter than air, the bottle should be supported in an inverted position during this operation; if the gas is heavier than air, the bottle should be in its normal upright position (see Section 8 (*a*)(*3*)). The sample should be displaced from the bottle to the analytical apparatus with a minimum of contact with acidified water.

Sampling Natural Gas Containing Carbon Dioxide

11. Natural gas containing more than 0.5 per cent carbon dioxide should be collected in dry containers because carbon dioxide is very soluble in water. Sampling of such gases must proceed in accordance with the dry methods listed under Section 8 (*a*)(*5*). Displacement from the container to the test apparatus should be done with mercury or release of pressure. Gas containing less than 0.5 per cent carbon dioxide should also be sampled in dry containers, but because of the very low percentage and less

chance of absorption with a minimum of contact with water, it may be sampled by the water displacement method previously described unless unusual accuracy in the carbon dioxide determination is required. The dry and wet methods described under Section 8 (*a*) may be used for this purpose. Displacement of the sample from the container to the test apparatus may be done with mercury, water, or by release of pressure.

(ASTM Section 12(a) and (b) not included.)

Standard Method of

SAMPLING LIQUEFIED PETROLEUM GASES

ASTM Designation: D 1265–55

Approved as USA Standard Z11.91–1955

(Identical with ASTM Procedures)

Scope

1. This method describes the procedures for obtaining representative samples of liquefied petroleum gases such as propane, butane, or mixtures thereof, in containers other than those used in laboratory testing apparatus.

Outline of Method

2. A liquid sample is transferred from the source into a sample container by purging the container and filling it with liquid to 80 per cent of capacity.

General Information

3. Considerable effort may be required to obtain a representative sample, especially if the material being sampled is a mixture of liquefied petroleum gases. The following factors must be considered:

(*a*) Obtain samples of the liquid phase only.

(*b*) When it is definitely known that the material being sampled is composed predominantly of only one liquefied petroleum gas, a liquid sample may be taken from any part of the vessel.

(*c*) When the material being sampled has been agitated until uniformity is assured, a liquid sample may be taken from any part of the vessel.

(*d*) Because of wide variation in the construction details of containers for liquefied petroleum gases, it is difficult to specify a uniform method for obtain ing representative samples of heterogeneous mixtures. If it is not practicable to agitate a mixture for homogeneity, obtain liquid samples by a procedure which has been agreed upon by the contracting parties.

Obtaining Samples

4. Directions for sampling cannot be made explicit enough to cover all cases. They must be supplemented by judgment, skill, and sampling experience. Extreme care and good judgment are necessary to insure samples which represent the general character and average condition of the material. Because of the hazards involved, liquefied petroleum gases should be sampled by, or under the supervision of, persons familiar with the necessary safety precautions.

Apparatus

5. (*a*) *Sample Container.*—Use metal sample containers of a type which insure maximum safety and which are corrosion-resistant to the product being sampled. The size of the container depends upon the amount of sample required for the laboratory tests that are to be made. If the container is to be transported, it must often conform to the specifications published in *Tariff No. 10,* "I. C. C. Regulations for Transportation of Explosives and Other Dangerous Articles," its supplements or reissues. The container may be of the one-valve or two-valve type and may contain an outage tube. Typical sample containers are shown in Fig. 1.

(*b*) *Sample Transfer Line.*—A sample transfer line made of copper or aluminum tubing or other flexible metal hose, impervious to the product being sampled, is required. The most satisfactory line is one equipped with two valves on the sample-container end, Fig. 1, a control valve, *A*, and a vent valve, *B*.

PROCEDURE

Purging Sample Transfer Line

6. Connect the ends of the transfer line securely to the product source and to the inlet valve *C* of the container. Close the control valve *A*, vent valve *B*, and inlet valve *C*, Fig. 1. Open the valve

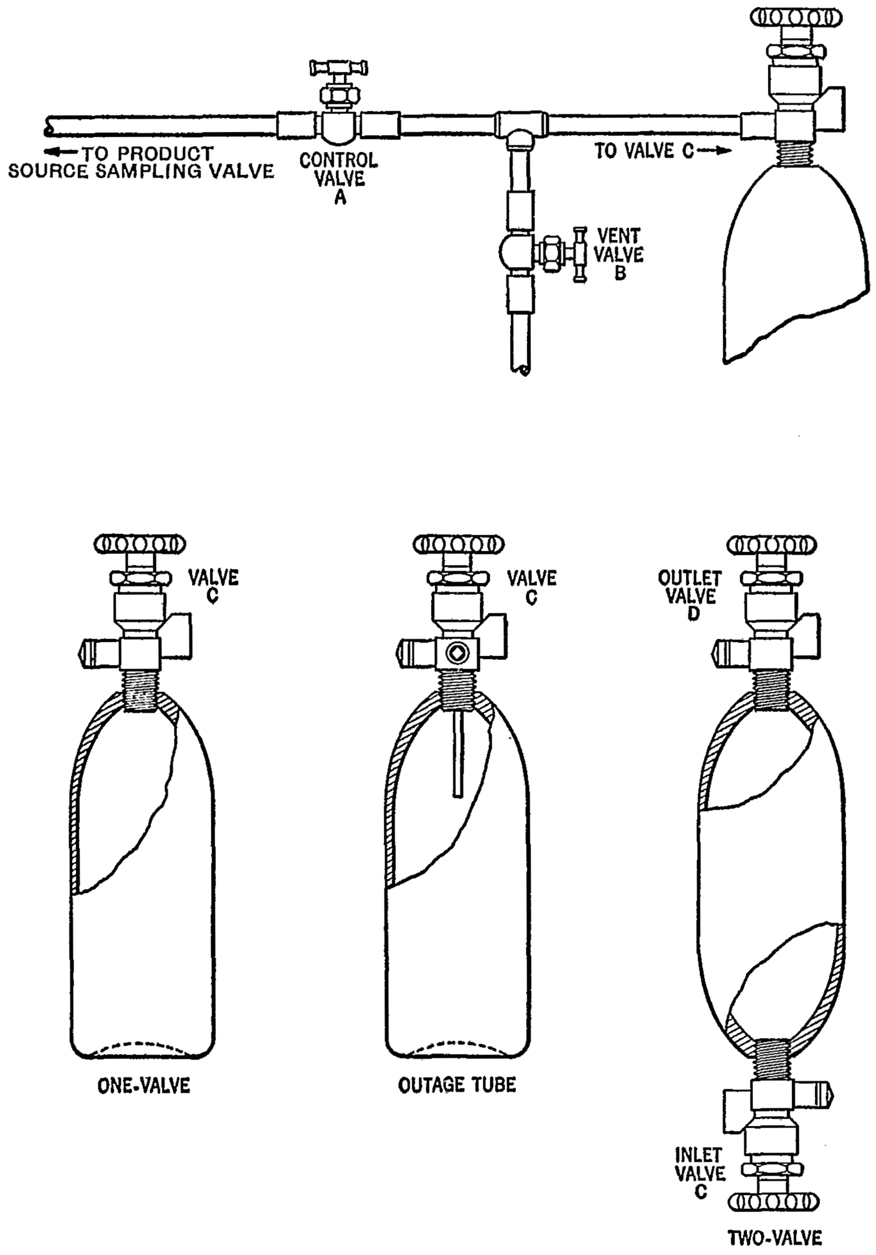

FIG. 1.—Sample Containers and Transfer Line.

at the product source and purge the transfer line by opening the control valve *A* and the vent valve *B*.

Purging Sample Container

7. (*a*) *One-valve Sample Container.*—Open the inlet valve *C* and partly fill the one-valve container. Close the control valve *A* and bleed a portion of the sample in the vapor phase through vent valve *B*. Invert the container and release the remainder of the sample as liquid through vent valve *B*. Repeat the purging operation at least three times.

(*b*) *Two-Valve Sample Container.*—With the two-valve container, Fig. 1, in an upright position and its outlet valve *D* at the top, close vent valve *B*, and inlet valve *C* and open control valve *A*. Open inlet valve *C*, and partly fill the container with sample by slowly opening the outlet valve *D*. Close the control valve *A*, and allow part of the sample to escape in the vapor phase through outlet valve *D*. Close outlet valve *D* and release the remainder of the sample in the liquid phase by opening vent valve *B*. Repeat the purging operation at least three times.

Transfer of Sample

8. Close the vent valve *B*, open the control valve *A*, and inlet valve *C*, and fill the container with sample. Close the inlet valve *C*, and the valve at the product source. Open the vent valve *B*. After the pressure is fully released, disconnect the transfer line from the source and from the sample container. Discard the sample if a leak develops or if either valve is opened during subsequent handling of the sample container before performing the operations outlined in Sections 9 (*a*) or (*b*).

Sample Outage

9. Immediately after obtaining the sample, provide a 20 per cent outage in the sample container as follows:

(*a*) *By Weight.*—Weigh the filled container, deduct its tare weight, and determine the weight of product that must be released to give a 20 per cent outage by volume. Draw off this amount by opening slightly the valve *C* with the cylinder in such position that the liquid phase of the material will be released.

***Caution.**—If the container cannot be weighed immediately, release a small amount of sample to prevent excessive pressure which may be caused by expansion of the sample when its temperature increases.*

(*b*) *By Outage Tube.*—If the sample container has an outage tube of the proper length (20 per cent outage), place the container in an upright position and immediately open valve *C* slightly. Allow the excess liquid to escape and close the valve at the first sign of vapor. If no liquid escapes, discard the sample and refill the container.

Checking for Leaks

10. After eliminating the excess liquid so that only 80 per cent of the sample

remains, immerse it in a water bath and check for leaks. If a leak is detected at any time during the sampling operation, discard the sample. Repair or replace the leaky container before obtaining another sample.

Care of Samples

11. Place samples in a cool location as soon as possible. Keep them there until all tests have been completed. Discard any samples in containers which develop leaks. Protect the valves on the sample container, either by packing the container in a crate in an approved manner or by using a protective cap, so that accidental unseating of the valve or tampering with it is avoided.

Standard Method of

SAMPLING MANUFACTURED GAS

ASTM Designation: D 1247–54

Approved as USA Standard Z77.7–1963

(Fig. 9 for Improved Apparatus for Taking Continuous Sample by Liquid Displacement and the corresponding text have been revised. The ASTM Procedure for Collecting Samples for Determination of Suspended Particles has been replaced by reference to ASME Performance Test Code for Determining Dust Concentration in a Gas Stream, PTC 27.)

(ASTM Paragraphs 1-4 omitted. See page 14 and 15: 16c Scope, General Considerations, etc.)

Outline of Method

5. (*a*) The method specifies the conditions for conducting a stream of gas from the sampling source into a purged container, and thus securing a representative sample. Snap samples may suffice, or a series of consecutive snap samples may be considered as an average sample. Average samples may also be obtained by continuous sampling into a portable container or direct to a recording or indicating instrument over a predetermined period of time.

(*b*) Purging may be accomplished by means of the gas to be sampled, either by displacement of air or by water displacement; or by the utilization of a vacuum.

(*c*) Manufactured gas will usually be under sufficient pressure to purge and fill the sample container; otherwise auxiliary mechanical equipment must be employed (Section 6 (*d*)).

(*d*) The choice of the type of sample ("snap" or "continuous"), the method of purging, the kind of container, and the selection of auxiliary pressure equipment, will be determined by the analyses to be done on the sample, by the composition of the gas to be sampled, and by the available equipment.

Apparatus

6. The sampling equipment should guard against contamination by air, leakage, and losses by absorption or chemical reaction. The use of rubber should be kept to a minimum, and any rubber used should be of a grade that will not react with the sample and that will have low permeability characteristics. Plastic tubing may be as satisfactory where flexibility is imperative. Rubber hose should not be used where high pressures are involved.

(*a*) *Sampling Probes* of metal are preferable because of their durability. Iron pipe, $\frac{1}{8}$ or $\frac{1}{4}$ in. in diameter, threaded or welded to the main or other source of sample and extending some distance into the vessel, makes a satisfactory connection. Condensate on the inside surface of the main will be avoided, and the point of average velocity of the gas, one sixth of the diameter of the main, can be reached at the same time. Figure 1 shows a simple open-end sampling tube. If unusually high temperatures are encountered, water-cooled probes (see Fig. 2) may be required.[3]

(*b*) *Sampling Lines.*—Iron pipe $\frac{1}{8}$ or $\frac{1}{4}$ in. in diameter, and copper, monel metal, or brass tubing $\frac{3}{32}$ to $\frac{3}{8}$ in. in outside diameter, are recommended as sampling lines. Where sulfur compounds are to be determined, glass or quartz tubing should be used for the low pressures and aluminum when higher pressures are met. Any sampling line should be as short and of as small a diameter as practicable to decrease purging time, particularly in the case of a continuous sampling line direct from the source of supply to analytical apparatus in order that the test instrument may follow closely any change in composition of the supply.

(*c*) *Sample Containers* may vary in size from 125 cu cm to several cubic feet. The design and type may take many forms, such as tubes, cylinders, or tanks, which may be sealed by stopcocks or valves. They shall be made of material that will not react with the sample, usually glass, steel, or any metal or alloy sufficiently strong and gastight. Figures 3, 4, and 5 illustrate typical sample

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[3] V. J. Altieri, "Gas Analysis and Testing of Gaseous Materials," Am. Gas Assn., pp. 76–79.

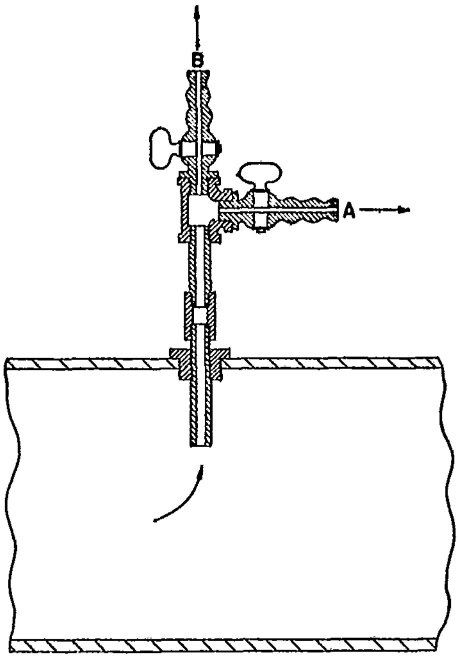


Fig. 1.—Simple Open-End Sampling Tube.

containers. Whenever necessary to ship a sample of manufactured gas under pressure, the container must meet the requirements of the Interstate Commerce Commission, and it should be correctly labeled for identification and proper handling by the analyst. If the sample is to be shipped under pressure the vessel must comply with the requirements of, and be approved by, the Interstate Commerce Commission.

(*d*) *Aspirators and Pumps.*—When the gas to be collected is not under positive pressure, some form of aspirating device (see Fig. 6) must be employed to draw the gas through the sampling probe and into the sample container. This device may be of any of the following types:

(*1*) A very simple form of aspirator, which also serves as a sample container, is shown in Fig. 6 (*a*). It consists of two interchangeable bottles of equal size. Water from the upper bottle, *A*, flows through the siphon tube, *E*, to the lower bottle, *C*, thereby creating a vacuum at tube *F*. If tube *F* is connected to the sampling probe, the gas will be aspirated into bottle *A*. When all of the water has been siphoned from the upper bottle into the lower bottle, they may be interchanged and the aspirating continued as before.

(*2*) A double-action, rubber-bulb hand pump, as shown in Fig. 6 (*b*), is convenient for purging sampling apparatus and filling sample containers. It may be used for either suction or pressure as it has a simple valve at each end, the two being of opposite action. In use, one end of the empty sample container is connected with the gas supply and the bulb is connected to the other end with the valves in such a position that the pressure and relief on the bulb will draw air out of the container and admit the gas. Fifty compressions of an ordinary 40- to 60-cu cm capacity bulb will completely replace the air in a 250-cu cm sample container. A large enough safety is provided because the bulbs become less efficient with use, although their usefulness can be fairly well determined by compressing the bulb, closing the intake end, and noting whether there is any leakage, and then repeating, endeavoring to compress the bulb with the effluent end closed. Dust sometimes collects on the ledges of the valve seats, and a seemingly defective bulb is often remedied by the removal of such dust or by wetting the valve seats with water. An added precaution against air contamination through leaky valves should be taken during sampling. This is most readily accomplished by connecting a length of rubber tubing to the effluent end of the bulb and placing the outlet of this tube under water.

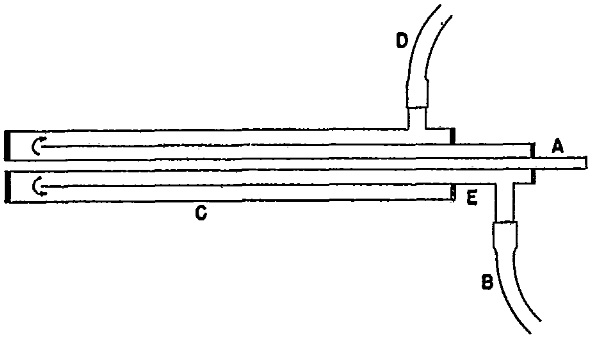
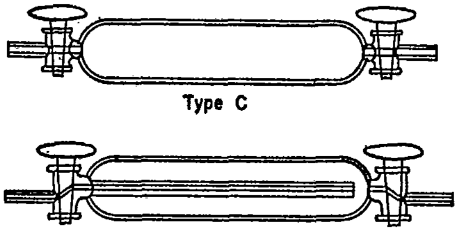


Fig. 2.—Water-Cooled Sampling Tube.


Type C

Type F

Fig. 3.—Glass Gas Sample Containers.

(*3*) A hand pump equipped with double-acting valves (Fig. 6 (*c*)) may be used.

(*4*) When running water is available, an ordinary laboratory filter pump of the "Chapman" type, as shown in Fig. 6 (*d*), may be used for aspirating the gas through the sampling apparatus. If a water pump of this type is not available, one may readily be improvised.

(*e*) *Confining or Displacing Medium.*—The confining and displacing medium used in the sample container should not react with the container or the sample. Water is the most convenient, but has more or less solvent action on all gases. The error may be minimized by slightly acidifying the water or by dissolving certain salts in it; for example, sodium chloride. Mercury is the most satisfactory liquid and should be used for precise work as no solubility precautions are necessary; however, it has the disadvantages of its cost, excessive weight, and the fact that it reacts with hydrogen sulfide. Displacement of the sample from the container to the test apparatus may be accomplished by release of pres-

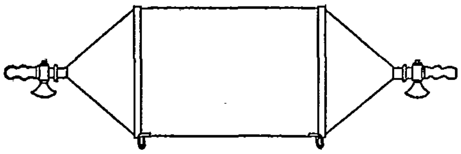


Fig. 4.—Metal Gas Sample Container.

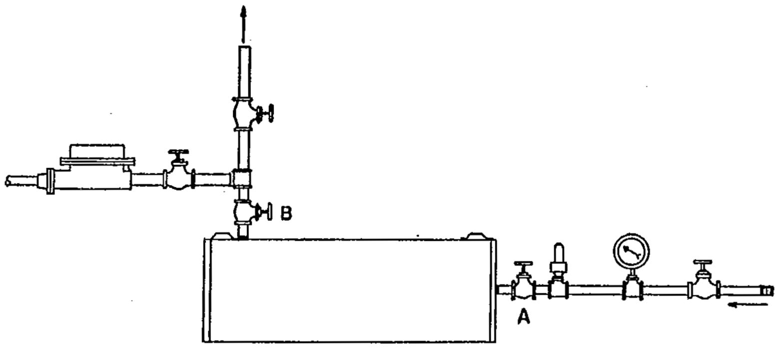


Fig. 5.—High-Pressure Sample Container.

sure if neither water nor mercury is permissible.

(*f*) *Stopcock Lubricant.*—An excessive amount of grease should be avoided when lubricating stopcocks, since many gases, particularly the hydrocarbons, are soluble in these greases. The new silicone lubricants may be superior to the older commercial products for this purpose.

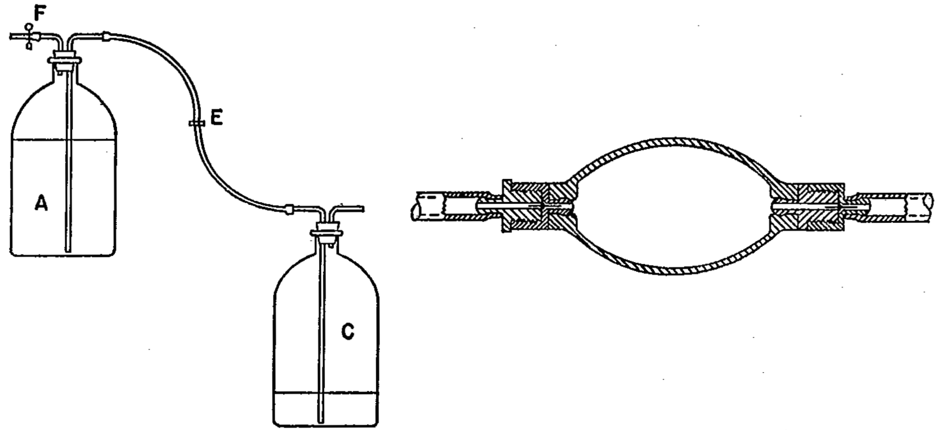
Procedure for Collection of Snap Samples

7. (*a*) Sample containers shown in Fig. 3, type *C*, and in Fig. 4 are generally used for taking snap samples.

(*b*) If there is an abundant supply of gas and appreciable pressure, dry procedures (air displacement) may be used. In this method, the container is purged with the gas to be sampled until the original contents are displaced, a flow of gas equivalent to ten times the volume of the sampling container being sufficient. If it is desired to use the air displacement method under negative pressure, an aspirating device of the type described in Section 6 (*d*) may be connected to the end of the sample container and purging operations performed until the original air has been displaced.

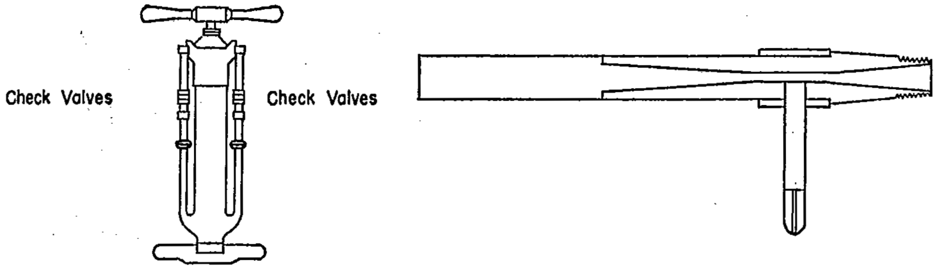
(*c*) In taking a sample when the gas supply is limited, the liquid displacement method is usually employed. The container is first filled with displacing liquid and then connected to the gas supply by means of connections that have previously been purged of air and dead gas. The latter may be done by gas displacement, that is, allowing the primary stream to flow for a short time before sampling or filling the connections with the displacing liquid before connecting the container. The container is then filled by allowing the displacing liquid to run out ahead of the gas, after which the outlet end of the container is closed and then the inlet.

(*d*) When the gas to be sampled is not under pressure, one of the various types of aspirators or suction pumps previously described should be used to set up a primary stream of gas. A satisfactory ar-



(*a*) Aspirating Bottles

(*b*) Rubber Bulb Hand Aspirator



(*c*) Hand Pump

(*d*) Chapman Filter Pump

Fig. 6.—Apparatus for Inducing or Forcing Gas Flow.

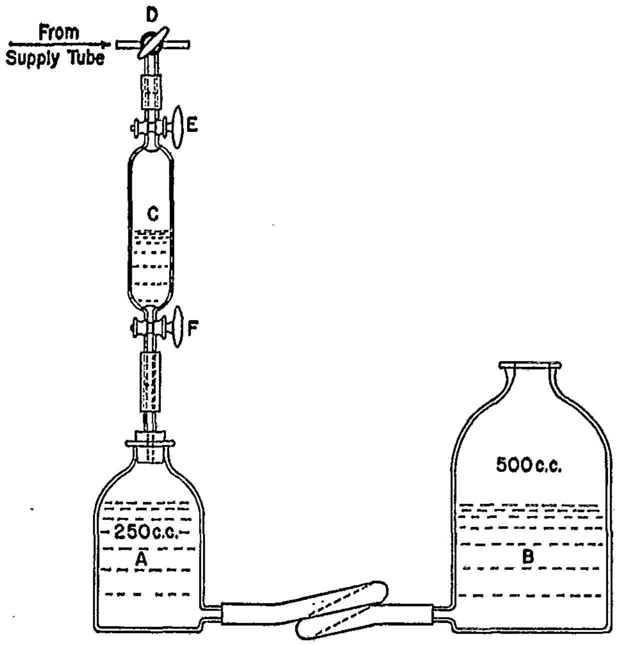


FIG. 7.—Filling Sample Containers by Liquid Displacement.

rangement for filling containers either by water or mercury displacement from streams under supply positive pressure, neutral pressure, or a few inches of negative pressure is similar to the device shown in Fig. 7. If the gas is under appreciable positive pressure, bottle *A* may be omitted from the device and the hose connected directly to the sample container, *C*, but if the gas is at neutral pressure, and especially if it is under slight negative pressure, *A* is necessary. The container, *C*, is filled with the displacing liquid from the aspirator bottle and then connected to the sampling tube, *D*, upon which the connection is also filled with the liquid or purged by drawing a portion of the sample and rejecting it either back into the primary sampling stream if there is a continuous flow, or to the exterior by means of a three-way stopcock, as shown. After the connections have been purged, the sample container is filled by allowing the liquid to return to the aspirator bottles. In case of neutral or negative pressure, bottle *A* is partly filled with gas at the time of taking the sample and, after closing stopcock *E*, the aspirator bottle, *B*, is raised; this forces some gas back into the container; stopcock *F* is then closed. This restores atmospheric pressure or, what is more desirable, the sample can be put under positive pressure which tends to avoid air contamination through leaks at *E* and *F* during the interim before analysis. The entire device may be mounted on a ring stand with a large clamp to receive the sample container, *C*.

Procedures for Collection of Continuous Samples

8. (*a*) Figure 8 shows a simple arrangement of two 8- to 10-liter aspirator bottles connected by about 4 ft of medium-heavy-wall rubber tubing. In use, the lower bottle is placed 2 to 4 ft below the upper one. The flow of water can be regulated more easily at a greater difference in the two heights of the bottles, and this results in a more uniform rate of collecting gases over long periods. In constructing the bottle, care should be taken that the "ell" inlet of *B* does not extend below the stopper and trap gas.

To collect a sample, connect the bottles to the secondary gas outlet as shown, except that *F* shall be connected to *G*. With screw clamps open, force the confining liquid to the point *E*. Then, by lowering *D*, draw enough gas into *B* to purge the connection (about one fourth the volume of *B*) and immediately discharge it back through *E*. Repeat the purging procedure and when the liquid reaches *E* the second time, close screw clamps *D* and *G*. Remove the connection to *G* and replace it in the stopper of bottle *C*, upon which the apparatus is ready for collecting a sample. The screw clamp *D* may be adjusted to any desired flow of solution and, consequently, collection of sample. The correct adjustment of the regulating pump can be made easily by observing the amount of water dripping from *F*. The size of the drop for the particular tube in *F* should be determined and used as a basis for calculating rates of collection of sample.

After the gas has been collected, close screw clamp *D*, then *A*, and again connect *F* to *G* (being careful to avoid entrapping air bubbles). Place the sample under slight positive pressure by raising *C* until the level of the liquid is about an inch or two above that in *B* and open *D* for a minute or two. The sample may now be taken to the laboratory or a snap sample taken for analysis.

(*b*) An improved and more desirable method for collecting accumulative samples, using aspirating bottles, is shown in Fig. 9. In the diagram, *A* and *B* are aspirator bottles of suitable size for collecting the samples. If 24-hr samples are to be collected, the capacity of the bottles should be not less than 10 liters

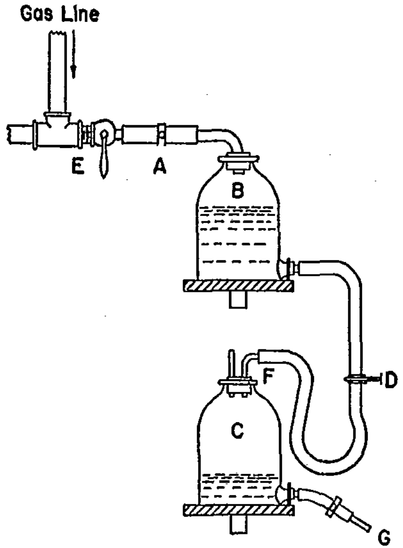


FIG. 8.—Apparatus for Taking Continuous Sample by Liquid Displacement.

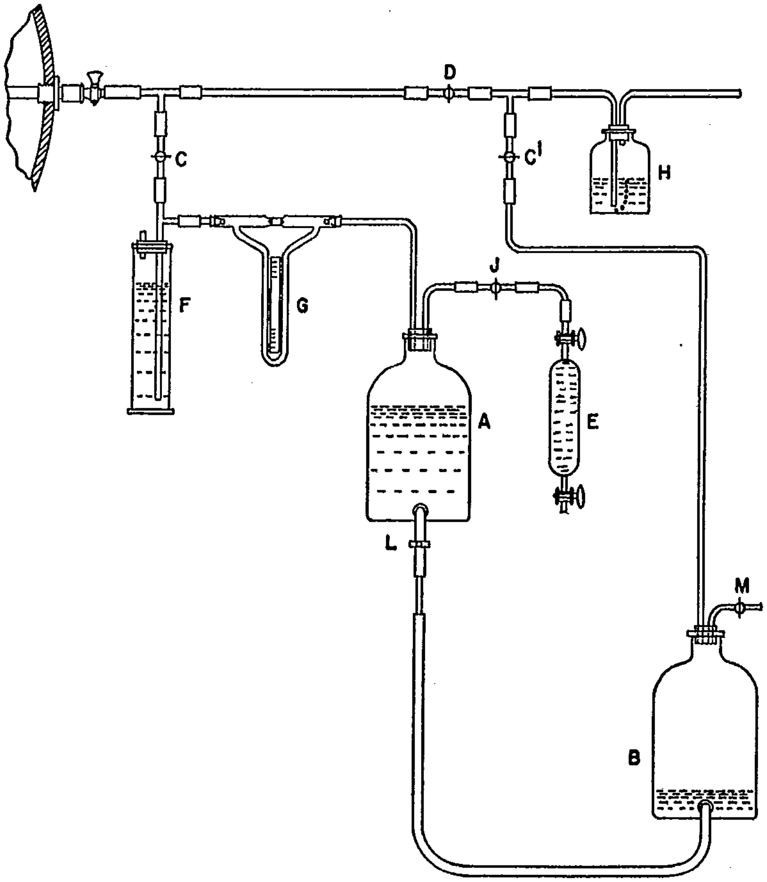


FIG. 9.—Improved Apparatus for Taking Continuous Sample by Liquid Displacement.

each. Bottle *A* is connected to the gas line with glass or metal tubing, but may be connected to *B* with rubber tubing. Bottle *B* should be connected to the gas line by flexible tubing. A flow indicator, *H*, of the bubble bottle type serves to give visual control of the flow of gas through the primary gas line. A pressure regulator, *F*, and a flow meter, *G*, are provided for regulating the rate of collection. The sample container, *E*, is not connected until the sample is to be tested.

To collect a sample, open stopcock *D* and allow the primary stream of gas to flow through the bubble bottle to a bleeder connection. Fill bottle *B* with the confining liquid and, with all stopcocks closed, except screw clamp *L* at the outlet of *A*, break the connection between bottle *A* and the flow meter, *G*. Open stopcock *C′* to admit the gas to bottle *B*. Raise *B* so that the gas pressure forces the liquid back into *A* and the air, or gas from the previous sample, contained in *A* is forced out through the tube to where the connection is broken at *G*. Also purge piping with liquid to *J* allowing liquid to flow from outlet at *J* before closing this stopcock. When *A* is filled with the liquid as far as the broken connection, close stopcock *C′* and screw clamp *L*. Now, open stopcock *C* and allow the gas to purge through *F* and *G*. Connect the flow meter *G* to *A* again and lower bottle *B*. Open the outlet stopcock at *M* and connect to a burner or purge line, and adjust the screw clamp *L* at the bottom of *A* to give the desired rate of flow as indicated by the flow meter.

At the end of the sampling period, close stopcock *C*, the stopcock *M* at the outlet *B*, and take the sample from *A* by attaching a sample container *E*, as shown in Fig. 10. Transfer a portion of the gas to the sample container by raising the level of bottle *B*. For additional assurance that a true average sample is obtained for the test, the liquid in *A* should be agitated to mix the gas in *A* thoroughly before starting the withdrawal.

(*c*) The sample container illustrated in *F*, Fig. 3, is used for collecting continuous samples by mercury displacement, as shown in Fig. 10. The container should have a capacity of about 250 cu cm.

To take a sample, open stopcocks *A* and *B*. As the mercury flows from the lower outlet, the gas will be drawn into the container and will collect above the mercury. As long as the surface of the mercury remains above the gas inlet tube, the flow of mercury will be constant and the same volume of gas will be collected in each equal interval of sampling period. The time required for the mercury to flow from the container may be varied by attaching a glass orifice to the outlet end of the container. The rate of sampling is fixed by the stopcock and by the distance *C–D* between the end of the inlet tube and the end of the stopcock. This sampler may also be used with water or salt solution.

After the sample of gas has been collected (stop the flow when the level of the mercury is about the level of *C*) and close stopcocks *A* and *B*; then fill the tube above *A* with mercury from a small funnel whose stem has been drawn out to a capillary. Invert the container and, by means of a rubber tube attached to an aspirator bottle or levelling bulb reservoir filled with mercury, admit mercury through *A* (using precaution not to entrap air in the connection) and put the gas under a pressure of about 100 mm of mercury, as observed by the height of the level of the mercury in the reservoir and the height of the mercury at *C*. Close stopcock *A* and return the vessel to its original position, as shown in the illustration. The mercury will then be well above the level of *C* and the stopcocks *A* and *B* will be mercury sealed against leaks.

When it is desired to remove the sample for analysis, again invert the container and attach *D* to the buret. By means of a mercury reservoir, mercury may be admitted to displace the gas while filling the buret.

(*d*) For collecting continuous samples of several cubic feet, a metal gas holder as shown in Fig. 11 is recommended. Adjust the pressure regulator outlet and orifice size to permit continuous flow of gas into the holder to completely fill it in the time desired for taking an average sample. Purge the sample line and holder thoroughly with the gas being sampled; then start the sampling period with the holder either completely filled with water, or the small section of the holder crown sheet, which may extend above the water, filled with the same gas as it is intended to sample.

(*ASTM Section 9 replaced by the following.*)

Procedure for Collecting Samples for the Determination of Suspended Particles

When the dust content of the gas is an important characteristic to be determined, additional precautions must be taken to assure obtaining a representative sample. Complete instructions for obtaining samples of dust are given in the ASME Performance Test Code for Determining Dust Concentration in a Gas Stream, PTC 27.* In general, separate samples of gas will have to be taken for analytical determination of other characteristics.

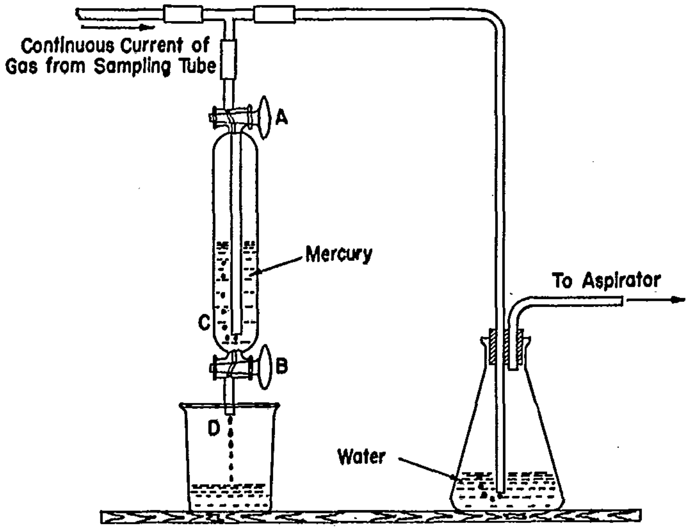


Fig. 10.—Apparatus for Taking Continuous Sample by Mercury Displacement.

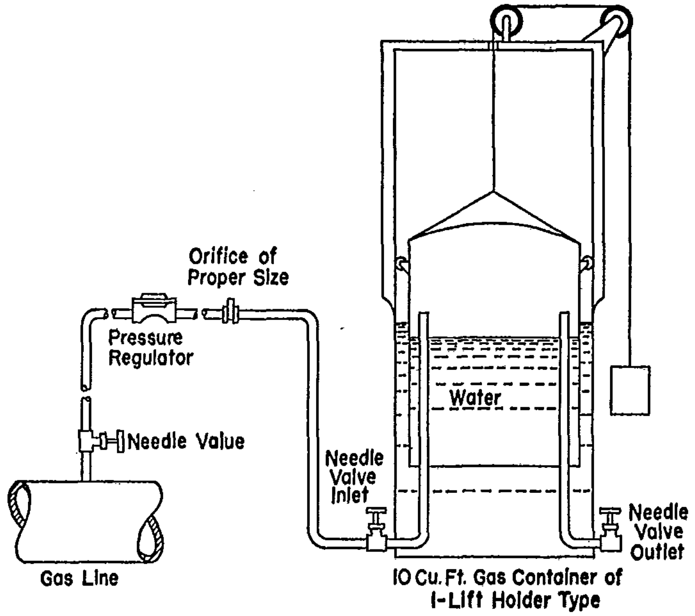


Fig. 11.—Arrangement of Equipment Employing a Gas Holder for Collecting an Average Sample Over Water.

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* See Bibliography Reference (9).

Standard Methods for

MEASUREMENT OF GASEOUS FUEL SAMPLES

ASTM Designation: D 1071–55

Approved as USA Standard Z77.5–1963

(The description of rotary displacement meters and calibration has been omitted. Under Calibration of Rate-of-Flow Meters, the formula units and text have been revised. A slight change was made in the specification for oil for secondary standards.)

Scope

1. These methods are applicable to the measuring of gaseous fuel samples, including liquefied petroleum gases, in the gaseous state at normal temperatures and pressures. The apparatus selected covers a sufficient variety of types so that one or more of the methods prescribed may be employed for laboratory, control, reference, or in fact any purpose where it is desired to know the quantity of gaseous fuel or fuel samples under consideration. The various types of apparatus are listed in Table I.

Terminology and Units of Measurement

2. (*a*) *Units of Measurement.*—All measurements shall be expressed in English units (that is: foot, pound (mass), second, and degrees Fahrenheit.)

(*b*) *Standard Conditions.*—The standard conditions at which gaseous fuels samples shall be measured, or to which such measurements shall be referred, are as follows:

(*1*) A temperature of 60.0 F.,

(*2*) A pressure of 30.000 in. of mercury, the mercury to be at the ice point temperature and subject to an acceleration of gravity of 32.174 ft. (980.665 cm.) per sec. per sec., and

(*3*) A condition of complete water-vapor saturation (Note).

NOTE.—This condition is equivalent to saying that the absolute partial pressure of the dry gas shall be 29.478 in. of mercury. In the sale of "natural" gaseous fuels the customary basis is "a condition of dryness with respect to water-vapor and other normally condensible constituents."

(*c*) *Standard Cubic Foot of Gas.*—A standard cubic foot of gas is that quantity of gas which will fill a space of exactly 1 cu. ft. when under the standard conditions (Paragraph (*b*)).

(*d*) *Temperature Term for Volume Reductions.*—For the purpose of referring a volume of gaseous fuel from one temperature to another temperature (that is, in applying Charles' law), the temperature terms shall be obtained by adding 459.7 to each temperature in degrees Fahrenheit.

Apparatus

3. The various types of apparatus used for the measurement of gaseous fuel samples may be grouped in three classes, as shown in Table I. References to the portions of these methods covering the capacity and range of operating conditions, and the calibration, of each type are given in Table I.

TABLE I.—APPARATUS FOR MEASURING GASEOUS FUEL SAMPLES.

Apparatus	Capacity and Range of Operating Conditions Covered in Section No.	Calibration Procedure Covered in Section No.
Containers:		
Cubic-foot bottle, immersion type or moving-tank type.....	4	11
Portable cubic-foot standard (Stillman-type)...............	4	11
Fractional cubic-foot bottle......	4	11
Burets, flasks, etc., for chemical and physical analysis..........	5	11
Calibrated gasometers (gas meter provers).....................	6	12 to 15
Gas meters, displacement type:		
Liquid-sealed rotating-drum meters........................	7	16 to 21
Diaphragm- or bellows-type meters, equipped with observation index.....................	8	22
Rotary displacement meters.....	9	23
Gas meters, rate-of-flow type:		
Porous plug and capillary flowmeters	10	24
Float (variable-area, constant-head) flowmeters.............	10	24
Orifice, flow nozzle, and venturi type flowmeters..............	10	24

CAPACITY OF APPARATUS AND RANGE OF OPERATING CONDITIONS

Cubic-Foot Bottles, Standards, etc.

4. The capacities of cubic-foot bottles, standards, etc., are indicated by their names. A portable cubic-foot standard of the Stillman type is shown in Fig. 1 and a fractional cubic-foot bottle is shown in Fig. 2. The temperatures and pressures at which these types of apparatus are used must be very close to those existing in the room in which they are located. Since these containers are generally used as standards for the testing of other gas-measuring devices, the rate at which they may be operated is of little or no importance. It will always be low, and probably nonuniform, and in any given instance will be affected by the test being made and the connections used.

Burets, Flasks, etc.

5. The capacities of burets, flasks, etc., will depend upon their function in the equipment and service in which they are to be used. The range of temperatures and pressures under which they may be used, which will be affected by their function, will depend upon the material of construction and may be relatively high (for example, 1000 F. and 10,000 psi.) if suitable materials are used.

Calibrated Gasometers

6. The stock capacities of calibrated gasometers (gas meter provers) are 2, 5, and 10 cu ft. The temperature and pressure at which they can be operated

must be close to the ambient temperature and within a few inches of water column of atmospheric pressure. The equivalent rates of flow that may be attained, conveniently, are as follows:

Size, cu. ft.	Equivalent Rate, cu. ft. of air per hr.
2	990
5	2250
10	5000

Liquid-Sealed Rotating-Drum Meters

7. (*a*) The drum capacities of commercial stock sizes of liquid-sealed rotating-drum meters range from $\frac{1}{20}$ cu. ft. (or 1 liter) to 7.0 cu. ft. per revolution. A 0.1-cu. ft. per revolution meter is shown in Fig. 3. The operating capacities, defined as the volume of gas having a specific gravity of 0.64 that will pass through the meter in 1 hr. with a pressure drop of 0.3 in. water column across the meter, range from 5 to 1200 cu. ft. per hr. Liquid-sealed rotating-drum meters may be calibrated for use at any rate for which the pressure drop across the meter does not blow the meter seal. However, if the meter is to be used for metering differing rates of flow, a calibration curve should be obtained, as described in Section 19, or the meter should be fitted with a rate compensating chamber (see Appendix).

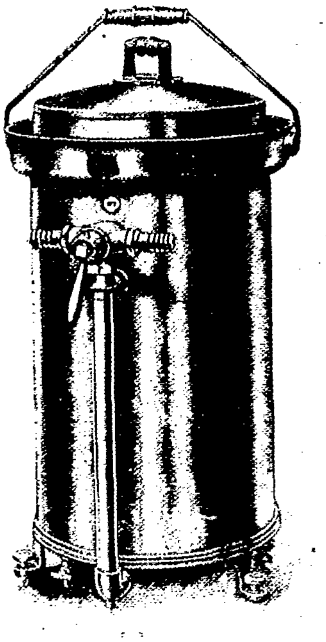


FIG. 1.—Stillman-Type Portable Cubic-Foot Standard.

(*b*) The temperature at which these meters may be operated will depend almost entirely upon the character of the sealing liquid. If water is the sealing liquid, the temperature must be above the freezing point and below that at which evaporation will affect the accuracy of the meter indications (about 120 F.). Outside of these limits some other liquid will be required.

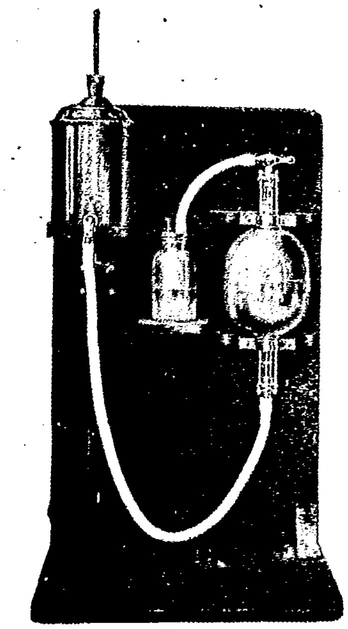


FIG. 2.—One-Tenth Cubic Foot Bottle, Transfer Tank, and Bubble-Type Saturator for Testing Laboratory Wet Gas Meters.

(*c*) While the cases of most meters of this type may withstand pressures of about 2 in. of mercury column above or below atmospheric pressure, it is recommended that the maximum operating pressure to which they are subjected should not exceed 1 in. of mercury or 13 in. of water column. For higher pressures the meter case must be proportionally heavier or the meter enclosed in a suitable pressure chamber. For pressures more than 1 in. of mercury (13 in. of water) below atmospheric pressure, not only must a heavier case or a pressure chamber be used, but a sealing fluid having a very low vapor pressure must be used in place of water.

Diaphragm-Type Test Meters

8. (*a*) The displacement capacities of commercial stock sizes of diaphragm type test meters range from about 0.05 to 2.5 cu ft per revolution. The operating capacities, defined as the volume of gas having a specific gravity of 0.64 that a meter will pass with a pressure drop of 0.5 in. of water column across the meter, range from about 20 to 1800 cu. ft. per hr. Usually these meters can be operated at rates in excess of their rated capacities, at least for short periods. A meter having a capacity of 1 cu. ft. per revolution is shown in Fig 4.

(*b*) The temperature range under which these meters may be operated will depend largely upon the diaphragm material. For leather diaphragms, 0 F. to 130 F. is probably a safe operating range. At very low temperatures the diaphragms are likely to become very stiff and cause an excessive pressure drop across the meter. At higher temperatures the diaphragms may dry out rapidly, or even become scorched causing embrittlement and leaks.

(*c*) The pressure range (linepressure) to which these meters may be subjected safely will depend upon the case material and design. For the lighter sheet metal (tin case) meters, the line pressure should not be more than 3 or 4 in. of mercury column above or below atmospheric pressure. For use under higher or lower line pressures, other types of meter cases are available, such as cast aluminum alloy, cast iron, or pressed steel.

(*ASTM Section 9 not included.*)

NOTE.—The diaphragm-type test meter and the diaphragm-type consumers meter are similar in most respects. The principal difference is the type of index or counter. The test meter index has a main hand indicating 1 cu.ft. per revolution over a 3-in. or larger dial, with additional smaller dials giving readings to 999 before repeating. On the index of consumers meters, aside from the test hand, the first dial indicates 1000 cu. ft. per revolution of its hand so that the smallest volume read is 100 cu. ft. The maximum reading for a consumers meter index may be 99900 or 999900. Another minor difference is that the maximum rated capacity for the larger consumers meters may be 17000 cu. ft. per hr.

Rate-of-Flow Meters

10. (*a*) Rate-of-flow meters, as the name implies, indicate rates of flow, and volumes are obtained only for a definite time interval. They are especially use-

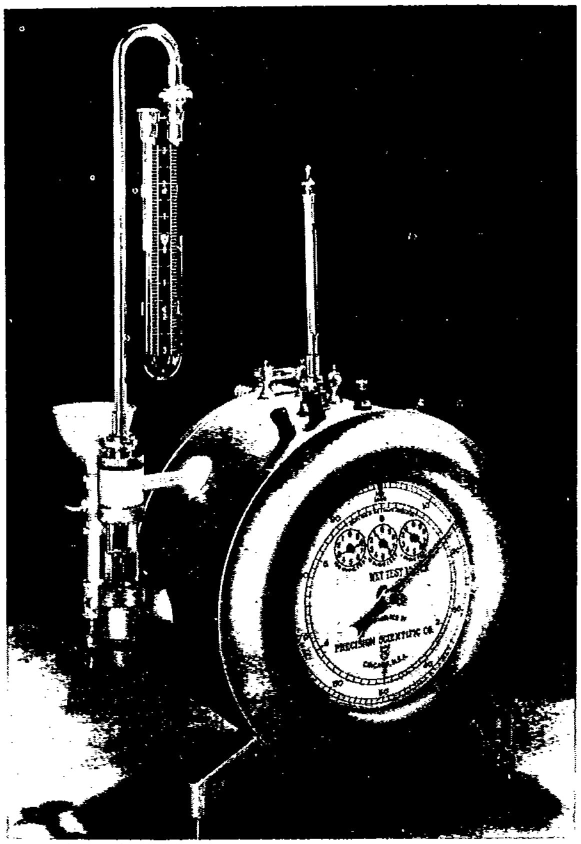


FIG. 3.—Liquid-Sealed Rotating-Drum Gas Meter of 0.1 cu. ft. per Revolution Size.

ful in those situations where the flow is steady, but are not suited for use in the measurement of specified quantities nor on flows that are subject to wide or more or less rapid variations of either rate or pressure. In the smaller sizes they may be particularly useful for both regulating and measuring continuous samples of a gaseous fuel.

(*b*) No definite limits can be set to the range of rate of flow to which these meters may be applied, nor to the range of temperatures and pressures under which they may be operated. Where meters of this type are desired it will usually be possible to design one to meet the particular service requirements. Of particular interest for continuous sampling and sample measurement, are flowmeters of the capillary tube and porous plug (for example, sintered glass filter) type. The rates of flow that they can meter satisfactorily range upward from about 0.03 cu. ft. per min. The pressure drop across the metering element is not only low (a few inches of water column) but its relationship to the rate of flow is very nearly linear.

CALIBRATION OF APPARATUS

Calibration of Primary Standards

11. (*a*) Cubic-foot bottles and fractional cubic-foot bottles are calibrated by weighing the quantity of distilled water that will be delivered between the gage marks (Note 1), correcting for the buoyancy of the air. At the standard conditions specified in Section 2 (*b*) the weight of water contained between the gage marks of a correctly adjusted cubic-foot bottle should be 62.299 lb.

NOTE 1.—It is now the practice at the National Bureau of Standards to calibrate or adjust these standards "to deliver" the specified quantity of water from a *wet* condition. To do this, the standard is filled with water, then emptied slowly over a period of 3 min and allowed to drain for an additional 3 min. Next the quantity (weight) of distilled water contained between the two gage marks is determined. The corresponding volume of this quantity of water, adjusted to a temperature of 60 F, should be 1.000 ± 0.05 per cent.

(*b*) A Stillman-type portable cubic-foot standard is calibrated by comparison with an immersion-type cubic-foot bottle. The calibration involves adjusting the stroke of the bell so that as 1 cu. ft. of air is transferred from the bottle, or the reverse, the pressure within the system does not change, provided the temperature of the entire system is maintained constant. This requires that the test should be made in a room in which the temperature can be maintained constant and uniform within less than 0.5 F. Moreover, to diminish the cooling effects of evaporation from the surfaces of the bottle and bell, the sealing fluid should be a light, low-vapor pressure oil. Other observations forming a part of this calibration are those of the time intervals required for raising the bottle and bell from their respective tanks and the intervals they are held up for drainage to take place before pressure readings are made. From these times, corrections are determined for the volumes of undrained liquid.

(*c*) Burets, flasks, etc., are considered a part of the analytical apparatus in which they are used, and methods of calibrating them therefore are not covered here (Note 2).

NOTE 2.—An outline of such methods is given in National Bureau of Standards *Circular C434*, "Testing of Glass Volumetric Apparatus," by E. L. Peffer and Grace C. Mulligan.

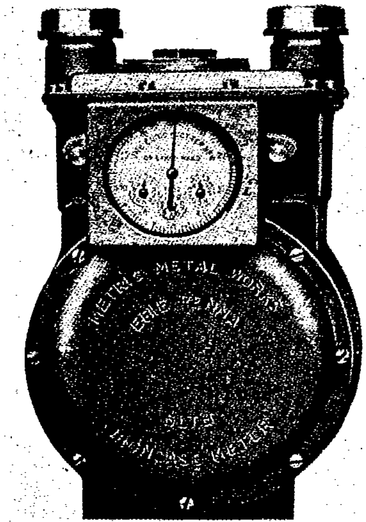


FIG. 4.—Iron-Case Diaphragm-Type Gas Meter with Large Observation Index.

Calibration of Secondary or Working Standards (Provers), General Considerations

12. (*a*) Gas meter provers of 2-, 5-, and 10-cu. ft. capacity customarily are calibrated by comparison with a cubic-foot bottle or standard as described in Sections 13 and 14. The procedure consists of measuring air out of or into the prover by means of the standard, 1 cu. ft. at a time, noting the reading of the prover scale at the start and finish of each transfer. Some general considerations to be observed are given in the following Paragraphs (*b*) and (*c*).

(*b*) Provers should be located in a well-lighted room provided with some degree of temperature regulation. It is desirable that this regulation should be adequate to maintain the temperature within plus or minus 2 F. of the desired average temperature. The prover tank should be raised from the floor by legs or blocks as this not only reduces the lag between the prover and room temperatures but decreases the accumulation of moisture on the underside of the tank. If water is used as the sealing fluid in the provers, the relative humidity within the room should be maintained as high as possible. However, it is recommended that the sealing fluid used in provers (and in cubic-foot bottles and standards also) should be a light oil with a low vapor pressure.

NOTE 1.—The use of oil as a sealing fluid will decrease the cooling effect due to evaporation, when the prover bell is raised from the tank, and will also retard any tendency of the bell to corrode.

NOTE 2.—These requirements will be met by an oil having an open cup flash point over 310°F and a Saybolt Universal viscosity less than 100 seconds at 100°F. (Commercial No. 2 Paraffin Oil usually meets these requirements.)

(*c*) Before starting a calibration the bell should be examined to see that it is clean and free of dents. It should move freely throughout its entire travel with neither binding nor excessive play within its guides at any position. To facilitate reading the prover scale to one decimal place beyond that normally used when testing meters, the regular scale pointer may be replaced with a short auxiliary scale covering a 0.2-cu. ft. interval of the main scale. This scale should be divided into 10 or 20 divisions, and mounted so that its mid-point will be at about the same elevation as the regular pointer.

Calibration of Provers by Means of an Immersion-Type Bottle

13. (*a*) While it is possible to measure air out of a prover into an immersion bottle under the usual prover pressure, it is difficult not to lose some air as the lower neck of the bottle is raised close to the surface of the sealing fluid in its tank. Therefore, it is advisable to make the test at atmospheric pressure. This requires increasing the counterweights until they just balance the bell. This adjustment is necessary if air is to be measured *into* a prover from an immersion bottle.

(*b*) Starting with the prover bell raised and the connection between prover and bottle open, adjust the position of the prover bell to zero scale reading. Raise the bottle, thereby drawing air into it from the prover. As the lower neck of the bottle reaches the surface of the sealing fluid, proceed carefully so as to stop just short of breaking the seal, and close the valve between prover and bottle. Observe and record the scale reading. Vent the air in the bottle as it is again lowered into the tank. Open the valve between prover and bottle, adjust the prover bell to a scale reading of 1.00, and repeat the process of removing another cubic foot of air from the prover.

(*c*) In measuring air into the prover, reverse the procedure just described. In this case, adjust the prover bell to a scale reading at one of the even foot marks, and hold it there while lowering the bottle until the bottom of the lower neck just meets the surface of the sealing fluid. Release the prover bell and measure a cubic foot of air into it by lowering the bottle.

Calibration of Provers by Means of a Moving-Tank Type of Bottle or a Stillman-Type Portable Cubic-Foot Standard

14. (*a*) With either a moving-tank type of bottle or a Stillman-type portable cubic-foot standard the calibration may be carried out under the usual prover pressure. This requires, when using a moving-tank type of bottle, that the valves in the connections between the bottle and prover shall be open while adjusting the quantity of water in the tank and the positions of the stops so that the water will come to rest in the planes of the gage marks about the upper and lower necks of the bottle. Also, since the transfer of air to or from the prover takes place within a completely closed system, there is no possibility of losing a small amount of air at one end of the transfer, as with an immersion-type bottle.

TABLE II.—SAMPLE DATA SHEET FROM CALIBRATION OF GAS METER PROVER.

Serial No. 272 Date: April 30, 1947

Scale Interval	Prover Scale Readings		Difference of Scale Readings	Delivery Capacity of Interval	Temperatures		
	Start	Stop			Room	Standard	Prover
0 to 1	0.000	0.991	0.991	1.009	81.9	82.0	82.7
	1.000	0.008	0.992	1.008			
	0.000	0.992	0.992	1.008			
	1.000	0.008	0.992	1.008			
1 to 2	1.000	1.999	0.999	1.001			
	2.000	1.006	0.994	1.006			
	1.000	1.998	0.998	1.002			
	2.000	1.005	0.995	1.005			
to 3	2.000	3.003	1.003	0.997			
	3.000	2.000	1.000	1.000			
	2.000	3.005	1.005	0.995			
	3.000	1.999	1.001	0.999			
3 to 4	3.000	3.998	0.998	1.002			
	4.000	3.008	0.992	1.008			
	3.000	3.996	0.996	1.004			
	4.000	3.007	0.993	1.007			
4 to 5	4.000	4.999	0.999	1.001	81.9	82.7	83.0
	5.000	4.003	0.997	1.003			
	4.000	4.999	0.999	1.001			
	5.000	4.002	0.998	1.002			
0 to 1	0.000	0.991	0.991	1.009			
1 to 2	1.000	1.996	0.996	1.004			
2 to 3	2.000	3.001	1.001	0.999			
3 to 4	3.000	3.997	0.997	1.003			
4 to 5	4.000	4.999	0.999	1.001			

(*b*) The procedure followed with either type of standard is very simple. After the connections have been checked for leaks, and with the valves between prover and standard open, bring an even foot mark on the prover scale in line with the index zero. Transfer a cubic foot of air to the standard, and note and record the prover scale reading. Discharge the air in the standard from the system and repeat the cycle.

(*c*) If so desired, several transfers each may be made for the same 1-cu. ft. interval of the prover scale before going on to the next interval. In doing this the prover scale reading should be readjusted to the even foot mark before a transfer in either direction is started, being careful to have the connection between prover and standard open so that both are under the full prover pressure.

NOTE: *Example.*—The observations and calculations involved in the calibration of a 5-cu. ft. gas meter prover with a Stillman-type standard are shown in Table II. The average delivery capacities of the 0 to 1 and 1 to 2-cu. ft. intervals, from the five determinations on each interval, are 1.008 and 1.004 respectively. This means that if a correctly adjusted gas meter is tested against the 0 to 2-cu. ft. interval, the final prover scale reading would be 1.99.

Calibration of Large Provers

15. The method to be used in calibrating gasometers of over 10-cu. ft. capacity will depend upon the capacity, design, and mode of operation of the gasometer. If it is not too large (100 cu. ft. or less) it may be most convenient to use a cubic-foot standard or a 5- or 10-cu. ft. prover that has been calibrated. For other gasometers it will probably be necessary to determine the capacity from a measurement of the dimensions. The procedure usually followed is to measure the outside circumference of the prover bell at several sections. From these measurements and the metal thickness, the average inside cross-sectional area and capacity per unit height are computed. In making this calculation it may be necessary to take account of changes of the sealing fluid height produced by raising and lowering of the bell.

Calibration of Small Water-Sealed Rotating Drum Meters, Especially for Use with Water-Flow Calorimeters (General Considerations)

16. (*a*) The objective of the calibration of a rotating-drum gas meter may be:

(*1*) To establish that relative elevation of the sealing water (that is, the amount of sealing water) with which the meter will indicate correctly (for example, within 0.2 per cent) the volume of gas, at the outlet conditions, that passes through it, or

(*2*) With a given quantity of sealing water, to determine the factor (calibration factor) by which the indications of the meter are to be multiplied to give the correct volumes of gas, at outlet conditions, that have passed through the meter.

(*b*) The two procedures described in Section 18 are intended for the routine calibration of a 0.1-cu ft wet test meter that is to be used in conjunction with a water-flow calorimeter in the determination of the heating valve of a fuel gas. Furthermore, it is recommended that these calibrations be made with the meter in the position in which it will be used in the calorimetric determinations. When the conditions under which the meter will be used are such that the rate of flow through the meter will be less than 8 cu ft per hr the procedure described in Section 18(*a*) to (*c*), using a 0.1- cu ft bottle, may be followed. If the rate of flow through the meter, when in use, will exceed 8 cu ft per hr, the aspirator method of calibration described in Section 19 should be followed.

(*c*) The average rate of flow at which the calibration is performed should be adjusted and maintained as nearly as possible the same as that at which the meter will operate when in use. In no event should the difference between the test rate and the use rate exceed 30 per cent of the use rate. This is because the volume of gas delivered per revolution of a liquid-sealed rotating-drum meter increases slightly with increasing rate of flow. In this connection it may be noted that by proper adjustment of the rate during calibration the aspirator procedure may be followed when the meter is to be used at rates below 8 cu ft per hr.

(*d*) The calibration procedures are applicable when either fuel gas or air is used as the testing medium. If gas is used, the discharge from the meter must be vented or burned. If air is used, the meter water must be resaturated with gas prior to its use in subsequent calorific value tests.

(*e*) When the purpose of the test is to determine the correct amount of sealing water for the meter (see Paragraph (*a*) (*1*)) and this has been done by one of the test procedures described in Section 18, bring the metering drum to a position about midway between two of the seal-off positions, preferably with the long index hand nearly over the large dial zero, and open both the inlet and outlet of the meter to atmosphere; without altering the leveling adjustment of the meter, set the water level gage to the height of the bottom of the water meniscus in the gage glass.

If the gage is the yoke type, the plane of the yoke top should coincide with that of the bottom of the meniscus. If the gage is the pointer type, start with the tip *below* the water surface and raise it until the tip appears to just meet its image in the water surface as viewed from below. Lock the gage in the position thus determined so that it may be used for checking the proper quantity of water in the meter before each subsequent use of the meter.

(*f*) When the purpose of the test is to determine a calibration factor to be used in conjunction with a predetermined amount of sealing water (see Paragraph (*a*) (*2*)), it is usually convenient to set the surface of the sealing water to the last position of the water-level gage. In this case, the position of the metering drum should be adjusted as prescribed in Paragraph (*e*), and add water to the meter until its surface is slightly above the gage. Then *very* slowly (a drop at a time) withdraw water until, with a yoke-type gage, the bottom of the water meniscus in the gage glass is in the plane of the top of the gage yoke. If the gage is the pointer type, withdraw water until the reflection of the point, as viewed from slightly below, appears to just touch the tip of the gage point.

Preparation of Test Assembly for Calibration of Small Water-Sealed Rotating-Drum Meters

17. (*a*) The essential items of equipment and the connections between them are shown diagrammatically in Figs. 5 and 6. Where the installation is to be maintained in a permanent location, some of the connections may be made with metal tubing. All other connections, and especially the flexible connections, should be made with a synthetic tubing, such as neoprene or Tygon, of appropriate size and strength.

(*b*) If possible, the meter and calibration equipment (and the flow calorimeter also) should be located in a temperature-regulated room. Where such a room is not available the equipment should be in a location protected from drafts, direct sunlight, and the direct effects of radiators or heaters. In no case should the following temperature differences be exceeded:

	Permissible Variation from Room Temperature
Meter water temperature	±1.0 F
Reservoir water temperature	±1.0 F

The saturator water should be within a few degrees (2 or 3 F) of room temperature, and preferably on the high side.

(*c*) Carefully examine the meter to be tested for any outward signs of damage. The drum should rotate freely without binding at any position. The water-level gage glass should be clean, or if necessary it should be cleaned with soap or alcohol and rinsed thoroughly. If the water-level gage is of the central pointer type, see that its tip is clean and sharp. The leveling screws in the meter base should be straight and turn freely but not loosely. The spirit levels (or level) should be so mounted on the top of the meter case that once in place their positions relative to the meter case cannot be altered.

(*d*) If the meter had been emptied, fill it with clean water (preferably distilled water) to slightly above the gage mark. Check for any water leakage, especially around the lower end of the gage glass and the front bearing of the drum shaft. Level the meter by means of the adjusting screws in the feet and by reference to the spirit levels on the meter.

(*e*) When a water-sealed rotating-drum meter is in operation the surface of the water in the gage glass rises and falls noticeably four times during each revolution of the drum (and of the large hand of the meter index). These fluctuations occur as one drum compartment seals off and another unseals to the outlet. With many of these meters, particularly the 0.1-cu ft per revolution size, the large index hand is mounted directly on the drum shaft. With other sizes this hand is geared to make an even multiple or submultiple of turns with respect to the drum. The position (azimuth) of the hand on its shaft should be such that the hand will pass the zero of its dial nearly midway between two fluctuations of the water surface in the gage glass. If it does not do this, loosen the lock nut by which the hand is secured and shift the position of the hand as may be needed; then tighten the lock nut. If possible the relative position of the hand on the shaft should be marked so that it may be reset in the same position in case it becomes loose or displaced during subsequent handling of the meter.

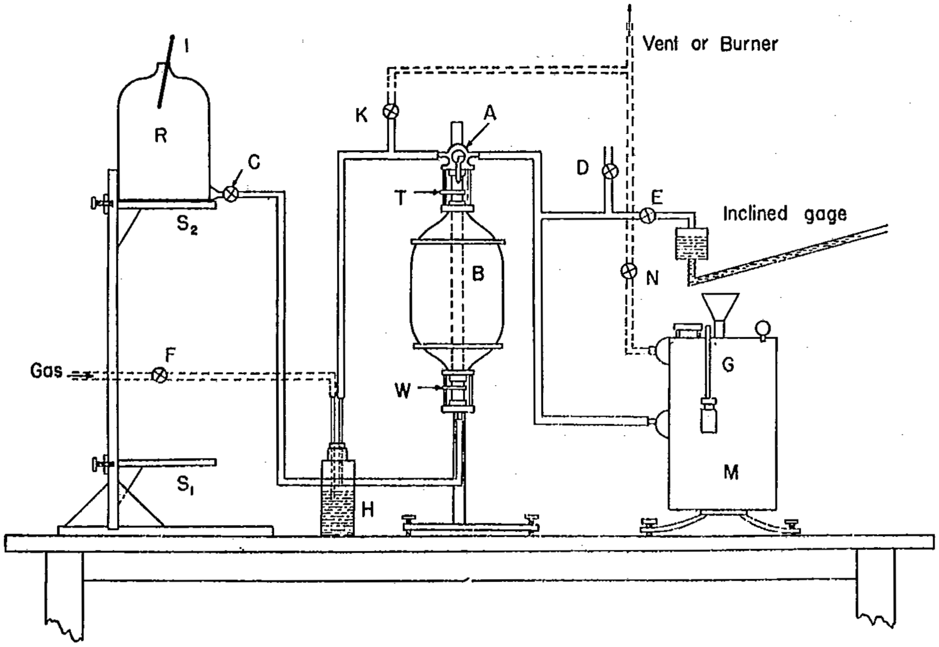
(*f*) If the water in the meter has been changed, or water is added to the meter, it should be saturated (or partially saturated) with air or gas, whichever is to be used in the test. This may be done by operating the meter with air or gas for three or more revolutions.

(*g*) A check for leaks in the connections may be made as follows: Referring to Fig. 5, turn cock *A* to connect bottle *B* to meter *M*. Close cocks *D*, *E*, *C*, and *N*, and place reservoir *R* on shelf S_2 (Note). Open cock *C* slowly while observing the water in the manometer of the meter. When the pressure in the system forces the water in the manometer to its limit, close cock *C* and read the manometer. If after 5 min the manometer reading has not changed, the system is free of leaks.

NOTE.—If the test is to be made with air, the meter outlet may be closed with a stopper.

(*h*) Occasionally, when leakage is indicated that cannot be located externally, it may be necessary to check for leaks in the meter drum, and this may be done in the following manner. First calibrate the meter at the normal rate as described in Section 18. Then repeat the calibration with cock *C* partly closed so that it requires 10 to 12 min for the transfer to be made. If the slow calibration does not differ from the first by more than 0.001 cu ft there is probably no leak in the drum.

(*i*) The modifications to this procedure where the aspirator method is used (see Fig. 6) would be: Close off the inclined gage, as with a pinch clamp, and also the inlet to the meter. Withdraw water from the aspirator bottle, *A*, until the meter manometer is near its limit, in this case a negative gage



NOTE.—Dotted lines indicate additional connections when gas is used. In this case it may be preferable to attach the inclined gage to the meter outlet.

FIG. 5.—Schematic Diagram of Equipment and Connections for Calibration of a 0.1-cu ft Wet Test Meter with a 0.1-cu ft Bottle.

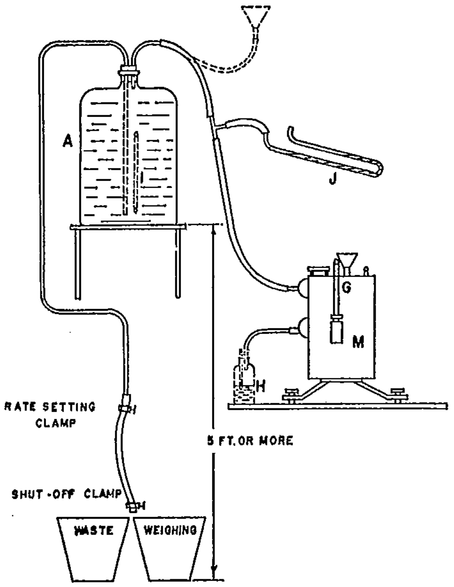


FIG. 6.—Simple Equipment for Calibration by Aspirator Method.

pressure. The procedure from this point would be the same as already described.

Calibration of Small Water-Sealed Rotating-Drum Meters by Means of a 0.1-cu ft Bottle

18. (*a*) *Adjusting Water Level.*—Adjust the water level in the reservoir and bottle system as follows:

(*1*) Vent the bottle to atmosphere by setting cocks *A* and *D*.

(*2*) Place reservoir *R* on self S_2 and observe the water level at gage *T*. Add or remove water to bring the level exactly to the gage mark.

(*3*) Close cock *D* and shift cock *A* to connect the bottle to the saturator *H* (if gas is used in the test, open cock *F* part way). Move the reservoir from shelf S_2 to shelf S_1.

(*4*) When the water level passes gage *W*, again bring the bottle to atmospheric pressure through cocks *A* and *D*. Thirty seconds later, check the water level and if necessary adjust the position of shelf S_1 to bring the water level exactly to the plane of the gage.

(*b*) *Adjusting for Rate of Test:*

(*1*) With reservoir *R* on shelf S_1, set cock *A* to connect the bottle to the meter, with cock *D* closed, *E* open, and meter, outlet open (or cock *N* open). Close cock *C* and place reservoir *R* on shelf S_2.

(*2*) Open cock *C* and observe the time interval, in seconds, required for the meter hand to pass from 0.01 to 0.09.

(*3*) Divide 288 by the observed time interval. The quotient is the average calibration rate in cubic feet per hour. If this rate is within ±30 per cent of the rate at which the meter is to be used, no further adjustment for rate is necessary.

If, however, the rate is found to be more than 30 per cent higher than the desired rate, it may be slowed by placing a clamp on the hose between the reservoir and the bottle. Repeat the rate test with various adjustments of the clamp until the desired rate is obtained.

(*c*) *Calibration Procedure Using Air.*—If air is used as the testing medium, proceed with the calibration of the meter as follows:

(*1*) For starting, the reservoir should be on shelf S_1, cocks *C* and *E* open, cock *D* closed, and cock *A* set to connect the bottle *B* with saturator *H*. The meter hand should be at approximately zero.

(*2*) Read and record the room temperature, saturator temperature, meter temperature and barometric pressure,

(*3*) Close cock *C*, and move reservoir *R* to shelf S_1,

(*4*) Open cock *C*, reading and recording the time,

(*5*) Read and record the reservoir water temperature.

(*6*) Thirty seconds after the water appeared close to the lower gage marker, open cock *K*; shift cock *A* to connect the bottle *B* with the meter *M*, and open cock *D*,

(*7*) Move the meter hand from nearly zero to exactly zero and hold it there until the inclined gage reads zero, then close cock *D*. Record the meter reading (zero).

(*8*) Quickly transfer reservoir *R* to shelf S_2,

(*9*) Note and record the meter water temperature.

(*10*) After the water has come to rest in the upper gage glass at or close to gage marker *T*, force the meter hand so as to produce zero reading on the inclined gage. Then read and record the reading of the meter hand.

(*11*) While still holding the meter hand to produce zero reading of the inclined gage, again turn cock *A* to connect bottle *B* with the saturator, and close cock *K*.

(*12*) Close cock *C* while moving the reservoir to shelf S_1 and then open cock *C*.

(*13*) Read and record the time when the water appears in the lower gage glass close to the gage marked *W*. Open cock *K*. Read and record the reservoir water temperature.

(*14*) Thirty seconds after the water was approximately at the lower gage marker, turn cock *A* so that the bottle *B* is isolated from both saturator and meter. Close cock *C* and replace reservoir *R* on shelf S_2. The meter hand should be at the same reading as in Step (*11*).

(*15*) Turn cock *A* to connect bottle *B* with meter *M*, and then open cock *C*.

(*16*) Repeat Steps (*9*) through (*15*) until the meter has completed four or more revolutions.

(*17*) Divide the difference between the final and initial meter reading by the number of revolutions. The result is the indication of the meter for 0.1 cu ft of air (or gas) as delivered by the bottle.

NOTE 1: *Example.*—Let us assume that the bottle temperature was 71.0 F, the meter temperature 70.2 F, and the meter indication 0.0999. Taking the pressure at the meter outlet as the "metering pressure" gives, in this case, $p_m = p_b = 29.70$ in. of mercury. Then the indication of the meter adjusted to the bottle temperature would be as follows:

$$0.0999 \times \frac{459.7 + 71.0}{459.7 + 70.2} \times \frac{29.70 - 0.74}{29.70 - 0.76} = 0.1001$$

NOTE 2.—The effect of using 460 in place of 459.7 in this relation will be less than 1 part in 20,000 in most cases.

NOTE 3.—As provided by the instructions, the observed temperatures should not differ by more than 1 F. On the other hand, if the difference is 0.3 F or less, no adjustment need be made because the effect will be less than the smallest amount to which the meter reading can be estimated.

(*18*) If the objective of the calibration is to make the meter indication per revolution correspond as nearly as possible to the delivery capacity of the standard bottle, that is as nearly 0.1000 as possible, then if the value obtained by Step (*17*) differs from 0.1000 by more than 0.0002 adjustment should be made to the quantity of sealing water in the meter. Changing the quantity of sealing water in the meter by 10 ml ($\frac{1}{3}$ oz) changes the capacity of the meter per revolution by about 0.0002 cu ft.

(*19*) When the object of the test is to determine the calibration factor by which the indications of the meter (as previously adjusted) should be multiplied in order to obtain the true volume (in terms of the volume of the bottle), the first step is to adjust the meter indication for any observed temperature difference between the bottle and meter using the method just described. Then the required correction factor will be equal to one tenth of the reciprocal of the adjusted meter indication.

NOTE 4: *Example.*—Assume that the meter indication, after adjustment, as shown above, for any temperature difference between bottle and meter is 0.0991. Then the meter correction factor is

$$0.1 \times \frac{1}{0.0991} = 1.0091$$

(*d*) *Calibration Procedure Using Gas.*—If gas is used in the calibration of the meter, the additional connections indicated by dotted lines in Fig. 5 will be needed. Also several of the steps will be modified as follows:

(*1*) For starting, the reservoir should be on shelf S_1; cock C open; cocks D, E, F, and K closed; and cock A set to connect the bottle B with saturator H. The meter hand should be approximately at zero.

(*2*) Read and record room temperature, saturator temperature, meter temperature, and barometric pressure.

(*3*) Close cock C and place the reservoir on shelf S_1.

(*4*) Open cocks C and F as nearly simultaneously as possible.

(*5*) As soon as water appears in lower gage glass, close cock F and open cock K. Note and record the (approximate) time when the water passed the lower gage mark W. Read and record reservoir water temperature.

(*6*) Thirty seconds after the water passed the lower gage marker, shift cock A to connect the bottle B with meter M, and open cocks D and E.

(*7*) to (*11*) Proceed as directed in Paragraph (*c*), Steps (*7*) to (*11*).

(*12*) Close cock C while moving reservoir to Shelf S_2, then open cocks C and F as nearly together as possible.

(*13*) Same as Step (*5*) in this paragraph.

(*14*) Continue in accordance with Paragraph (*c*), Steps (*13*) to (*19*).

Calibration by the Aspirator or Weighed-Water Method

19. (*a*) A simple and accurate method of calibrating laboratory meters is that of displacement, using an aspirator bottle. Inexpensive equipment for this method is shown in Fig. 6. The volume of gas drawn through the meter for a given number of revolutions of the index is calculated from the corresponding weight of water displaced from the bottle.

(*b*) Before starting a calibration, the system should be operated through several cycles of emptying and filling the bottle so as to bring the temperatures of all parts as close together as possible. To do this, open cock B and allow the water to drain from the bottle into a suitable container; this draws air through the humidifier and meter and into the bottle. To return the water to the bottle, open the connection between bottle and meter by disconnecting it (or by opening a cock); then with length of rubber tubing and funnel, shown in dotted lines in Fig. 6, the water can be returned to the bottle. The same water should be used as this will help equalize temperatures.

(*c*) When temperatures are as nearly uniform as it seems possible to attain, set the water discharge tube or diverter to discharge water into a waste bucket and open cock B. As the index of the meter passes through the zero position, shift the discharge tube (or diverter) to allow water to run into the weighing bucket. After the index of the meter has made the desired number of revolutions, shift the discharge back to the waste bucket just as the index passes through the zero position. Close the cock B. Calculate the volume of air which passed through the meter into the bottle from the weight of water displaced.

TABLE III.—SAMPLE DATA SHEET FOR CALIBRATION OF METER WITH AN ASPIRATOR BOTTLE.

Time	(Start)	2:54:38	(End)	2:59:17
Meter reading, cu. ft.	(Start)	26.6000	(End)	26.9000
Room temperature, deg. Fahr.				77.7
Meter temperature, deg. Fahr.				78.4
Bottle temperature, deg. Fahr.				77.4
Gas pressure at meter inlet, inches of water				1.42
Gas pressure in bottle, inches of water				1.10
Weight of water, lb.				18.6974
Calculations:				
Weight of water at 77.4 F., lb.				18.6974
Correction for buoyancy = 18.6974×0.00106				+0.0198
Correction for density of water at 77.3 F. to density at 39.2 F. = $18.6974 \times \left[\frac{1.00000}{0.99703} - 1\right]$				+0.0557
Correction for temperature difference = $18.6974 \times \left[\frac{459.7 + 78.4}{459.7 + 77.4} - 1\right]$				+0.0348
Correction for pressure difference[a] = $18.6974 \times \left[\frac{(29.92 + 0.0737) \times (1.10 - 0.948)}{(29.92 + 0.0737) \times (1.42 - 0.980)} - 1\right]$				+0.0051
Corresponding weight of water at maximum density				18.8128
Equivalent volume, cu. ft.				0.3014
One revolution of index				0.1005

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[a] 0.0737 = conversion factor, inches of water to inches of mercury,

$$\frac{(0.948)}{0.980} = \frac{\text{vapor pressure, inches of mercury, bottle}}{\text{vapor pressure, inches of mercury, meter}}$$

NOTE 2: *Example.*—An example of the observations and calculations involved in such a test is shown in Table III.

The above example was taken from the National Bureau of Standards Technologic Paper 36, p. 37. The same result is obtained by converting to volume after applying the buoyancy correction and multiplying the result by $\frac{F_b}{F_m} - 1$ where F is the correction factor for gas volume, subscript b refers to the bottle, and subscript m refers to the meter.

Accuracy of Laboratory Wet Gas Meters and an Evaluation of the Methods of Calibration

20. (*a*) The smallest division of the main dial of a wet test meter such as is shown in Fig. 3 represents 0.001 cu. ft. It is customary practice to estimate the meter reading to $\frac{1}{10}$ of these divisions, or 0.0001 cu. ft. However, one can hardly claim an accuracy of this last estimated figure better than plus or minus 1, which is equivalent to an uncertainty of plus or minus 0.1 per cent of the volume represented by a single revolution of the large hand.

(*b*) There are two other important sources of variation or uncertainty in the indications of these meters. One of these is the mechanical condition of the meter. Of course it is usually assumed that the meter is or should be in good mechanical condition. But even when this condition appears to be satisfied, it has been noticed that a slight longitudinal movement of the shaft in its bearings may cause a change in the meter indication of 0.2 to 0.5 per cent, and of course excessive dryness or tightness of the front bearing packing will cause irregular operation.

(*c*) The other source of variation is that of the observer. As a measure of this variation, several experienced observers were asked to level and adjust the quantity of sealing water in a meter. After each such adjustment, the meter was calibrated by an aspirator method. The maximum spread between these calibrations was 0.46 per cent and the average difference was plus or minus 0.1 per cent. As a result of these several factors, it is concluded that, on the average, the recorded indications of these meters are subject to an uncertainty of about plus or minus 0.2 per cent.

Calibration of Large Water-Sealed Rotating-Drum Meters

21. Water-sealed rotating-drum gas meters, registering 1 cu. ft. or more per revolution of the main index hand, may be tested with a cubic-foot bottle of the moving-tank type. The procedure will be similar to that described in Section 18 for the calibration of the 0.1 cu. ft. meter. The aspirator method may be used also, provided the aspirator tank has sufficient capacity, at least 1.5 cu. ft., to allow for starting and stopping. Finally, if the accuracy requirements of the meter are not too high, the test may be made with a gas meter prover. However, to keep the rate of flow within the meters operating range and to avoid blowing the seal, it will be necessary to increase the counterweights of the prover bell, or to regulate the rate by a valve placed on the meter outlet.

Calibration of Small Dry Diaphragm Meters

22. (*a*) Connect the meter to a prover, using the proper size of hose coupling, and by opening the prover valve pass a small amount of air (or gas) through the meter to ensure that it is operating properly. Test for tightness of the connections and the soundness of the meter by closing the meter outlet and opening the prover valve, thus applying the full prover pressure to the meter and connections. Keeping the meter outlet closed, close the prover valve and observe the pressure gage. If the pressure falls, there is a leak either in the connections or the meter case that must be stopped before proceeding with the test.

(*b*) Place the proper cap on the meter outlet to allow air (or gas) to pass at about one fifth the rated capacity of the meter. By manipulation of the prover valve, bring the meter test hand in line with one of the divisions of its dial (preferably on its upward swing) and close the valve. Fill the prover with air (or gas) and set to zero scale reading. Open the prover valve allowing air (or gas) to pass through the meter until the test hand makes exactly one revolution, closing the valve quickly. Note and record the prover scale reading to the nearest 0.01 cu. ft.

(*c*) Calculate the meter correction and the meter "proof" as follows:

Correction to meter reading, per cent =

$$\frac{A - B}{B} \times 100$$

Percentage error (meter "proof") =

$$\frac{B - A}{A} \times 100$$

where:

A = prover reading, and

B = meter reading.

(*d*) Gas meters are ordinarily tested at two rates of flow, which are approximately one fifth rated capacity and full rated capacity. Prover pressures are ordinarily adjusted to 1.5 in. of water. The number of cubic feet required to cause one revolution of a meter test hand is 1, 2, 5, or 10, depending on the size of the meter and type of index.

(*ASTM Section 23 not included.*)

NOTE.—More detailed discussions of gas meter testing are given in the report of the 1920 Consumers' Meters Committee of the American Gas Association, Proceedings of the Second Annual Convention, and the report of the 1930 Subcommittee on Meters, Distribution Committee, American Gas Association.

Calibration of Rate-of-Flow Meters

24. (a) The method selected for the calibration of a gas meter of the rate-of-flow type will depend largely upon the mode of operation and size or capacity of the meter. For example, a small rate-of-flow meter of the float and tapered tube type may be calibrated by passing air through it from or into a prover. The flow is adjusted to give a desired reading of the meter and the time interval for a convenient number of cubic feet intervals on the prover scale to pass the index mark is obtained with a stopwatch, or some other more accurate means of measuring the time interval. Other data that should be recorded are the pressure and temperature of the air in the prover and at the inlet. Also, it may be desirable to determine the relative humidity of the air. With these data it will be possible to calculate the mass or volume rate of flow referred to any specified set of conditions.

(*b*) A small orifice meter or a flowmeter of the capillary tube type may be calibrated in much the same way as described in Paragraph (*a*). In this case, it will be necessary to measure the static pressure on the inlet side of the orifice or capillary tube and the pressure drop across it. From the pressure and temperature (and humidity) the density of the fluid (air and moisture) entering the orifices and the "flow coefficient" of the orifice may be calculated as follows:

$$\rho_1 = 1.3273 \frac{p_1 - 0.378e}{459.7 + t}$$

$$Q_1 = 0.0997\, K D_2^2 \sqrt{h/\rho_1}$$

$$w = 0.0997 K D_2^2 \sqrt{h\rho_1}$$

where:

D_2 = diameter of the orifice, in.

e = pressure of water vapor at the temperature and relative humidity of the air, in. Hg

h = pressure drop across orifice, inches of water,

K = orifice flow coefficient (a ratio),

p_1 = absolute pressure at the orifice inlet, in. Hg

t = temperature of the air (usually at the orifice inlet), °F

Q_1 = actual volume rate of flow at orifice inlet conditions as calculated from the prover observations, cubic feet per second,

w = actual mass rate of flow as calculated from the prover observations, pounds per second,

ρ_1 = density of the fluid (air and moisture) at the orifice inlet, pounds per cubic foot.

(*c*) If the rate of flow is subject to variations such that the differential pressure, *h*, will vary by more than 3 in. of water from the value at which *K* was determined, several values of *K* corresponding to different values of *h* should be determined. These may be plotted against *h*, or better against h/p_1.

NOTE 1.—For a more complete treatment of the calibration and use of rate-of-flow meters, reference should be made to Bibliography References (2) and (3).

NOTE 2.—For the application of rate-of-flow meters, particularly orifice meters, to the commercial metering of fuel gases, see Bibliography Reference (4).

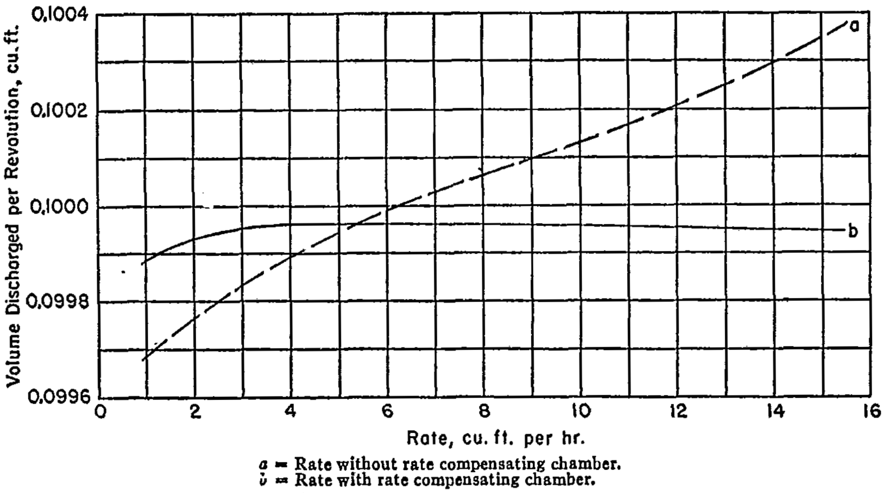

FIG. 7.—Calibration Curves of a Wet Test Meter Without and With a Rate Compensating Chamber.

APPENDIX

RATE COMPENSATING CHAMBERS FOR LIQUID-SEALED ROTATING-DRUM METERS

From the curve in Fig. 7, it is seen that the volume discharged per revolution by a wet gas meter increases as the rate of flow increases. This change with rate may amount to as much as 1 per cent over the operating range of the meter. The explanation for it is that the increase in the rate of flow through the meter is accompanied by (or is caused by) an increase in the pressure drop through the metering drum. This increase in the pressure drop through the meter drum depresses the surface of the water within the measuring compartments as they are filled with gas, thereby increasing the volume of gas that the drum will contain per revolution.

This change in the elevation of the water surface within the metering compartment with change in rate of flow may be diminished or completely compensated for by attaching to or incorporating within the meter case an auxiliary water compartment of a special cross-sectional shape. There is also a restricting orifice or tube placed in the inlet of the meter and so situated that the gas pressure within the auxiliary water compartment is greater than within the metering drum. This pressure difference increases as the rate of flow increases and causes water from the auxiliary compartment to be displaced into the main body of the meter in such amount as will maintain the surface of the water in the metering compartments at a constant elevation In this way the volume of gas discharged per revolution of the drum remains practically constant over the full operating range of the meter, as shown by Fig. 7. It may be noted that, in general, the pressure drop across the metering drum is less than half the total pressure drop across the meter, since the drop in the inlet tube was the larger part of the total. For this reason, the inclusion of the regulating orifice or tube does not increase the over-all pressure drop to any significant extent.

A complete description of this method of rate compensation is given in U. S. Patent No. 2321038, assigned to the U. S. Government.

VOLUMETRIC ANALYSIS OF FUEL GASES

The current ASTM Standard for volumetric analysis applies specifically to the analysis of natural gas. The same method may be applied to all gases in which hydrocarbons are the only fuel components provided the sample for analysis can be completely vaporized at atmospheric pressure and temperature.

In addition, the same methods, with slight extensions of the apparatus, can be applied also to the volumetric analysis of the other two classes of fuel gas with which this Code is concerned, those containing significant concentrations of other combustible constituents and high inert gases.

Since the latter gases may contain significant amounts of unsaturated hydrocarbons, carbon monoxide, and hydrogen, consideration must be given for their removal prior to the determination of methane and ethane by slow combustion in the normal procedure.

The unsaturated hydrocarbons are removed by the use of fuming sulfuric acid as described in the normal procedure (Paragraph 7c, page 29). Extension of the apparatus should include a pipette containing ammoniacal cuprous chloride, or one of the proprietary preparations such as "Cosorbent" for the removal of carbon monoxide. In addition, it will be necessary to estimate hydrogen from catalytic combustion on copper oxide or "Hopcalite" with subsequent determination of methane and ethane by slow combustion.

Standard Method for
ANALYSIS OF NATURAL GASES BY THE VOLUMETRIC - CHEMICAL METHOD

ASTM Designation: D 1136–53

Approved as USA Standard Z77.1–1955

(*Identical with ASTM Procedures*)

Scope

1. This method is intended for the analysis of natural gases when the complete composition is not required (Note). If more than two saturated hydrocarbons are present, the true composition is not given. Acid gases are determined as a group, unsaturated hydrocarbons as a group, and inert gases (nitrogen, helium, neon, argon) as a group. The data obtained by this method are usually sufficient for the calculation of heating value and specific gravity when the gas contains only small amounts of C_3 and heavier hydrocarbons. When the entire hydrocarbon content of a gas is calculated as methane and ethane only, the calculated heating value and specific gravity, as well as the composition, will be in error. The extent of this error depends on the partial pressures of the C_3 and heavier hydrocarbons in the gas. Thus, C_3H_8 is calculated as $2C_2H_6 - CH_4$, and the error in heating value is only 0.07 Btu. per cubic foot for each 1 per cent C_3H_8. C_4H_{10} is calculated as $3C_2H_6 - 2CH_4$, with an error of 0.54 Btu. per cubic foot per 1 per cent C_4H_{10}. Each 0.1 of propylene causes an error of 0.1 Btu. per cubic foot. (Usually no unsaturates, or only very small amounts, are found in a natural gas.) Calculated specific gravity is in error by 0.0008 for each 1 per cent propane, 0.0005 for each 0.1 per cent propylene, and 0.001 for each 1 per cent butane. From such considerations, it may be established when it is reasonable or unreasonable to use the analytical data for calculating these characteristics.

NOTE.—The determination of the complete composition of natural gas is covered in the Standard Method for Analysis of Natural Gases and Related Types of Gaseous Mixtures by the Mass Spectrometer (ASTM Designation: D 1137).[3] In selecting the method most suitable for the particular problem at hand, consideration should be given to the relative precision and accuracy obtainable by the mass spectrometer method[4] as compared to those indicated in Section 10 of this volumetric-chemical method.

Principle of Method

2. The method combines absorption and combustion methods. Acid gases, oxygen, and unsaturated hydrocarbons are absorbed; saturated hydrocarbons are burned with excess oxygen over hot platinum; and the contraction, carbon dioxide produced, and oxygen consumed are all measured.

Apparatus

3. The apparatus shall be of the conventional volumetric type in which volumes are made comparable by means of a pressure – temperature compensator with manometer interposed between the compensating tube and buret, the pipets are connected to the buret by a manifold, and mercury is used as the confining fluid.[5] The apparatus shall comply with the following detailed requirements:

(*a*) The apparatus shall be equipped with the following pipets placed in the following order, starting next to the buret and from thence outward:

(*1*) A simple bubbling or contact pipette containing KOH solution.

(*2*) A simple bubbling pipette containing fuming sulfuric acid.

(*3*) A distributing-tip bubbling pipette containing alkaline pyrogallol solution.

(*4*) A slow combustion pipette with platinum spiral.

(*5*) A simple bubbling pipette containing KOH solution.

(*6*) A distributing tip bubbling pipette containing alkaline pyrogallol solution.

The pipets shall be so designed that they will not trap gas on the return passage to the buret. They should be efficient enough to remove oxygen from the mixture in four to five passes, and CO_2 or unsaturated hydrocarbons in three passes. The slow combustion pipet must be free from all leaks when hot as well as cold.

(*b*) The buret shall be engraved with all marks extending slightly over halfway around the circumference, graduations corresponding to odd numbered milliliters three fourths of the way around, and graduations corresponding to even numbered milliliters completely around. The length of the graduated section (100 ml.) shall be about 60 cm., each 0.2-ml. interval to be separated about 1.2 mm. The buret should be calibrated by weighing mercury delivered between measured intervals and should be accurate within 0.1 ml. in 100 ml. over-all, and 0.02 ml. in 10 ml.

(*c*) The manometer shall present no significant error of capillarity and shall be connected so that the gas in the arm attached to the distributor can be displaced into the the distributor by using the monometric fluid as the confining fluid for this purpose.

(*d*) All connections preferably should be made with interchangeable, spherical, ground-glass joints. All stopcocks shall

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[3] See p. 1168.

[4] Martin Shepherd, "Analysis of a Natural Gas by Volumetric Chemical Methods and by the Mass Spectrometer," *Analytical Chemistry*, Vol. 19, p. 635 (1947).

[5] This apparatus complies with the requirements for type V_1R_1Hg apparatus as given in the report by Martin Shepherd on "Analysis of a Standard Sample of Natural Gas by Laboratories Cooperating with the American Society for Testing Materials," *Journal of Research*, Nat. Bureau Standards, Vol. 38, No. 1, January, 1947, p. 19. (*Research Paper RP1759*.)

be precision ground and free from leakage when properly lubricated.

(*e*) The volumetric reproducibility of the apparatus, as determined by actual measurement, shall be within 0.02 ml. on repeated measurement of a single portion of gas, or 0.05 ml. when three separate portions of gas are measured and thereafter combined and measured (see Section 6 (*b*)).

Reagents

4. (*a*) *Potassium Hydroxide Solution.*—Dissolve A.C.S. grade KOH sticks or pellets in distilled water until an excess of solid KOH remains. Cool this solution to about 3 C. below the lowest temperature that will exist in the pipet during analysis. Decant the clear solution for use.

(*b*) *Alkaline Pyrogallol Solution.*—To each 100 ml. of the KOH solution add 17 g. of reagent grade pyrogallol crystals, protect from air in a glass-stoppered reagent bottle, and place in a refrigerator to keep cool until the crystals are dissolved. This solution will generate no significant amount of CO.

(*c*) *Fuming Sulfuric Acid.*—A.C.S. grade fuming sulfuric acid containing at least 15 per cent free SO_3.

(*d*) *Ascarite* (or an equivalent CO_2 absorbent consisting of a 20- to 30-mesh inert base impregnated with NaOH) may occasionally be required for the accurate determination of small amounts of CO_2, and is used to remove SO_3 when the accurate determination of small amounts of unsaturated hydrocarbons is made.

Sampling

5. The sample shall be representative of the material being sampled and shall be taken from its source without change of composition. If rubber tubing is used at all, it must be used only to secure butt joints in glass or metal tubing. The sample shall be taken under slight pressure in a glass sampling pipet equipped with three-way stopcocks at each end, so that the sampling line may be thoroughly flushed before admitting the sample over mercury into the sampler and again after connecting to the buret. If sulfur gases (or oxides of nitrogen) are to be determined, the sample shall be taken directly into evacuated glass. The sample shall be stored only as long as absolutely necessary. The lubricant on the stopcocks of the sampler should be equilibrated with respect to the sample if C_3 and heavier hydrocarbons are present.

NOTE.—This sampling procedure is applicable only to gaseous samples.

Preparation and Standardization of Apparatus

6. (*a*) Test the assembled apparatus for leaks by applying approximately 15 cm. (6 in.) mercury gage positive, then negative pressure, and measuring any change in volume that may occur as one after another the sections of the apparatus are opened to the buret at 5- or 10-min. intervals. A total change of volume greater than 0.03 ml. indicates possible leakage.

(*b*) Determine the volumetric reproducibility of the apparatus as follows:

(*1*) Take approximately 90 ml. of air into the buret, balance the pressure, and read the volume. Destroy the balance, rebalance, and read again Make and record ten such measurements. Note the temperature of the water jacket.

(*2*) Raise the temperature of the water in the water jacket 2 C. and repeat the measurements made in step (*1*).

(*3*) and (*4*) Repeat steps (*1*) and (*2*) with approximately 30 ml. of air in the buret.

(*5*) Take three successive portions of about 30 ml. of air, measure each and transfer to the combusion pipet, then return and measure the combined volume of the three portions. Repeat this procedure three times. Record all data.

NOTE.—Tolerances on volumetric reproducibility are given in Section 3(*e*).

(*c*) Equilibrate the reagents with respect to the sample to be analyzed. This is best done by performing four analyses before making umpire or very important analyses. For usual work, equilibrate by making six passes into each reagent, using the gas that is to go into each reagent during the actual analysis.

(*d*) Wet the buret wall with a film of water by taking several milliliters of water into the buret and slowly expelling it.

(*e*) Flush the manifold, pipet inlets, and arm of manometer connected to the manifold with nitrogen, and balance to the reference (compensator) pressure.

Procedure for Absorption Analysis

7. (*a*) Transfer about 95 to 100 ml. of the sample to the buret without contamination, allow 3 min. to saturate the sample with respect to water if it is dry, and then adjust the pressure until the manometer indicates the sample is at the reference (compensator) pressure. Measure this volume, V_1, to the nearest 0.02 ml.

(*b*) *Removal of Carbon Dioxide or Acid Gases* (Note).—Displace the gas in the arm of the manometer connected to the distributor (manifold) into the buret, and then transfer the sample to the KOH pipet *1*. Return the gas to the buret and pass twice more into the KOH solution; then allow to stand 3 min. in the buret, balance the manometer, and measure the volume, V_2, to the nearest 0.02 ml.

(*c*) *Removal of Unsaturated Hydrocarbons* (Note).—Displace the gas from the manometer arm and pass twice in and out of pipet *2* containing fuming sulfuric acid, once into pipet *1*, then once again into pipet *2*, and twice into pipet *1*. Finally, measure the volume V_3 of the gas after standing 3 min. in the buret.

(*d*) *Removal of Oxygen* (Note).—Displace the gas from the manometric arm and pass twice into pipet *3* containing alkaline pyrogallol solution, once each into pipets *1* and *2*, and finally twice more into pipet *3*. Measure the residual volume, V_4.

NOTE: *Avoidance of Errors Caused by Physical Absorption.*—It is very important that the reagents be properly equilibrated with respect to the particular mixture brought into contact with them before trustworthy results are obtained. Reproducibility will serve as a guide to proper equilibration. Changes in temperature and pressure may alter equilibria; and overnight standing usually does, since the atmospheric arm of the pipet offers no real bar to the escape of dissolved gases, even though equipped with oil seal or rubber bag.

If the acid gases, oxygen, and the unsaturated hydrocarbons occur in small amounts—say less than 0.5 per cent—they are best determined in reaction tubes[6] rather than in pipets. Such tubes, in principle, form a part of the distributor,

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[6] Suitable reaction tubes are described by Martin Shepherd, "Modifications of Apparatus for Volumetric Analysis," *Journal of Research*, Nat. Bureau Standards, Vol. 26, No. 4, April, 1941, p. 354. (*Research Paper RP1382.*)

are about 8 to 10 cm. long and have a 5- to 6-cm. bore, and contain small amounts of reagents so that the appreciable errors of solubility are avoided. For example, a series of three tubes containing Ascarite (or equivalent CO_2 absorbent), 10 drops of fuming sulfuric acid on glass wool, and (again) Ascarite are ideal for removing traces of unsaturated hydrocarbons. A tube containing 20 drops of alkaline pyrogallol solution will yield better oxygen determinations than ordinarily obtained for a natural gas. Many of the oxygen determinations reported for natural gases have been significantly too high, and unsaturates are often reported when none are present. A small tube of Ascarite will suffice to remove CO_2 from such gases.

Procedure for Combustion Analysis

8. (*a*) Prepare nitrogen, for use as a transfer gas, by absorption of oxygen from uncontaminated air in pipet *6* containing alkaline pyrogallol solution. Flush the distributor with this nitrogen and balance to reference pressure; then measure about 40 ml. of the nitrogen, V_5, and transfer it for storage over the KOH solution in pipet *5*.

(*b*) Measure about 95 ml. of approximately pure and carefully analyzed oxygen, V_6, and transfer to the slow combustion pipet. Let V_7 represent the volume of the inert impurities in this oxygen.

(*c*) Measure a fresh sample, V_8, of gas for combustion analysis (about 35 ml., or less than 35 ml. when the proportion of heavier hydrocarbons is great). If the absorption analysis shows more than 0.2 per cent unsaturated hydrocarbons, pass this sample through fuming sulfuric acid before the combustion analysis. Adjust the pressure in the buret and slow combustion pipet to atmospheric, with the platinum wire glowing dull red; then open the combustion pipet to the buret and *slowly* pass the sample over the hot platinum spiral. Allow fully 15 min. for this first passage of sample into the combustion zone. When the sample has all left the buret, displace the gas from the manometer arm connected to the distributor and pass this into the combustion pipet. Then return the gas from the combustion pipet to the buret until the mercury is just under the platinum spiral, taking about 5 min. for this, and reverse the flow to return the gas to the combustion pipet. Three more complete passes to and from the buret should complete the combustion. On the last pass, allow the gas in the combustion pipet *to cool before returning to the* buret. Measure the residue, V_9.

NOTE.—No more than 0.1 ml. of water should be allowed to collect in the combustion pipet.

(*d*) *Removal of CO_2 Produced.*—Displace the gas from the manometer and pass three times from the buret into the KOH solution in pipet *5*, once into the combustion pipet, and once more into pipet *5*. Measure the residue, V_{10}.

(*e*) *Removal of Excess Oxygen.*—Displace the gas from the manometer and pass four times into pipet *6*, once into pipet *5*, once into the combustion pipet, and once again into pipet *6*. Measure the residue, V_{11}.

Calculations

9. (*a*) From the results of the absorption analysis (Section 7), calculate the percentages of carbon dioxide, unsaturated hydrocarbons, and oxygen present in the original sample, as follows:

Carbon dioxide (or acid gas), per cent

$$= \frac{V_1 - V_2}{V_1} \times 100$$

Unsaturated hydrocarbons, per cent

$$= \frac{V_2 - V_3}{V_1} \times 100$$

$$\text{Oxygen, per cent} = \frac{V_3 - V_4}{V_1} \times 100$$

where:

V_1 = volume of sample taken for absorption analysis,

V_2 = volume of sample after removal of CO_2 (acid gases),

V_3 = volume of sample after removal of unsaturated hydrocarbons, and

V_4 = volume of residual gas after removal of oxygen.

(*b*) Calculate the results of the combustion analysis (Section 8) as follows (Notes 1 and 2):

$$TC = V_6 + V_8 - V_9$$

$$V_{12} = (V_1 - V_2)\frac{V_8}{V_1}$$

$$V_{13} = (V_3 - V_4)\frac{V_8}{V_1}$$

$$CO_2 = V_5 + V_9 - V_{10} - V_{12}$$

$$O_2 = V_6 - V_7 + V_{13} - (V_{10} - V_{11})$$

$$N_2 = V_{11} - V_5 - V_7$$

$$CH_4\text{, per cent} = \tfrac{1}{3}\,[7\,(TC + CO_2) - 9\,O_2]\,\frac{100}{V_8}$$

$$C_2H_6\text{, per cent} = \tfrac{1}{3}\,[6\,O_2 - 4\,(TC + CO_2)]\,\frac{100}{V_8}$$

where:

TC = total contraction of sample upon combustion,

CO_2 = carbon dioxide produced by combustion of the sample,

O_2 = oxygen consumed,

V_1 and V_2 = values defined in Paragraph (*a*),

V_5 = volume of nitrogen taken as a transfer gas,

V_6 = volume of oxygen taken for combustion, the actual volume of pure oxygen being V_6 corrected,

V_7 = volume of inert impurities in the oxygen taken for combustion,

V_8 = volume of sample taken for combustion,

V_9 = volume of residual gas after combustion of sample,

V_{10} = volume of residue after removal of CO_2 produced by the combustion, plus the transfer nitrogen, and

V_{11} = volume of residue after removal of excess O_2, plus the transfer nitrogen,

V_{12} = volume of CO_2 originally present in the sample, and

V_{13} = volume of O_2 originally present in the sample.

NOTE 1.—If the sample has been passed through fuming sulfuric acid prior to the combustion analysis, results of the analysis shall be corrected to the basis of the original sample.

NOTE 2.—If propane or other hydrocarbons are present, the results will be in error. A full discussion of this is given in a report by Martin Shepherd.[7]

Accuracy

10. Since it is not possible to determine more than two saturated hydrocarbons by this method, and the errors caused by the presence of other hydrocarbons depends upon their identity and amounts,

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[7] See the report by Martin Shepherd on "Analysis of a Standard Sample of Natural Gas by Laboratories Cooperating with the American Society for Testing Materials," *Journal of Research*, Nat. Bureau Standards, Vol. 38, No. 1, January, 1947, p. 19 (*Research Paper RP1759.*)

no statement can be made concerning the actual accuracy of the method with respect to the hydrocarbons. Any C_3H_8 would be calculated as $2C_2H_6 - CH_4$; C_4H_{10} would be calculated as $3C_2H_6 - 2CH_4$; and so on. If C_3H_6 is present, the errors in CH_4 and C_2H_6 are indicated thus:

$CH_4 \rightarrow CH_4 - 2/3\ C_3H_6$, and $C_2H_6 \rightarrow C_2H_6 + 5/3\ C_3H_6$

The accuracy of determinations of other components and the precision of all can be estimated from the results of a cooperative study of this method.[7] The following table gives these estimations for some of the important components:

Gas	Probable Accuracy	Reproducibility	
		Different Laboratories and Apparatus	One Laboratory and Apparatus
Carbon dioxide, per cent.............	0.05	0.05	0.02
Oxygen, per cent...	0.1 to 0.2	0.1	0.03
Unsaturated hydrocarbons as a group, per cent...	...	...	0.01
Nitrogen, per cent..	0.6	0.6	0.1
Methane, per cent..	...	1.0	0.2
Ethane, per cent....	...	1.0	0.2

OTHER ANALYTICAL METHODS

Advanced methods are now available for the identification and measurement of the specific components that used to be lumped under the general designations of "saturated hydrocarbons" or "illuminants" in the volumetric-chemical methods. These methods require the use of specialized apparatus which usually is installed only in major laboratories. For important test programs, however, it may be necessary to secure the use of such facilities in order to obtain the significantly improved characterization of the fuel that their use makes possible. These methods include the use of the mass spectrometer and of gas chromatography.

In the mass spectrometer, a mixture of gases to be analyzed is discharged through a narrow aperture into a highly evacuated chamber. The gas is ionized and the individual ions passed through the chamber under the influence of a magnetic field, substantially without collision with other molecules, ionized or un-ionized. The magnetic field acts on the individual ions in such a way as to disperse their trajectories, so that the particles of least mass, i.e., lowest molecular weight, are deflected most from their original direction. Ions having the same mass-to-charge ratio have the same deflection. A suitable sensing element can be used to measure the intensity of the individual ion beams at each location in the spectrum. The location and relative intensities of the ion peaks in the spectrum permit identification and calculation of the relative concentrations of the individual molecular species in the original mixture. Automatic equipment is available for carrying out this process, so that the analysis becomes a matter of interpreting a graphical result furnished by the spectrometer.

Most fuel gases can be analyzed by the procedures given in ASTM D 1137-53, Standard Method for Analysis of Natural Gases and Related Types of Gaseous Mixtures by the Mass Spectrometer. For analysis of other gas mixtures follow the more restrictive procedures of ASTM D 1302-61 T, Tentative Method for the Analysis of Carbureted Water Gas by the Mass Spectrometer. The detailed procedures for analysis by mass spectrometer are not included in this Code because of the limited availability of this type of analytical equipment.

Standard Method for
ANALYSIS OF NATURAL GAS BY GAS CHROMATOGRAPHY

ASTM Designation: D 1945–64

Approved as USA Standard Z11.160–1964

(*Identical with ASTM Procedures*)

Scope

1. This method covers the determination of the complete chemical composition of natural gases and similar gaseous mixtures within the range of composition shown in Table I. The method may be abbreviated for the analysis of lean natural gases containing negligible amounts of hexanes and heavier hydrocarbons, or for the determination of one or more components, as required.

Summary of Method

2. Components in a sample of natural gas are physically separated by gas chromatography and compared to corresponding components separated under identical operating conditions from a reference standard mixture of known composition. The numerous heavy-end components of natural gas are grouped into irregular peaks by reversing the direction of the carrier gas through the column at such time as to group the heavy-ends either as C_5 and heavier, C_6 and heavier, or C_7 and heavier. The chromatogram is interpreted by comparing the peak heights of the pentanes and lighter components with those obtained on the reference standard. The total area under the reverse flow peak is compared to the area of the pentane peaks in the standard.

Apparatus

3. (*a*) *Detector.*—The detector shall be a thermal conductivity-type or its equivalent in sensitivity and stability. It must be sufficiently sensitive to produce a peak height on the recorder chart of at least 20 mm for 1 per cent *n*-butane in a 0.5-ml sample under conditions used for this analysis.

(*b*) *Recorder.*—A strip chart recorder with a full-scale range of 10 mv or less shall be required. A maximum full-scale balance time of 2 sec and a minimum chart speed of $\frac{1}{2}$ in. per min shall be required.

(*c*) *Attenuator.*—A multistep attenuator for the detector output signal shall be necessary to maintain maximum peaks within the recorder chart range. The attenuator must be accurate to 0.5 per cent.

(*d*) *Sample Inlet System.*—Provision should be made to introduce two sizes of sample ranging from 0.25 to 0.5 ml, and 2 to 5 ml, respectively. The sample volume must be reproducible such that successive runs agree within 1 mm or 1 per cent (whichever is larger) on each component peak height. Samples for determination of hexanes and heavier components must be entered from a fixed volume loop or tubular section of not less than $\frac{3}{16}$-in. inside diameter tubing.

TABLE I.—NATURAL GAS COMPONENTS AND RANGE OF COMPOSITION COVERED.

Compound	Concentration Range, mole per cent
Helium	0 to 5
Oxygen	0 to 10
Nitrogen	0 to 20
Carbon Dioxide	0 to 10
Methane	50 to 100
Ethane	0 to 20
Propane	0 to 20
Normal Butane	0 to 10
Isobutane	0 to 10
Normal Pentane	0 to 2
Isopentane	0 to 2
Hexanes and heavier	0 to 2

(*e*) *Temperature Control.*—The analyzer columns shall be maintained at a temperature constant to 0.3 C during the course of the sample and corresponding reference standard runs.

(*f*) *Carrier Gas.*—The instrument shall be equipped with suitable facilities to provide a flow of carrier gas through the analyzer column at a flow rate that is constant to 1.0 per cent throughout the analysis.

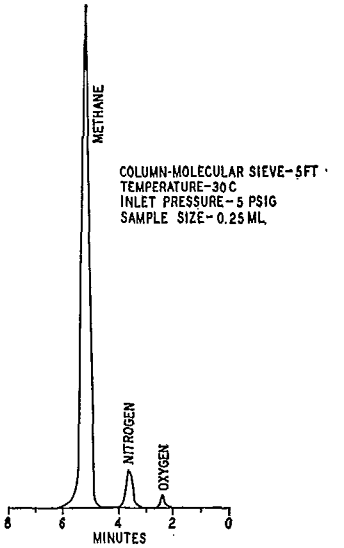

FIG. 1.—Separation Column for Oxygen, Nitrogen, and Methane.

(*g*) *Columns.*—An adsorption-type column and a partition-type column are required to make a complete analysis (Note 1).

NOTE 1.—The preparation and arrangement of columns found by test to meet requirements of this method are described in Appendix II.

(*1*) *Adsorption Column.*—This column must completely separate oxygen, nitrogen, and methane, as indicated by return of the recorder pen to the base line between each successive peak. A 5-ft column packed with molecular sieves will make this separation in about 6 min, as shown in Fig. 1.

(*2*) *Partition Column.*—This column must separate ethane through pentanes and CO_2. The recorder pen must return to the base line on propane and succeeding peaks, and on components eluted ahead of propane, the pen must return to within 2 per cent of full scale deflection, measured at the attenuation of the peak. Separation of CO_2 must be sufficient so that a 0.25-ml sample containing 0.1 mole per cent CO_2 will produce a clearly measurable CO_2 peak on the chromatogram. The separation should be completed within 40 min, including reversal of flow after *n*-pentane to give a group peak for hexanes and heavier components. Figures 2, 3, and 4 show example chromatograms obtained on suitable partition columns.

(*h*) *Drier.*—A drier must be provided ahead of the sample inlet for runs determining the hexanes and heavier components. The drier must remove moisture without removing components

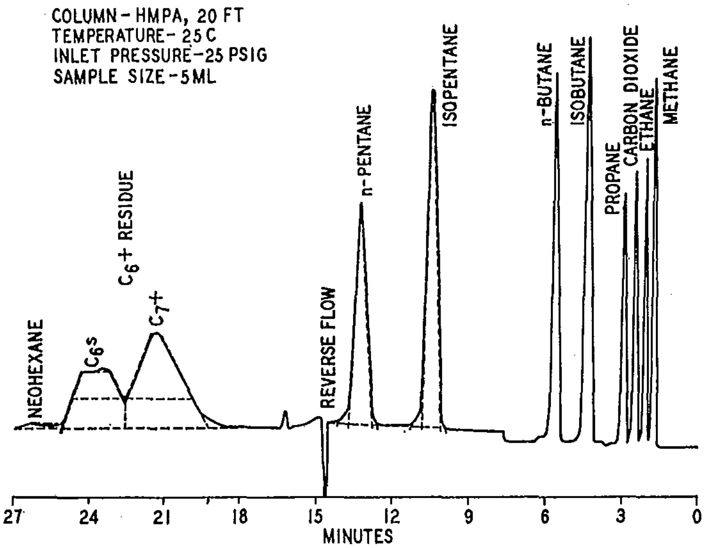

FIG. 2.—Chromatogram of Natural Gas (HMPA Column).

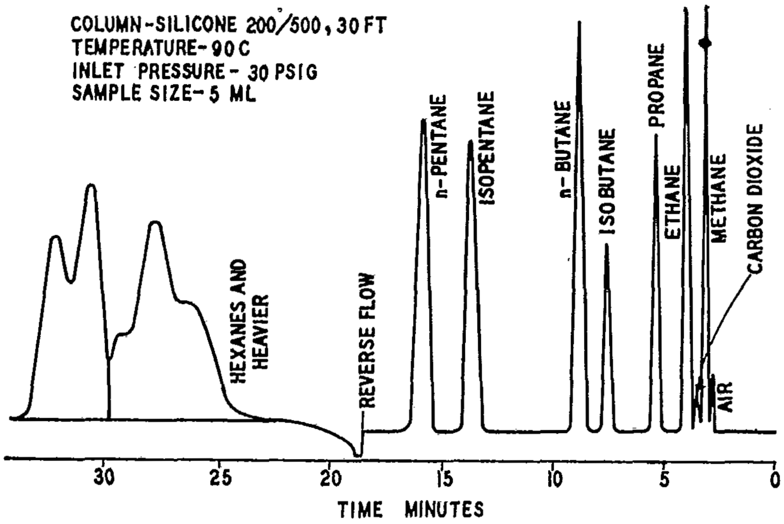

FIG. 3.—Chromatogram of Natural Gas (Silicone 200/500 Column).

that are to be determined in the analysis (Note 2).

NOTE 2.—See Appendix II for preparation of a suitable drier.

(*i*) *Four-Way Valve.*[3]—As required to permit the use of either the adsorption or partition column, or for reversing the carrier gas flow.

Reference Standard

4. A moisture-free gas mixture[4] shall be required that contains known percentages of the components, except oxygen (Note 3), hexanes, and heavier components, that are to be determined in the unknown sample. The concentration of a component in the reference standard mixture should be not less than one half of, nor differ by more than 10 mole per cent from, the concentration of the corresponding component in the unknown, except for methane which may differ by as much as 20 mole per cent when a sample volume of less than 0.3 ml is used. A reference standard may be prepared by blending pure components, or a natural gas mixture may be calibrated for use as a reference standard by methods given in Appendix III. Dry air is a suitable standard for oxygen and nitrogen.

NOTE 3.—Unless the reference standard is stored in a container that has been tested for inertness to oxygen, it is preferable to calibrate for this component by an alternate method.

Procedure

5. (*a*) *Sample Volume.*—The size of sample introduced to the chromatographic columns shall be between 0.25 and 0.5 ml. (This small sample size is necessary to obtain a linear detector response for methane.) Sufficient accuracy can be obtained for the determination of all but the minor constituents by the use of this size sample. Where increased sensitivity is required for the determination of components present in low concentrations, a sample size of up to 5 ml may be used. However, components whose concentrations are in excess of 5 per cent shall not be determined by the use of over a 0.5-ml sample size.

(*b*) *Apparatus Preparation.*—Place the proper column in operation as needed for the desired run (as described in either Paragraph (*d*), (*e*), or (*f*)). Adjust the operating conditions and allow to stabilize. After the base line has become steady and the instrument apparently stabilized, make check runs on the reference standard to establish instrument repeatability. The checks must agree within 1 mm or 1 per cent (whichever is larger) on each component peak height. The average or either of the two checks may be used as the reference standard for all subsequent runs until there is a change in instrument operating conditions.

(*c*) *Sample Preparation and Introduction.*—For samples containing more than about 10 grains of hydrogen sulfide (H_2S) per hundred cubic feet the H_2S

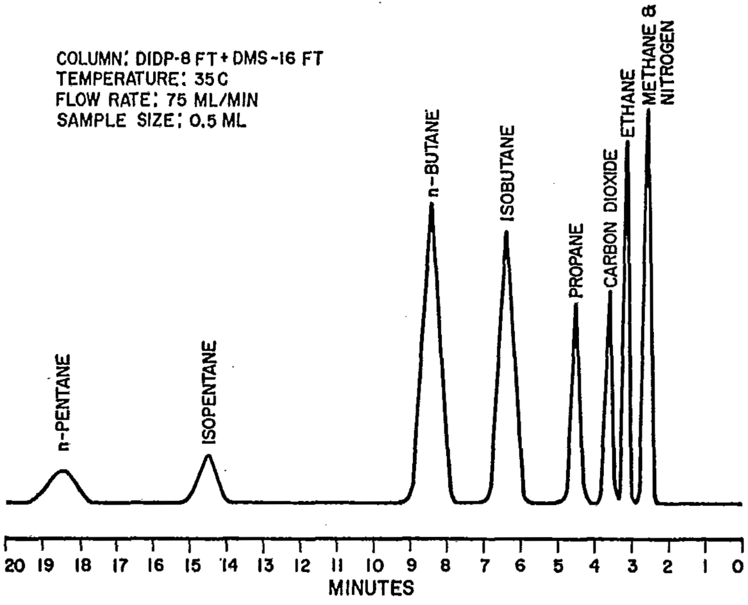

FIG. 4.—Chromatogram of Natural Gas (DIDP + DMS Column).

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[3] The Republic Lo-Temp Selector Valve, a 4-way flanged polytetrafluoroethylene (Teflon) plug, 310-6-1/8D, available from the Republic Manufacturing Co., Cleveland, Ohio, or a local distributor, has been found satisfactory for this purpose.

[4] A suitable reference standard is available from the Phillips Petroleum Co., Special Products Div., Bartlesville, Okla. It is identified as NGPA Natural Gas Reference Standard.

shall be removed by connecting a tube of sodium hydrate asbestos absorbent (Ascarite) ahead of the sample container during sampling or ahead of the drying tube when entering the sample. This also removes carbon dioxide and the results obtained will be on the acid-gas free basis.

(*1*) The temperature of the sample container should be above that at which the container was filled. If the container has been exposed to low temperatures it may require heating overnight to assure homogeneity of the sample. Connect the sample container outlet valve to the chromatograph inlet volume with a minimum length of metal or glass tubing. If hexanes and heavier are to be determined and the sample is not known to be free of water vapor, a drier shall be mounted between the container and the chromatograph inlet volume. Connections may be made with short pieces of vinyl (Tygon), but not rubber tubing. All lines, valves, and connections must be clean and dry.

(*2*) Open the sample-cylinder outlet valve and purge the sample through the inlet system and sample volume. Pass the outlet from the sample volume through a tube extended just below the surface of a container of water to indicate the rate of sample flow. Adjust the flow to one or two bubbles per second. Flush for 3 min or more. Adjust the recorder base line to coincide with the recorder zero. Enter the sample. If the sample container does not have sufficient pressure to flush the sample volume, either pressurize the sample container with helium or fill the sample volume to a reduced pressure. When the sample container is pressurized, normalize to 100 per cent; when the sample volume is filled to a reduced pressure, run the standard at the same pressure as the sample.

(*d*) *Partition Column Run for Ethane and Heavier Hydrocarbons and* CO_2. — This run is made using helium or hydrogen as the carrier gas; if other than a thermal conductivity detector is used, select a suitable carrier gas. Select a sample size in accordance with Paragraph (*a*). If the gas is lean, a 5-ml sample may be needed for good measurements of low concentration components, particularly the hexanes. Usually a 1 to 3-ml size sample will be satisfactory for most gases. Enter the sample and obtain a chromatogram through *n*-pentane and reverse the carrier gas flow if hexanes and heavier are to be determined (Note 4). Adjust the attenuator at each peak for maximum peak height within the recorder chart range. The run is complete for hexanes and heavier after the reverse flow peak is obtained as evidenced by the recorder pen returning to and remaining on the base line. Obtain a corresponding chromatogram on the reference standard. The reference standard run is complete after the elution of *n*-pentane (Note 5).

NOTE 4.—The carrier gas reversal may be made just after *n*-butane if C_6 and heavier breakdown is not needed and the approximate average molecular weight of the C_6 and heavier group is known.

NOTE 5.—No hexanes and heavier components should be present in the reference standard. This may be checked conveniently by obtaining a chromatogram that includes the reverse flow step on each new standard.

Methane may also be determined on this column if the column used will separate it from nitrogen and oxygen (that is, silicone 200/500) and the sample size does not exceed 0.5 ml.

(*e*) *Adsorption Column Run for Oxygen, Nitrogen, and Methane.*—This run shall be made using helium or hydrogen as the carrier gas; if other than a thermal conductivity detector is used, select a suitable carrier gas. The sample size must not exceed 0.5 ml for the determination of methane. Enter the sample and obtain a chromatogram through methane (Note 6). Likewise obtain a chromatogram on the reference standard showing nitrogen and methane. Obtain a chromatogram on dry air showing oxygen and nitrogen if oxygen is to be determined. The air may be entered at an accurately measured reduced pressure or from a helium-diluted mixture (Note 7).

NOTE 6.—It is recommended that the carrier gas flow be reversed to clean the column after each run.

NOTE 7.—For example, an approximately 1 per cent of oxygen mixture can be prepared by pressuring a container of air at atmospheric pressure to 300 psig with helium. This pressure need not be measured precisely as the nitrogen in the mixture thus prepared must be determined by comparison to nitrogen in the reference standard. The percentage of nitrogen is multiplied by 0.280 to obtain the oxygen mole per cent. Do not rely on oxygen standards that have been prepared for more than a few days.

(*f*) *Adsorption Column Run for Helium.*—This run shall be made using nitrogen or argon as the carrier gas. Enter a 3 to 5-ml sample and record the helium peak which will be just ahead of oxygen and will be obtained in about 2 min under normal conditions (Note 6). Obtain a corresponding chromatogram on a reference standard containing a suitable concentration of helium.

Calculations

6. (*a*) *Pentanes and Lighter Components.*—Measure the height of each component peak for pentanes and lighter, convert to the same attenuation for corresponding components in the sample and reference standard, and calculate the concentration of each component in the sample as follows:

$$C = S \times \frac{A}{B}$$

where:

C = component concentration in the sample in mole per cent,

A = peak height of component in the sample in millimeters,

B = peak height of component in the standard in millimeters, and

S = component concentration in the standard in mole per cent.

If air has been run at reduced pressure for oxygen or nitrogen calibration, or both, correct the equation for pressure as follows:

$$C = S \times \frac{A}{B} \times \frac{P_a}{P_b}$$

where:

P_a = pressure at which air is run in millimeters of mercury, absolute, and

P_b = barometric pressure during run in millimeters of mercury, absolute.

Composition values of 78.1 per cent nitrogen and 21.9 per cent oxygen shall be used for air because on a molecular sieve column argon elutes with oxygen.

(*b*) *Hexanes and Heavier Components.*—Measure the areas of the hexanes portion and the heptanes and heavier portion of the reverse flow peak (see Fig. 2, Appendix II, and Section E 6 of Appendix V). Also measure the areas of both pentane peaks on the sample chromatogram, and adjust all measured areas to the same attenuation basis.

(*1*) Calculate corrected areas of the reverse flow peaks as follows:

Corrected C_6 area = 72/86 × measured C_6 area

Corrected C_7 and heavier area = 72/*A* × measured C_7 and heavier area

where *A* = average molecular weight of the C_7 and heavier fraction (Note 8).

NOTE 8.—The value of 98 is usually sufficiently accurate for use as the C_7 and heavier fraction average molecular weight because the small amount of C_8 and heavier present is usually offset by the lighter methyl cyclopentane and cyclohexane that occur in this fraction. A more accurate value for average molecular weight of C_7 and heavier can be obtained as described in Section A3 of Appendix I.

(*2*) Calculate the concentrations of the two fractions in the sample as follows:

$$\text{Mole per cent } C_6 = \text{Corrected } C_6 \text{ area} \times \frac{\text{mole per cent } iC_5 + nC_5}{iC_5 \text{ area} + nC_5 \text{ area}}$$

$$\text{Mole per cent } C_7 \text{ and heavier} = \text{Corrected } C_7 \text{ and heavier area} \times \frac{\text{mole per cent } iC_5 + nC_5}{iC_5 \text{ area} + nC_5 \text{ area}}$$

If the mole per cent $iC_5 + nC_5$ has been determined by a separate run with a smaller size sample, this value need not be redetermined.

The entire reverse flow area may be calculated in this manner as C_6 and heavier or C_5 and heavier, should the carrier gas reversal be made after *n*-butane. The measured area should be corrected by using the average molecular weights of the entire reverse flow components for the value of *A*. The mole per cent and area of the $iC_5 + nC_5$ reverse flow peak of an identical size sample of reference standard (C_6 and heavier free) shall then be used for the final mole per cent value.

(*c*) Normalize the mole per cent values by multiplying each value by 100 and dividing by the sum of the original values. The sum of the original values should not differ from 100.0 per cent by more than 1.0 per cent.

Precision

7. The following criteria should be used to judge the acceptability of the results:

(*a*) Duplicate results by the same operator should not be considered suspect unless they differ by more than the following amounts:

Component, mole per cent	Repeatability
0 to 1	0.03
1 to 5	0.05
5 to 25	0.15
Over 25	0.30
C_6 and heavier fraction	5 per cent of amount

(*b*) Results on the same sample submitted by each of two laboratories should not be considered suspect unless the results differ by more than the following amounts:

Component, mole per cent	Reproducibility
0 to 1	0.06
1 to 5	0.10
5 to 25	0.20
Over 25	0.60
C_6 and heavier fraction	10 per cent of amount

APPENDIX I

SUPPLEMENTARY PROCEDURES

Analysis for Only Propane and Heavier Components

A1. (*a*) This determination can be made in 10 to 15 min run time by using column conditions to separate propane, isobutane, *n*-butane, isopentane, *n*-pentane, hexanes, and heptanes and heavier, but disregarding separation on ethane and lighter.

(*b*) Use a 15-ft hexamethylphosphoramide (HMPA) column at about 30 C with a carrier gas inlet pressure 30 psig, or a suitable length of another partition column that will separate propane through *n*-pentane in about 5 min. Enter a 1 to 5-ml sample into the column and reverse the carrier gas flow after *n*-pentane is separated. Obtain a corresponding chromatogram on the reference standard, which can be accomplished in 5 min run time as there is no need to reverse the flow on the reference standard. Make calculations in same manner as for the complete analysis method.

(*c*) A determination of propane, isobutane, *n*-butane, and pentanes and heavier can be made in about 5 min run time by reversing the carrier gas flow after *n*-butane. However, it is necessary to know the average molecular weight of the pentanes and heavier components.

Single-Run Analysis for Ethane and Heavier Components

A2. (*a*) In many cases a single-partition run using a sample size in the order of 1 to 5 ml will be adequate for determining all components except methane, which cannot accurately be determined using this size sample with peak height measurements because of its high concentration.

(*b*) Enter a 1 to 5-ml sample into the partition column and reverse the carrier gas flow after *n*-pentane is separated. Obtain a corresponding chromatogram on the reference standard. Measure the peak heights of ethane through *n*-pentane and the reverse flow area of the sample chromatogram. Measure the peak heights of ethane through *n*-pentane and the areas of the pentane peaks of the standard. Make calculations on ethane and heavier components in the same manner as for the complete analysis method. Methane and lighter may be expressed as the difference between 100 and the sum of the determined components.

Special Analysis to Determine Hexanes and Heavier Components

A3. (*a*) A short partition column can be used advantageously to separate heavy-end components and obtain a more detailed breakdown on composition of the reverse flow fractions. This information provides quality data and basis for calculating physical properties such as molecular weight on these fractions.

(*b*) Figure 5 is a chromatogram that shows components that are separated by a 5-ft HMPA column in 20 min. To make this determination, enter a 5-ml sample into the short column and reverse the carrier gas after separation of *n*-heptane. Measure areas of all peaks eluted after *n*-pentane. Correct each peak area to the mole basis by dividing each peak area by the molecular weight of the component. A value of 120 may be used for the molecular weight of the octanes and heavier reverse flow peak. Calculate the mole per cent of the hexanes and heavier components by adding the corrected areas and dividing to make the total 100 per cent.

APPENDIX II

PREPARATION OF COLUMNS AND DRIER

Columns

B1. (*a*) *Adsorption Column.*—For separating helium, oxygen, nitrogen, and methane (see Fig. 1).

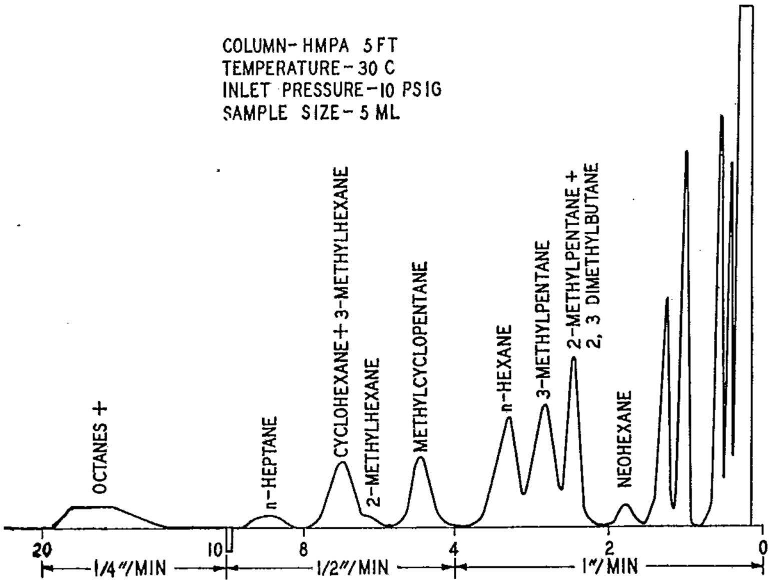

FIG. 5.—Composition of Hexanes and Heavier Fraction.

(*1*) Clean a 5-ft straight length of ¼-in. copper or other inert tubing with acetone and dry with a stream of clean, dry air.

(*2*) Dry 20 to 30 g of Type 5A or 13X, 30 to 60-mesh molecular sieves[5] in an oven at 400 to 600 F for 6 hr or more.

(*3*) Plug one end of the tube with glass wool and, with continuous light tapping or by use of an electric vibrator, fill the tube with the sieves from the other end, and plug it also with glass wool.

(*4*) Shape the finished column to mount conveniently in the chromatograph.

(*b*) *Partition Column.*—For separating ethane, carbon dioxide, propane, isobutane, *n*-butane, isopentane, *n*-pentane, and hexanes and heavier components (see Figs. 2, 3, and 4).

Preparation of Columns

B2. The procedures for the preparation of three columns that give satisfactory results for the required separation are as follows:

(*a*) *Hexamethylphosphoramide* (*HMPA*) *Column:*

(*1*) Clean a 20-ft length of ¼-in. copper or aluminum tubing with acetone and dry with a stream of clean, dry air or inert gas. Bend into a U-shape for filling.

(*2*) Dry 60 g of 35 to 80 mesh Chromosorb in an oven at 400 to 600 F for 6 hr or more.

(*3*) Mix 12-ml of hexamethylphosphoramide[6] with the 60 g of dry Chromosorb in a clean 8-oz screw-cap bottle. Shake gently for about 5 min to obtain a homogeneous mixture.

(*4*) Admit the packing into both ends of the tubing, using a small funnel and electric vibrator continuously to completely fill the column. Plug each end with ½ in. of glass wool.

(*5*) Shape the finished column to mount conveniently in the chromatograph. Because of the volatility of hexamethylphosphoramide, this column should not be heated above 35 C. The column packing is very satisfactory for use in an apparatus with a thermistor bead-type detector cell but is not recommended for use with a filament-type cell. Moisture on this column will cause the carbon dioxide peak to move towards the propane peak. The carbon dioxide separation efficiency can usually be regained by sweeping the column several hours with dry carrier gas.

(*b*) *Diisodecylphthalate-Dimethylsulfolane Column* (*DIDP + DMS*)*:*

(*1*) Clean a 16 and an 8-ft length of ¼-in. copper or inert tubing with acetone and dry with a stream of air.

(*2*) Dry about 80 g of 30 to 60 mesh Chromosorb pink in an oven at 400 to 600 F for 12 hr or longer.

(*3*) Weigh out 50 g of the dry Chromosorb into a 1 to 2-liter beaker.

(*4*) Weigh out 15 g of the stationary phase dimethylsulfolane[7] into a 250-ml beaker and add about 150 ml of methylene chloride as a solvent. Stir until uniform.

(*5*) Pour the solvent-stationary phase mixture into the larger beaker containing the Chromosorb support, and rinse with solvent to transfer any remaining material. Stir the mixture until it appears homogeneous.

(*6*) Place the mixture on a hot plate (set at low heat) in a hood and evaporate to dryness with constant stirring. A gentle air stream directed into the beaker will accelerate the drying process considerably.

(*7*) When a solvent odor can no longer be detected, the material is ready for packing into a column. It is usually advisable to screen the packing on a 60-mesh sieve at this point to remove fines formed by handling.

(*8*) Fill the 16-ft length of tubing with this packing by bending into a U-shape and filling from each end through a funnel. Vibrate the column constantly during the filling operation. Insert a glass wool plug into each end of the column to retain the packing.

(*9*) Prepare the 8-ft section of tubing in accordance with Steps (*1*) to (*8*) except that 25 g of Chromosorb shall be used in Step (*3*), and 7.5 g of diisodecylphthalate[8] shall be used for the stationary phase in Step (*4*).

(*10*) Shape the sections to fit into the chromatograph, and connect them in series, with the diisodecylphthalate section on the upstream end.

(*11*) Condition the column in the chromatograph by flowing helium through it overnight or longer if necessary at a temperature of about 50 C.

(*c*) *Silicone 200/500 Column:*

(*1*) Clean a 30-ft length of ¼-in. copper or aluminum tubing with acetone and dry with a stream of clean, dry air or inert gas. Bend into a U-shape for filling.

(*2*) Dilute 30 g of silicone 200/500[9] with about 300 g of ethyl ether in a filter flask and add 80 g of 30 to 60 mesh Chromosorb pink.[10] Shake the flask to disperse the solvent. Connect a vacuum line to the flask and evaporate the solvent. Swirl the flask gently several times while removing the solvent, to avoid concentration of the silicone in the upper layer.

(*3*) Admit the packing into both ends of the tubing, using a small funnel and an electric vibrator continuously to completely fill the column. Plug each end with ½ in. of glass wool.

(*4*) Shape the finished column to mount conveniently in the chromatograph. Condition the column by flowing helium through it at 90 C until a stable base line is obtained. This column will separate air, methane, carbon dioxide, ethane, propane, isobutane, *n*-butane, isopentane, *n*-pentane, and other natural gas hydrocarbons as described in the method.

Preparation of Drier:

B3. Prepare a drying tube that is satisfactory for use with this method as follows:

(*a*) Coat small glass beads with powdered phosphorous pentoxide by mixing in a porcelain dish.

(*b*) Fill a glass tube (½-in. diameter by 3 in. long) with the coated beads and plug both ends of the tube with glass wool.

(*c*) Mount as required to dry the sample stream, and replace after about half the length of the tube has become glazed.

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[5] There are a number of suppliers of molecular sieves; however, those available from the Coast Engineering Co., Hermosa Beach, Calif., have been found to be of proper mesh size, dry, and ready for use.

[6] Available from the Fisher Scientific Co., Pittsburgh, Pa.

[7] Available from Matheson Coleman and Bell Div., The Matheson Co., Inc., East Rutherford, N. J.

[8] Available from the Barrett Div., Allied Chemical Corp., 42 Rector St., New York, N. Y.

[9] Available from the Dow Corning Corp., Midland, Mich.

[10] Available from Johns-Manville Co., Celite Div., 22 E. 40th St., New York 16, N. Y.

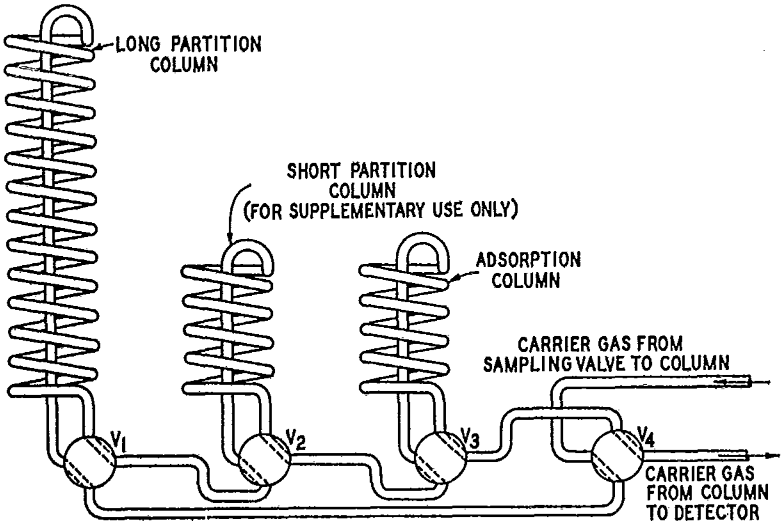

FIG. 6.—Column Arrangement.

Column Arrangement.

B4. For analyses in which hexanes and heavier components are to be determined, Fig. 6 shows an arrangement whereby columns can be quickly and easily changed by the turn of a selector valve. Two columns are necessary to determine all of the components covered in the method. However, short and long partition columns give the flexibility of three partition column lengths, by using them either singly or in series. The connection between V_1 and V_4 should be as short as possible (1 in. is practical) to minimize dead space between the columns when used in series. If all columns are chosen to operate at the same temperature, then stabilization time between changing columns will be minimized.

APPENDIX III

REFERENCE STANDARD MIXTURE

Preparation

C1. (*a*) Gas mixtures of the following compositions will suffice for use as reference standards for most analytical requirements (Note 9):

Component	Composition, mole per cent	
	Lean Gas	Rich Gas
Helium	1.0	0.5
Nitrogen	4.0	0.5
Methane	79.0	73.0
Ethane	6.0	10.0
Carbon Dioxide	1.0	1.0
Propane	4.0	7.0
Isobutane	2.0	3.0
n-Butane	2.0	3.0
Isopentane	0.5	1.0
n-Pentane	0.5	1.0
Total	100.0	100.0

NOTE 9.—If the mixture is stored under pressure, care should be taken to ensure that the partial pressure of any component does not exceed its vapor pressure at the temperature and pressure at which the sample is stored and used.

(*b*) A useful method for preparation of a reference standard by weight is as follows:

(*1*) Obtain the following equipment and material:

Cylinder, 5-gal.

Balance, 2000 g, sensitivity of 10 mg.

Pressure Cylinders, two, 100 ml.

Pure Components, methane through *n*-pentane, and CO_2. The pure components should be 99+ per cent pure. Run a chromatogram on each component to check on its given composition.

(*2*) Evacuate the 5-gal cylinder for several hours. Evacuate 100-ml cylinder *A* and obtain its true weight. Connect cylinder *A* to a cylinder of pure *n*-pentane with a metal connection of calculated length to contain approximately the amount of *n*-pentane to be added. Flush the connection with the *n*-pentane by loosening the fitting at the cylinder *A* valve. Tighten the fitting. Close the *n*-pentane cylinder valve and open the cylinder *A* valve to admit the *n*-pentane from the connection and then close. Disconnect and weigh cylinder *A* to obtain the weight of *n*-pentane added.

(*3*) Similarly, add isopentane, *n*-butane, isobutane, propane, ethane, carbon dioxide, and helium as desired to include in the reference standard. Weigh the cylinder *A* after each addition to obtain the weight of component added.

(*4*) Fill 100-ml cylinder *B* with helium to the required pressure. Connect it to the 5-gal cylinder with as short a connection as possible. Open valves on both cylinders and transfer the helium. Measure the pressure on cylinder *B* after the helium transfer.

(*5*) Connect 100-ml cylinder *A* to the 5-gal cylinder using as short a connection as possible. Open valves on both cylinders to transfer the mixture. Disconnect and weigh 100-ml cylinder *A* to obtain the weight of mixture not transferred. Analyze the mixture remaining in 100-ml cylinder *A* and calculate the weight of all components transferred in the 5-gal cylinder.

(*6*) Weigh a 1-qt cylinder containing pure methane at about 1500-lb pressure. Transfer the methane to the 5-gal cylinder until the pressure equalizes. Weigh the quart cylinder to determine the weight of methane transferred.

(*7*) Thoroughly mix the contents of the 5-gal cylinder by heating at the bottom by convenient means such as hot water or heat lamp and leaving in a vertical position for 6 hr or longer.

(*8*) From the weights and purities of all components added, calculate the composition and convert the weight per cent to mole per cent.

(*c*) Pure components may be used to check or determine the composition of one or all components of a gas mixture for use as a reference standard. The mixture may be blended from pure components or taken from a suitable source. One method of collecting a C_6 and heavier free mixture is to add approximately the desired amount of isopentane and *n*-pentane to a clean, dry sample cylinder and then to pressure to about 100 psig (or any pressure desired that is below dew point conditions for the gas) with dehydrated, C_6 and heavier free natural gas from a gasoline plant residue or from a pipeline.

Calibration with Pure Components

C2. (*a*) Into the adsorption column (helium carrier gas used) admit a sample volume (0.25 to 0.5 ml) of pure methane at 500 mm and pure nitrogen at 100 mm of mercury, absolute pressure. Run a sample of the standard mixture at 700-mm pressure, and obtain peaks for nitrogen and methane (Note 10).

NOTE 10.—Each run made throughout this procedure should be repeated to ensure that peak heights are reproducible after correction for pressure differences to ± 1 mm or 1 per cent of the mean value. All peaks should be recorded at an instrument attenuation that gives the maximum measurable peak height.

(*b*) Change the carrier gas to argon or nitrogen and, after the base line has stabilized, enter a sample of pure helium at 50-mm absolute pressure, recording the peak at an attenuation that allows maximum peak height. Run a sample of the mixture at 700-mm pressure, and obtain the helium peak.

(*c*) Switch to the partition column with helium carrier gas, and run the gas mixture at 700-mm pressure. Then admit samples of pure ethane and propane at 100-mm absolute pressure, and butanes, pentanes, and carbon dioxide at 50-mm pressure.

(*d*) Run the gas mixture at 700-mm absolute pressure.

(*e*) Calculate the composition of the prepared gas mixture as follows:

(*1*) Correct peak heights of all pure components and the respective components in the blend to the same attenuation.

(2) Calculate the concentration of each component as follows:

$$C = \frac{100 A V_f}{B} \times \frac{P_b}{P_a}$$

where:

C = component concentration in mole per cent,

A = peak height of component in blend in millimeters,

B = peak height of pure component in millimeters,

P_a = pressure at which blend is run in millimeters of mercury,

P_b = pressure at which component is run in millimeters of mercury, and

V_f = volume fraction of pure component (Note 11).

NOTE 11.—This term is 1.0000 if the calibration component is free of impurities.

(3) Normalize values to 100.0 per cent.

APPENDIX IV

SAMPLE CALCULATIONS

D1. The following example may be used as a guide for the calculation of results obtained with this method:

(a) Pentanes and lighter components:

Component	Sample		Reference Standard		S	A/B	C
	Peak Height	Attenuation	Peak Height	Attenuation			
Nitrogen	21	1	30	1	0.45 ×	21/30	= 0.32
Methane	126	32	112	32	73.73 ×	126/112	= 82.95
Carbon Dioxide	30	4	17	4	1.15 ×	30/17	= 2.02
Ethane	127	4	167	4	9.79 ×	127/167	= 7.45
Propane	73	4	118	4	7.10 ×	73/118	= 4.39
Isobutane	25	2	89	2	2.97 ×	25/89	= 0.83
n-Butane	62	1	165	1	2.88 ×	62/165	= 1.08
Isopentane	14	1	43	1	0.96 ×	14/43	= 0.31
n-Pentane	11	1	42	1	0.97 ×	11/42	= 0.25

(b) For hexanes and heavier components:

Observed area of hexanes portion of reverse flow peaks = 327 sq mm

Corrected area = 327 × 72/86 = 274 sq mm

Observed area of heptanes and heavier of reverse flow peak = 667 sq mm

Corrected area = 667 × 72/98 = 490 sq mm

Observed area of isopentane (0.31 mole per cent from Column C) = 492 sq mm

Observed area of n-pentane (0.25 mole per cent from Column C) = 398 sq mm

Total pentanes area (0.56 mole per cent) = 890 sq mm

Hexanes, C = 0.56 × 274/890 = 0.17 mole per cent

Heptanes and heavier, C = 0.56 × 490/890 = 0.31 mole per cent

(c) Complete analysis:

Component	C	Normalized, mole per cent
Nitrogen	0.32	0.32
Methane	82.95	82.88
Carbon Dioxide	2.02	2.02
Ethane	7.45	7.44
Propane	4.39	4.39
Isobutane	0.83	0.83
n-Butane	1.08	1.08
Isopentane	0.31	0.31
n-Pentane	0.25	0.25
Hexanes	0.17	0.17
Heptanes and heavier	0.31	0.31
Total	100.08[a]	100.00

[a] If all components are determined, this total should not vary more than ±1.00 per cent from 100.00 per cent. If so, check for possible error or change in operating conditions of instrument between sample and reference standard runs.

(d) To calculate liquids content as gallons per 1000 cu ft of gas at 14.696 psia and 60 F (GPM):

Component	mole per cent	cu ft per gal	GPM
Propane	4.39 × 10 ÷	36.35[b]	= 1.21
Isobutane	0.83 × 10 ÷	30.59[b]	= 0.27
n-Butane	1.08 × 10 ÷	31.75[b]	= 0.34
Isopentane	0.31 × 10 ÷	27.40[b]	= 0.11
n-Pentane	0.25 × 10 ÷	27.68[b]	= 0.09
Hexanes	0.17 × 10 ÷	24.4[c]	= 0.07
Heptanes and heavier	0.31 × 10 ÷	22.3[c]	= 0.14

[b] From NGPA Publications 2145—Revised 1957 for individual components. All values shown here are on the ideal or "perfect gas" basis.

[c] From Fig. 7.

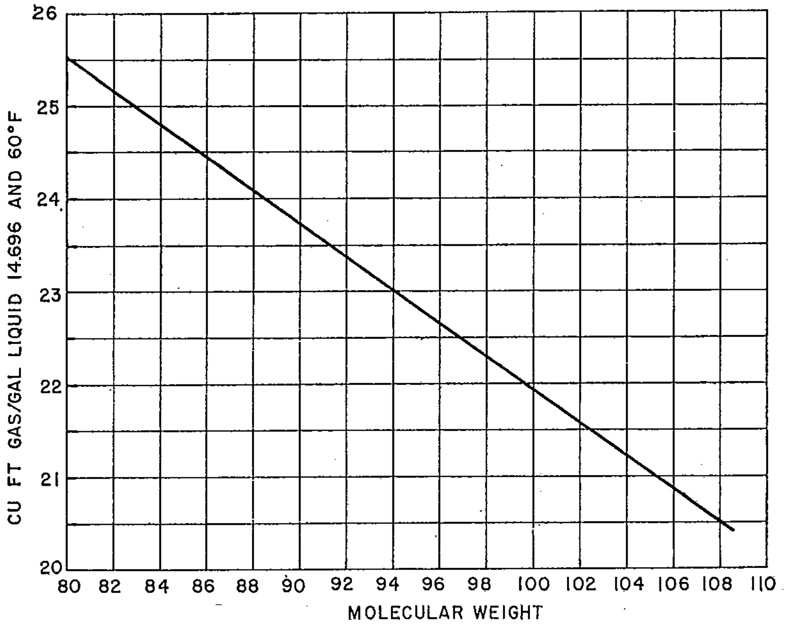

FIG. 7.—Average Molecular Weight of Natural Gas Hydrocarbon Mixtures.

APPENDIX V

PRECAUTIONS TO AVOID COMMON CAUSES OF ERRORS

Hexanes and Heavier Content Change

E1. The amounts of heavy-end components in natural gas are easily changed during handling and entering of samples to give seriously erroneous low or high values. Concentration of these components has been observed to occur in a number. of cases due to collection of heavier components in the sample loop during purging of the system. The surface effect of small-diameter tubing acts as a separating column and must not be used in the sampling and entering system when components heavier than pentanes are to be determined. An accumulation of oily film in the sampling system greatly aggravates this problem. Also the richer the gas, the worse the problem. Periodically, check C_6 and heavier repeatability of the apparatus by making several check runs on the same sample. It is helpful to retain a sample containing some hexanes and heavier for periodic checking. When enlargement of the heavy end peaks is noted, thoroughly clean the sampling valve and loop with acetone. This trouble has been experienced with some inlet systems even when clean and with the specified sample loop size. A safeguard then is to install a vacuum system so that the sample can be entered into an evacuated holder instead of by purging.

Acid Gas Content Change

E2. The carbon dioxide and hydrogen sulfide contents of gas are easily altered during sampling and handling. If samples containing CO_2 or H_2S, or both, are to be taken, use completely dry sample cylinders, connections, and lines, as moisture will selectively absorb appreciable amounts of the acid gases. If H_2S is present, use aluminum, stainless steel, or other materials inert to H_2S for the cylinder, valves, lines, and connections.

Sample Dew Point

E3. Nonrepresentative samples frequently occur because of condensation of liquid. Maintain all samples above the hydrocarbon dew point. If cooled below this, heat 20 F or more above the dew point for several hours before using. If the dew point is unknown, heat above the sampling temperature. It is good practice to heat all samples before using.

Sample Inlet System

E4. Do not use rubber or plastic that may preferentially adsorb sample components. Keep the system short and the drier small to minimize the purging required.

Sample Size Repeatability

E5. Varying back pressures on the sample loop may impair sample size repeatability. Keep the outlet tube from the sample loop just below the water level in the beaker or remove it entirely from the water before manipulating the entering valve.

Reverse Flow

E6. (*a*) Make it a practice to make all reverse flow determinations in the same carrier gas flow direction. All single-peak determinations and corresponding reference runs will then be made in the opposite carrier gas flow direction.

(*b*) Be sure the inlet drier is in good condition. Moisture on the column will enlarge the reverse flow peak.

(*c*) Be sure the column is clean by occasionally giving it several hours sweep of carrier gas reverse flow direction. A level base line should be quickly attained in either flow direction if the column is clean.

(*d*) When the reverse flow valve is turned there is a reversal of pressure conditions at the column ends that upsets the carrier gas flow. This flow should quickly return to the same flow rate and the base line level out. If it does not, the cause may be a leak in the carrier gas system, faulty flow regulator, or an unbalanced condition of the column or plumbing.

Reference Standard

E7. Maintain the NGPA Natural Gas Reference Standard at 70 F or above, which is safely above the hydrocarbon dew point. If it should be exposed to lower temperatures, heat at the bottom for several hours before removing a sample. If in doubt about the composition, check the *n*-pentane and isopentane values with pure components by the procedure described in Appendix II.

Measurements

E8. The base line and tops of peaks should be plainly visible for making peak height measurements. Do not use a fixed zero line as the base line, but use the actual observed base line. On high sensitivity, this base line may drift slightly without harm and it need not frequently be moved back to zero. A strip-chart recorder with an offset zero is desirable. The area of reverse flow peak may be measured by planimeter or geometric construction. The reverse flow area, and the pentanes peaks used for comparison should be measured by the same method. That is, use either geometric construction, as shown in Fig. 2, or planimeter, but do not intermix. When a planimeter is used, carefully make several tracings and use the average. This average shall be checked by a second group of tracings.

Miscellaneous

E9. (*a*) Moisture in the carrier gas that would cause trouble on the reverse flow may be safeguarded against by installing a cartridge of molecular sieves ahead of the instrument. Usually 3 ft of $\frac{1}{2}$-in. tubing packed with 30 to 60 mesh molecular sieves is adequate, if changed with each cylinder of carrier.

(*b*) Check carrier gas flow system periodically for leaks with soap or leak detector solution.

(*c*) Use electrical contact cleaner on the attenuator if noisy contacts are indicated.

(*d*) Peaks with square tops or omission of small peaks can be caused by a sluggish recorder. If this condition cannot be remedied by adjustment of the gain, check the tubes in the recorder.

Tentative Method for Analysis of Reformed Gas by Gas Chromatography, ASTM D 1946-62 T.
Not included because of its similarity to previous procedures for natural gas.

When the gas to be analyzed by chromatography contains significant amounts of hydrogen, carbon monoxide and ethylene as in reformed gases and similar mixtures, a slightly different procedure must be followed as given in Tentative Method for Analysis of Reformed Gas by Chromatography, ASTM D 1946-62 T. This method is not reproduced here because it is similar in most respects to ASTM D 1945-64 quoted previously.

Determination of Specific Minor Constituents

Certain minor constituents of fuel gases assume special importance because of their pronounced effects in specific services, or because of their effect on measurements of quantity. Accordingly, specific methods have been developed for determination of water vapor, oil vapor, sulfur, and dust.

Standard Method of Test for

WATER VAPOR CONTENT OF GASEOUS FUELS BY MEASUREMENT OF DEW-POINT TEMPERATURE

ASTM Designation: D 1142–63

Approved as USA Standard Z77.3–1964

(A method for determining the equilibrium water vapor content of natural gas at elevated pressures based on available data was omitted along with the accompanying tables.)

Scope

1. This method covers the determination of the water vapor content of gaseous fuels by measurement of the dew-point temperature and the calculation therefrom of the water vapor content (Notes 1 and 2).

NOTE 1.—Some gaseous fuels contain vapors of hydrocarbons or other components that easily condense into liquid and sometimes interfere with or mask the water dew point. When this occurs, it is sometimes very helpful to supplement the apparatus in Fig. 1 with an optical attachment[2a] that uniformly illuminates the dew point mirror and also magnifies the condensate on the mirror. With this attachment it is possible in some cases, to observe separate condensation points of water vapor, hydrocarbons, and glycolamines as well as ice points. However, if the dew point of the condensable hydrocarbons is higher than the water vapor dew point, when such hydrocarbons are present in large amounts, they may flood the mirror and obscure or wash off the water dew point. Best results in distinguishing multiple component dew points are obtained when they are not too closely spaced.

NOTE 2.—Condensation of water vapor on the dew-point mirror may appear as liquid water at temperatures as low as 0 F to −10 F. At lower temperatures an ice point rather than a water-dew point likely will be observed. The minimum dew point of any vapor that can be observed is limited by the mechanical parts of the equipment. Mirror temperatures as low as −150 F have been measured, using liquid nitrogen as the coolant with a thermocouple attached to the mirror, instead of a thermometer well.

Definitions

2. (*a*) *Water Dew-Point Temperature* of a gaseous fuel is the temperature at which the gas is saturated with water vapor at the existing pressure.

(*b*) *Saturated Water Vapor.*—When a gas containing water vapor is at the water dew-point temperature, it is said to be saturated at the existing pressure. Saturated water vapor, or equilibrium water vapor content, represents the water vapor concentration in a gas mixture which is in equilibrium with a liquid phase of pure water that is saturated with the gas mixture.

(*c*) *Specific Volume* of a gaseous fuel is the volume of the gas in cubic feet per pound.

Apparatus

3. (*a*) Any properly constructed dew-point apparatus may be used that satisfies the basic requirements that means must be provided (*1*) to permit a controlled flow of gas to enter and leave the apparatus while the apparatus is at a temperature at least 3 F. above the dew-point of the gas, (*2*) to cool and to control the cooling rate of a portion (preferably a small portion) of the apparatus, with which the *flowing* gas comes in contact, to a temperature low enough to cause vapor to condense from the gas, (*3*) to observe the deposition of dew on the cold portion of the apparatus, (*4*) to measure the temperature of the cold portion of the apparatus on which the dew is deposited, and (*5*) to measure the pressure of the gas within the apparatus or the deviation from the known existing barometric pressure. The apparatus should be constructed so that the "cold spot," that is, the cold portion of the apparatus on which dew is deposited, is protected from all gases other than the gas under test. The apparatus may or may not be designed for use under pressure.

(*b*) The Bureau of Mines type of dew-point apparatus[3] shown in Fig. 1 fulfills the requirements specified in Paragraph (*a*). Within the range of conditions specified in Section 1, this apparatus is satisfactory for determining the dew point of gaseous fuels. Briefly, this apparatus consists of a metal chamber into and out of which the test gas is permitted to flow through control valves *A* and *D*. Gas entering the apparatus through valve *A* is deflected by nozzle *B* towards the cold portion of the apparatus, *C*. The gas flows across the face of *C* and out of the apparatus through valve *D*. Part *C* is a highly polished stainless steel "target mirror," cooled by means of a copper cooling rod, *F*. The mirror, *C*, is silver-soldered to a nib on the copper thermometer well fitting, *I*, which is soft-soldered to the cooling rod, *F*. The thermometer well is integral with the fitting, *I*. Cooling of rod *F* is accomplished by vaporizing a refrigerant such as liquid butane, propane, carbon dioxide, or some other liquefied gas in the chiller, *G*. The refrigerant is throttled into the chiller through valve *H* and passes out at *J*. The chiller body is made of copper and has brass headers on either end. The lower header is connected with the upper header by numerous small holes drilled in the copper body through which the vaporized refrigerant passes. The chiller is attached to the cooling rod, *F*, by means of a taper joint. The temperature of the target mirror, *C*, is indicated by a calibrated mercury-in-glass ther-

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[3] W. M. Deaton and E. M. Frost, Jr., "Bureau of Mines Apparatus for Determining the Dew Point of Gases Under Pressure," *Bureau of Mines Report of Investigation 3399*, May, 1938.

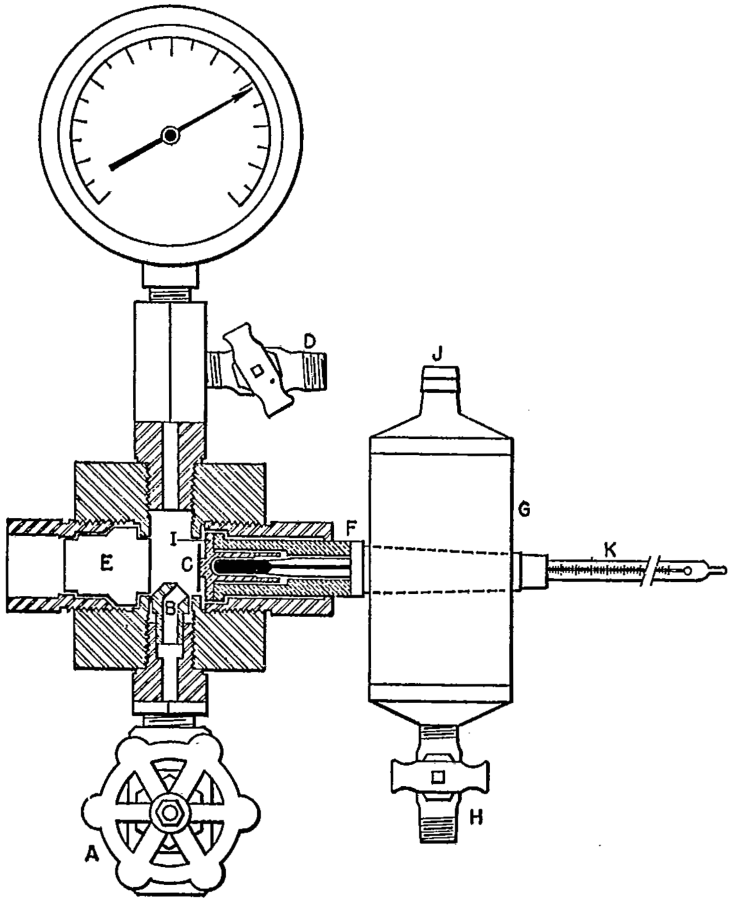


FIG. 1.—Bureau of Mines Dew-Point Apparatus.

mometer, *K*, whose bulb fits snugly into the thermometer well. Observation of the dew deposit is made through the pressure-resisting transparent window, *E*.

It will be noted that only the central portion of the stainless steel target mirror, *C*, is thermally bonded to the fitting, *I*, through which *C* is cooled. Since stainless steel is a relatively poor thermal conductor, the central portion of the mirror is thus maintained at a slightly lower temperature than the outer portion, with the result that the dew first appears on the central portion of the mirror and its detection is aided materially by the contrast afforded. The arrangement for measuring the temperature of the target mirror, *C*, also should be noted. The temperature is read with a mercury-in-glass thermometer, *K*, inserted in the cooling rod, *F*, so that the bulb of the thermometer is entirely within the thermometer well in fitting, *I*. The stud to which the stainless steel mirror is silver-soldered is a part of the base of the thermometer well, and as there is no metallic contact between the thermometer well and the cooling tube, other than through its base, the thermometer indicates the temperature of the mirror rather than some compromise temperature influenced by the temperature gradient along the cooling tube as would be the case if this type of construction were not used.

Tests with the Bureau of Mines type of dew-point apparatus are reported[3] to permit a determination with a precision (reproducibility) of ±0.2 F. and with an accuracy of ±0.2 F. when the dew-point temperatures range from room temperature to a temperature of 32 F. It is estimated that water dew points may be determined with an accuracy of ±0.5 F. when they are below 32 F. and not lower than 0 F., provided ice crystals do not form during the determination.

Procedure

4. (*a*) *General Considerations.*—The sample shall be taken so as to be representative of the gas at the source. It shall not be taken at a point where isolation would permit condensate to collect or would otherwise allow a vapor content to exist that is not in equilibrium with the main stream or supply of gas, such as the sorption or desorption of vapors from the sampling line or from deposits therein. The temperature of the pipelines leading the sample directly from the gas source to the dew-point apparatus, and also the temperature of the apparatus, shall be at least 3 F. higher than the observed dew point. The determination may be made at any pressure, but the gas pressure within the dew-point apparatus must be known with an accuracy appropriate to the accuracy requirements of the test. The pressure may be read on a calibrated bourdon-type pressure gage; for very low pressures or more accurate measurements a mercury-filled manometer or a dead-weight gage should be used.

(*b*) *Detailed Procedure for Operation of Bureau of Mines Dew-Point Apparatus.*—Introduce the gas sample through valve *A* (Fig. 1), opening this valve wide if the test is to be made under full source pressure (Note 3), and controlling the flow by the small outlet valve, *D*. The rate of flow is not critical but should not be so great that there is a measurable or objectionable drop in pressure through the connecting lines and dew-point apparatus. A flow of 0.05 to 0.5 cu. ft. per min. (measured at atmospheric pressure) usually will be satisfactory. With liquefied refrigerant gas piped to the chiller throttle valve, *H*, "crack" the valve momentarily, allowing the refrigerant to vaporize in the chiller to produce suitable lowering in temperature of the chiller tube, *F*, and target mirror, *C*, as indicated by the thermometer, *K*. The rate of cooling may be as rapid as desired in making a preliminary test. After estimating the dew-point temperature, either by a preliminary test or from other knowledge, control the cooling or warming rate so that it does not exceed 1 F. per min. when this temperature is approached. For accurate results, the cooling and warming rates should approximate isothermal conditions as nearly as possible. The most satisfactory method is to cool or warm the target mirror stepwise. Steps of about 0.2 F. allow equilibrium conditions to be approached closely and favor an accurate determination. When dew has been deposited, allow the target mirror to warm up at a rate comparable to the recommended rate of cooling. The normal warming rate usually will be faster than desired. To reduce the rate, "crack" valve *H* momentarily at intervals to supply cooling to the cooling tube, *F*. Repeat the cooling and warming cycles several times. The arithmetic average of the temperatures at which dew is observed to appear and disappear is considered to be the observed dew point.

TABLE I.—VAPOR PRESSURES AND SPECIFIC VOLUMES OF SATURATED WATER VAPOR AT VARIOUS TEMPERATURES[a]

Temperature, deg. Fahr.	Vapor Pressure of Liquid Water		Vapor Pressure of Ice		Specific Volume of Saturated Water Vapor, cu. ft. per lb.	Temperature, deg. Fahr.	Vapor Pressure of Liquid Water, psi. absolute	Specific Volume of Saturated Water Vapor, cu. ft. per lb.
	mm. of mercury	psi. absolute	mm. of mercury	psi. absolute				
0..........	1.139	0.022 02	0.958	0.018 52	14 810			
1..........	1.195	0.023 11	1.010	0.019 53	14 080	51........	0.184 73	1 645.4
2..........	1.251	0.024 19	1.063	0.020 56	13 400	52........	0.191 69	1 588.7
3..........	1.310	0.025 33	1.120	0.021 66	12 750	53........	0.198 88	1 534.3
4..........	1.373	0.026 55	1.180	0.022 82	12 140	54........	0.206 30	1 481.9
5..........	1.436	0.027 77	1.241	0.024 00	11 550	55........	0.213 97	1 431.5
6..........	1.505	0.029 10	1.308	0.025 29	11 000	56........	0.221 88	1 383.1
7..........	1.573	0.030 42	1.374	0.026 57	10 480	57........	0.230 06	1 336.5
8..........	1.647	0.031 85	1.446	0.027 96	9 979	58........	0.238 49	1 291.7
9..........	1.723	0.033 32	1.521	0.029 41	9 507	59........	0.247 20	1 248.6
10..........	1.807	0.034 94	1.599	0.030 92	9 060	60........	0.256 18	1 207.1
11..........	1.883	0.036 41	1.681	0.032 51	8 636	61........	0.265 45	1 167.2
12..........	1.970	0.038 09	1.767	0.034 17	8 234	62........	0.275 02	1 128.7
13	2.057	0.039 78	1.856	0.035 89	7 851	63........	0.284 88	1 091.7
14..........	2.149	0.041 56	1.950	0.037 71	7 489	64........	0.295 05	1 056.1
15..........	2.247	0.043 45	2.050	0.039 64	7 144	65........	0.305 54	1 021.7
16..........	2.345	0.045 35	2.151	0.041 59	6 817	66........	0.316 36	988.65
17..........	2.450	0.047 37	2.260	0.043 70	6 505	67........	0.327 50	956.78
18..........	2.557	0.049 44	2.373	0.045 89	6 210	68........	0.339 00	926.08
19..........	2.607	0.051 63	2.489	0.048 13	5 929	69........	0.350 84	896.49
20..........	2.785	0.053 85	2.610	0.050 47	5 662	70........	0.363 04	867.97
21..........	2.907	0.056 21	2.740	0.052 98	5 408	71........	0.375 61	840.47
22..........	3.032	0.058 63	2.872	0.055 54	5 166	72........	0.388 56	813.97
23..........	3.163	0.061 16	3.013	0.058 26	4 936	73........	0.401 90	788.40
24..........	3.299	0.063 79	3.160	0.061 10	4 717	74........	0.415 64	763.75
25..........	3.433	0.066 38	3.310	0.064 01	4 509	75........	0.429 79	739.97
26..........	3.585	0.069 32	3.471	0.067 12	4 311	76........	0.444 35	717.03
27..........	3.735	0.072 22	3.636	0.070 31	4 122	77........	0.459 35	694.90
28..........	3.893	0.075 28	3.810	0.073 67	3 943	78........	0.474 78	673.54
29..........	4.054	0.078 39	3.989	0.077 14	3 771	79........	0.490 66	652.93
30..........	4.224	0.081 68	4.178	0.080 79	3 608	80.......	0.507 01	633.03
31..........	4.397	0.085 02	4.373	0.084 56	3 453	81........	0.523 82	613.82
32..........	4.579	0.088 54	4.579	0.088 54	3 305	82........	0.541 12	595.27
33..........	...	0.092 227	...	...	3 180.5	83........	0.558 92	577.36
34..........	...	0.095 999	...	...	3 061.7	84........	0.577 22	560.06
35..........	...	0.099 908	...	...	2 947.8	85........	0.596 04	543.35
36..........	...	0.103 96	...	...	2 838.7	86........	0.615 40	527.21
37..........	...	0.108 15	...	...	2 734.1	87........	0.635 30	511.62
38..........	...	0.112 49	...	...	2 633.8	88........	0.655 75	496.54
39..........	...	0.116 99	...	...	2 537.6	89........	0.676 78	481.98
40..........	...	0.121 64	...	...	2 445.4	90........	0.698 38	467.90
41..........	...	0.126 46	...	...	2 356.9	91........	0.720 59	454.28
42..........	...	0.131 45	...	...	2 272.0	92........	0.743 40	441.12
43..........	...	0.136 60	...	...	2 190.5	93........	0.766 84	428.40
44..........	...	0.141 94	...	...	2 112.3	94........	0.790 91	416.09
45..........	...	0.147 46	...	...	2 037.3	95........	0.815 64	404.19
46	...	0.153 17	...	...	1 965.2	96........	0.841 03	392.67
47..........	...	0.159 07	...	...	1 896.0	97........	0.867 11	381.53
48..........	...	0.165 17	...	...	1 829.5	98........	0.893 88	370.75
49..........	...	0.171 48	...	...	1 765.7	99........	0.921 37	360.32
50..........	...	0.177 99	...	...	1 704.3	100........	0.949	350.22

[a] The values for vapor pressure, from 0 F. to 32 F., were calculated from data in the International Critical Tables.[4] All other values were taken from the "Heating, Ventilating, Air Conditioning Guide," Am. Soc. Heating and Air-Conditioning Engineers, 1958, pp. 41–44. Data on specific volumes of saturated water vapor at various temperatures obtained were from Goff and Gratch.[5]

NOTE 3.—If the water vapor content is to be calculated as described in Section 5(*b*), the gas sample should be throttled at the inlet valve, *A*, to a pressure within the apparatus approximately equal to atmospheric pressure. The outlet valve may be left wide open or restricted, as desired. The pressure existing within the apparatus must, however, be known to the required accuracy.

Calculations

5. (*a*) If an acceptable chart showing the variation of water vapor content with saturation or water dew-point temperatures over a suitable range of pressures for the gas being tested is available, the water vapor content may be read directly, using the observed water dew-point temperature and the pressure at which the determination was made.

(*b*) If such a chart is not available, the water vapor content of the gas may be calculated from the water dew-point temperature and the pressure at which it was determined (see Note 3, Section 4), as follows:

$$W = w \times 10^6 \times \frac{P_b}{P} \times \frac{T}{T_b}$$

where:

W = pounds of water per million cubic feet of gaseous mixture at pressure P_b and temperature T_b,

w = weight of saturated water vapor, in pounds per cubic foot, at the water dew-point temperature, that is, the reciprocal of the specific volume of saturated vapor (Table I),

P_b = pressure-base of gas measurement, in pounds per square inch absolute pressure,

P = pressure at which the water dew point of gas was determined, in pounds per square inch absolute pressure,

t = observed water dew-point temperature, in degrees Fahrenheit,

T = Rankine (Absolute fahrenheit scale) water dew point, $t + 460$, at pressure P, and

T_b = base temperature of gas measurement, $t_b + 460$.

Note 4: *Example 1*

Given: Water dew point = 37 F. at 15.0 psi. absolute pressure,

What is the water vapor content per million cubic feet of gas (gas measurement base of 60 F. and 14.7 psi. absolute pressure)?

From Table I the specific volume of saturated water at 37 F. is 2734.1 cu. ft. per lb., from which:

$$w = \frac{1}{2734.1} = 0.0003658 \text{ lb per cu. ft.}$$

and

$$W = 0.0003658 \times 10^6 \times \frac{14.7}{15.0} \times \frac{460 + 37}{460 + 60}$$
$$= 344 \text{ lb. per million cubic feet}$$

Example 2

Given: Water dew point = 5 F. at 14.4 psi. absolute pressure,

From Table I, the specific volume of saturated water vapor with respect to ice at 5 F. is 11,550 cu. ft. per lb., from which $W_{ice,\ 5F} = 0.0000866$, but the observed water dew point was in equilibrium with subcooled liquid water at 5 F. From Table I (data from International Critical Tables[4]), the vapor pressures of subcooled liquid water and of ice at 5 F. (−15 C.) are 1.436 mm. and 1.241 mm. of mercury, respectively.

Since the vapor pressure of subcooled liquid water is greater than ice at the same temperature, the weight per cubic foot of water vapor in equilibrium with liquid water will be proportionately larger than the value calculated from the specific volume read from the table, which is for equilibrium with ice.

Hence,

$$W_{liq.,\ 5F} = W_{ice\ 5F} \times \frac{1.436}{1.241}$$
$$= 0.0000866 \times 1.157$$
$$= 0.0001002$$

and

$$W = 0.0001002 \times 10^6 \times \frac{14.7}{14.4} \times \frac{460 \times 5}{460 + 60}$$
$$= 91.5 \text{ lb. per million cubic feet}$$

In reporting the results of this test, state the dew-point temperature and the pressure at which it was measured as well as the water content in pounds per million cubic feet of gaseous mixture.

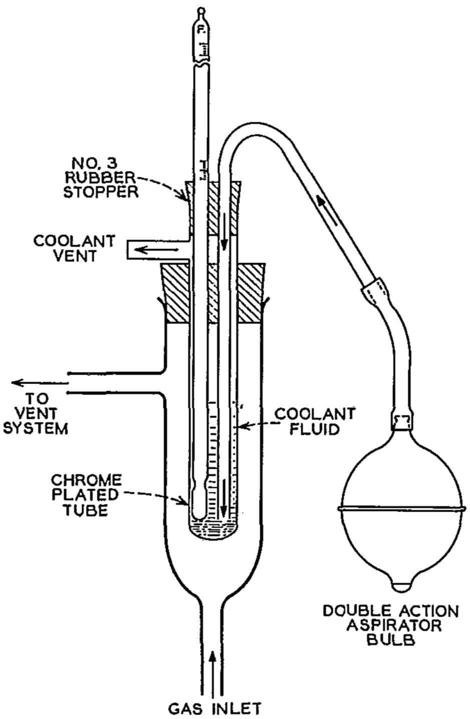
(ASTM Section 5(c) and Fig. 2 and Tables II and III not included.)

SIMPLIFIED METHOD OF MEASUREMENT OF THE WATER DEW-POINT TEMPERATURE OF GAS

Scope

This method of test is designed for use at normal atmospheric pressure for the determination of the water dew-point temperature of gas. It is a simple procedure suitable for field testing work. The lowest readings attainable are of the order of zero degrees Fahrenheit.

The equipment (See Figure) consists of a highly polished metal tube incased in a glass jacket. Facilities are provided to cool the metal tube and to measure the temperature of this tube.



Dew Point Apparatus

Procedure

The highly polished tube is filled about one-third of its capacity with a low boiling solvent such as acetone or ether. The rubber stopper assembly including the thermometer and aspirator tube is replaced in the metal tube. Gas is admitted to the apparatus at a slow rate and then it is vented to a safe location. The metal tube is cooled by aspiration of air through the solvent. The temperature of the dew point of the gas corresponds to the initial appearance of moisture on the surface of the highly polished tube. A slight rise in the temperature of the metal tube will cause the film moisture to disappear. Successive observations will show agreement within 2°F of the dew-point temperature.

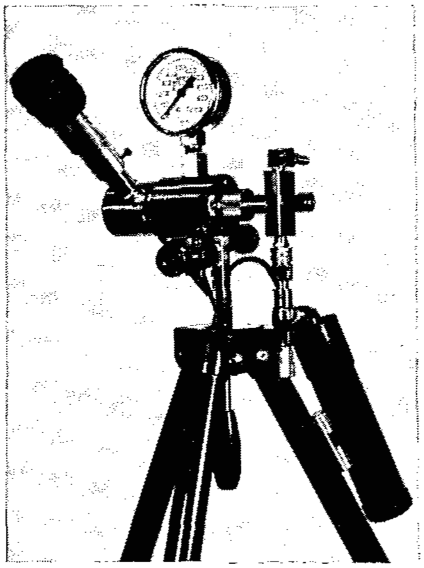
Calculation

Calculations described in paragraph 5, page 42, are equally applicable to this method.

METHOD OF MEASUREMENT OF THE OIL DEW-POINT TEMPERATURE OF GAS

Scope

This method of test is used to indicate the likelihood that hydrocarbons will condense under conditions of use of the gas by measuring the temperature at which the oil dew-point occurs: (a) Condensation of water vapor may interfere with the measurement of the oil dew-point observation. This method is limited to gaseous fuels having a water dew point lower than the oil dew point. (b) This method is limited to conditions wherein the dew-point temperature at the test pressure is lower than the ambient temperature of the test equipment and the temperature of the pipeline conducting the gas from the source to the apparatus.



Oil Dew Point Apparatus

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[4] "International Critical Tables," National Research Council, Vol. III, pp. 210–211, (1928). Published by McGraw-Hill Book Co., Inc., New York, N. Y.

[5] John A. Goff and S. Gratch, "Low-Pressure Properties of Water from −160 to 212 F.," *Heating, Piping, and Air Conditioning*, Vol. 18, No. 2, February, 1946 pp. 125–136.

Apparatus

Recent developments have resulted in improvements in the U.S. Bureau of Mines Dew-Point Apparatus which is described previously in the Standard Method for Test and Water Vapor Content of Gaseous Fuels by Measurement of the Dew-Point Temperature, ASTM Designation D 1142-63. The significant structural features include: (a) the optical system provides 16X magnification, (b) the reflecting mirror to the optical system provides additional safety for the operator should the viewing window of the test cell rupture at elevated pressures; (c) a uniform source of illumination is supplied by the use of an incandescent light bulb; (d) the entire equipment is mounted on an adjustable tripod for ease of handling.

The accompanying illustration shows the equipment[1] assembled for test.

Procedure

The test procedure is comparable to the test procedure described previously in ASTM Designation D 1142-63. In accordance with this procedure, it will be noted that an iridescent film appears on the cooled mirror surface when the oil dew-point temperature is attained. Attainable accuracy of test is 2°F. Further cooling of the mirrored surface will result in a distinct heavy deposit of moisture when the water dew point is reached.

(*Precaution*: The maximum working pressure of the instrument should not be exceeded.)

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[1] This equipment is available from UGC Instruments, Shreveport, La.

Standard Method of Test for

TOTAL SULFUR IN FUEL GASES

ASTM Designation: D 1072–56

Approved as USA Standard Z77.6–1963

(*Identical with ASTM Procedures*)

Scope

1. This method is intended for the determination of total sulfur in combustible fuel gases, when present in concentrations between 1.0 and 30 grains of sulfur per 100 cubic feet. It is applicable to natural gases, manufactured gases, and mixed gases, such as are distributed by gas utility companies.

Outline of Method

2. A metered sample of gas is burned in a closed system in an atmosphere of sulfur-free air. The oxides of sulfur produced are absorbed in sodium carbonate solution, wherein they are oxidized to sulfate. The sulfate in the absorbent solution is subsequently determined by titration with standard barium chloride solution, using tetrahydroxyquinone as an indicator.

Apparatus

3. The apparatus shall consist of the following:

(*a*) *Burner* (Fig. 1), as specified in the Appendix.

(*b*) *Chimneys, Absorbers and Spray Traps*, (Fig. 2), as specified in the Appendix.

(*c*) *Flowmeter.*—A calibrated capillary flowmeter for predetermining and indicating the rate of flow of gas to the burner. The capillary selected should be of such size that at the required rate of flow the differential pressure is at least 20 cm of water. A scale divided into millimeters will then provide a reading precision of ±0.5 per cent. Other metering devices, such as a rotameter or a dry displacement meter, will be suitable if the precision of reading the scale is equivalent. A flow controlling valve is attached to the inlet connection of the flowmeter.

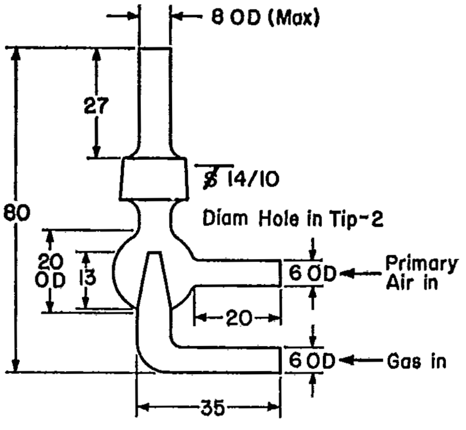
(*d*) *Vacuum System.*—A vacuum manifold equipped with a vacuum regulating device, valves, etc. A convenient arrangement for multiple tests is shown in Fig. 3, but any other similar system may be used. The system shall be connected to a vacuum pump of sufficient capacity to permit a steady gas flow of 3 liters of air per minute through each absorber and to maintain a constant manifold pressure of approximately 40 cm of water below atmospheric.

(*e*) *Air Purifying System.*—A device to supply purified air to the burner manifold at a nearly constant pressure of approximately 20 cm of water and to the chimney manifold at a pressure of 1 to 2 cm of water. A convenient arrangement for multiple tests is illustrated in Fig. 4, but any other similar system may be used. The tubing that connects the chimneys to the manifold shall be of an internal diameter not smaller than 0.63 cm in order to prevent unnecessary restriction of air flow.

(*f*) *Manometer.*—A water manometer for indicating the gas pressure at the point of volume measurement. It is connected between the flowmeter and the burner, with one leg open to the atmosphere.

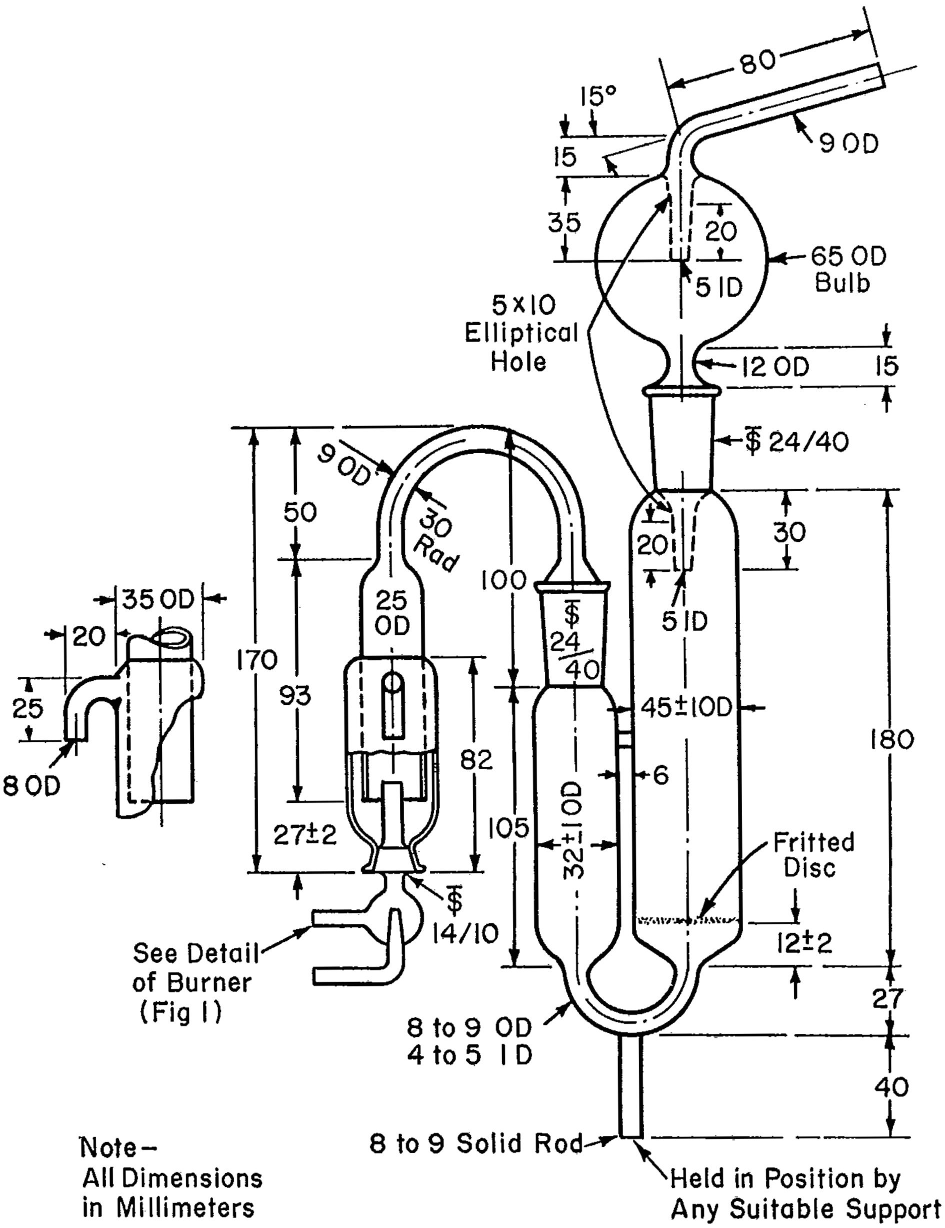
Reagents and Materials

4. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications established by the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. References to water shall be understood to mean distilled water.



Note.-All dimensions in millimeters

FIG. 1.—Gas Burner for Sulfur Determination.



Note - All Dimensions in Millimeters

NOTE.—In case of those dimensions for which no specific tolerances are designated above, the peremissible variation is ±10 per cent to the nearest millimeter, provided, however, that in no case shall the deviation be greater than 5 mm.

FIG. 2.—Detailed Drawing of Combustion and Absorption Apparatus for Sulfur Determination.

(*a*) *Alcohol.*—Ethyl alcohol, denatured by Formula 30 or 3-A, or isopropyl alcohol.

(*b*) *Standard Barium Chloride Solution (1 ml = 1 mg S).*—Dissolve 7.634 g of cp $BaCl_2 \cdot 2H_2O$ in water and dilute to 1 liter. Standardize the solution gravimetrically by precipitation as barium sulfate.

(*c*) *Hydrochloric Acid (2.275 g HCl per liter).*—Compare this solution by titration with the Na_2CO_3 solution (Paragraph (*g*)), using methyl orange indicator. Adjust, if necessary, so that 1 ml of HCl solution is equivalent to 1 ml of Na_2CO_3 solution.

(*d*) *Hydrogen Peroxide (30 per cent).*

(*e*) *Methyl Orange Indicator Solution.*—Dissolve 0.1 g of methyl orange in 100 ml of water.

(*f*) *Silver Nitrate Solution (17 g $AgNO_3$ per liter).*—Dissolve 1.7 g of $AgNO_3$ in 100 ml of water. Keep in a brown bottle.

(*g*) *Sodium Carbonate Solution (3.306 g Na_2CO_3 per liter).*—Dissolve 3.306 g of Na_2CO_3 in water and dilute to 1 liter.

(*h*) *Sodium Hydroxide Solution (100 g NaOH per liter).*—Dissolve 100 g. of technical grade NaOH pellets in water and dilute to 1 liter.

(*i*) *Sulfuric Acid (1:16).*—Mix 60 ml of H_2SO_4 (sp gr 1.84) with 960 ml of water.

(*j*) *Tetrahydroxyquinone Indicator (THQ)*, in powdered form.[3]

Preparation of Apparatus

5. (*a*) Place 300 to 400 ml of NaOH solution in the first scrubber (Fig. 4) and the same amount of H_2O_2 - H_2SO_4 solution (300 ml of water, 30 ml of H_2SO_4 (1:16), and 30 ml of H_2O_2 (30 per cent)) in the second scrubber. Replace these solutions whenever the volume becomes less than two thirds of the original.

(*b*) When the apparatus is first assembled, adjust the valve between the

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[3] Tetrahydroxyquinone Indicator (THQ) is obtainable from the W. H. and L. D. Betz Laboratories, Gillingham and Worth Sts., Philadelphia 24, Pa.

vacuum manifold and the spray trap so that approximately 3 liters of air per minute will be drawn through the absorber when the chimney outlet is open to the atmosphere, the absorber is charged with 30 ± 2 ml of water, and the pressure in the vacuum manifold is maintained at approximately 40 cm of water below atmospheric. When all adjustments have been made, remove the water from the absorbers.

(*c*) With the burner control valve closed, the valve to the vacuum regulator fully open, and the pressure in the vacuum manifold adjusted to approximately 40 cm of water below atmospheric, turn on the purified air. Adjust the chimney manifold control valve so that, at the required flow through the absorber, only a small stream of air escapes at the pressure-relief valve, a small stream of air enters at the vacuum regulator, and the pressure in the chimney manifold is 1 to 2 cm of water. Minor adjustment of the vacuum regulator and vacuum control valve may be necessary to achieve this condition (Note 1).

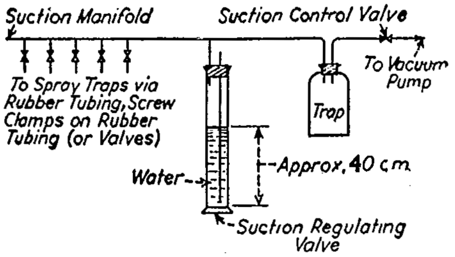

FIG. 3.—Suction System for Sulfur Determination.

NOTE 1.—It is convenient to balance the air flow system by regulating the pressure in the vacuum manifold. This is done by raising or lowering the air-inlet tube in the vacuum regulator by sliding it in a rubber sleeve.

(*d*) When first assembling the apparatus, connect the gas sample line by means of glass or aluminum tubing to the inlet of the flowmeter. Connect the outlet of the flowmeter in a similar way to the lower side-arm of the burner. Adjust the valve for controlling the rate of flow of gas so that gas is burned at a rate to liberate approximately 250 to 500 Btu per hour (Note 2). This rate should be indicated by two index marks on the columns of the flowmeter U-tube or timing a rate-index device. Make the primary air connection from the purified air line to the upper side arm of the burner by means of rubber or plastic tubing.

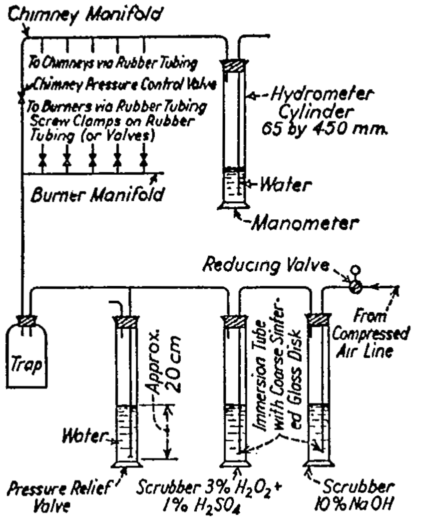

FIG. 4.—Purified Air System for Sulfur Determination.

NOTE 2.—Using this gas rate, the chimney and absorber should not become overheated during a test. The appropriate volumetric rate of gas flow will therefore depend on the heating value of the gas being tested.

(*e*) Wash the spray trap, absorber, and chimney well with water before each test. Charge the larger bulb of the absorber with 10 ml of Na_2CO_3 solution (Note 3) and 20 ml of water. Attach the spray trap and chimney, and connect them respectively to the vacuum line and to the purified air line by means of rubber or plastic tubing. Close the chimney opening by means of a cork.

NOTE 3.—This quantity of Na_2CO_3 solution is adequate to absorb the SO_2 from the combustion products of 1 cu ft of gas containing 15 grains of sulfur per 100 cu ft. For higher concentrations of sulfur in the gas, the volume of Na_2CO_3 solution should be proportionately increased, but the total initial liquid volume in the absorber should not exceed 30 ml.

Procedure

6. (*a*) Before the beginning of each test, purge the flowmeter, burner, and connection with the gas sample, and light the flame on the burner. Adjust the gas flow rate by its valve to conform with the requirements prescribed in Section 5 (*d*). Adjust the primary air flow so that a soft blue flame is obtained, with no yellow tip.

(*b*) To start a determination, the suction on the absorber and the air flow having been adjusted, insert the burner into the chimney, fastening it in place with rubber bands or springs. Check, and readjust if necessary, the indicated rate of gas flow and the primary air flow to obtain a stable flame. Note the time at which the burner was inserted, or note the meter reading if an integrating meter is used.

(*c*) Continue the test until approximately 1 cu ft of gas is burned. Maintain the flowmeter differential at a constant value during this period. Note the time, or the meter reading if an integrating meter is used, and remove the burner from the chimney, replacing it with the cork, continuing the suction on the absorber until the latter attains room temperature. Extinguish the flame.

(*d*) Unless an integrating type meter is used for gas measurements, disconnect the burner from the flowmeter. Attach in its place a connection to a calibrated wet test meter (0.100 cu ft per revolution) that has been purged with 5 cu ft of the gas being tested. Adjust the flowmeter differential and the manometer reading to that existing during the determination in Paragraph (*c*), and time with a stopwatch one complete revolution of the wet test meter. A needle value may be required at the inlet of the wet test meter in order to adjust the pressure and flow of gas so that both the flowmeter and the manometer indicate the same values, respectively, that existed during the determination. Calculate the volume of gas in standard cubic feet burned during the determination as follows:

$$V = \frac{t_d}{10t_o} \times \frac{520}{T_d} \times \frac{\left(P + \frac{m}{13.6} - w\right)}{30 - 0.522}$$

where:

V = volume of sample burned, in standard cubic feet at 60 F, 30 in. of mercury, saturated,
t_d = time for determination, in seconds,
t_o = time of one revolution of wet test meter during calibration, in seconds,
T_d = meter temperature, degrees Fahrenheit absolute,
P = barometric pressure, in inches of mercury,

m = manometer reading, in inches of water, and
w = vapor pressure of water at meter temperature, in inches of mercury.

NOTE 4.—This calibration procedure avoids the necessity of calculating corrections of the flowmeter calibration for each gas tested, and is believed to be more precise.

(*e*) If a calibrated integrating dry displacement meter is used for gas measurements, calculate the volume of gas in standard cubic feet burned during the determination as follows:

$$V = V_m \frac{520}{T_d} \times \frac{\left(P + \frac{m}{13.6} - w'\right)}{30 - 0.522}$$

where:
V_m = meter reading at end of determination minus the meter reading at the start of the determination, in cubic feet,
w' = actual partial pressure of water vapor in gas at dry meter temperature, and
all other symbols are defined as in Paragraph (*d*).

Analysis of Absorbent

7. (*a*) When the absorber has cooled to room temperature, wash the chimney and trap with the smallest possible quantity of water, and add the washings to the solution in the absorber. Add three drops of methyl orange indicator to the solution. Titrate the excess Na_2CO_3 in the absorber with HCl to the methyl orange end point, mixing the solution after each addition of acid by alternate sucking and blowing on one end of the absorber.

(*b*) Discharge the tan color of the acid methyl orange with a few drops of Na_2CO_3 solution and add 50 ml of ethyl or isopropyl alcohol. Add about 0.5 g of tetrahydroxyquinone indicator (THQ). After mixing the solution well, titrate with $BaCl_2$ solution. After 1 or 2 ml of the $BaCl_2$ solution have been added, add 1 ml of 0.1 *N* $AgNO_3$ solution, and continue titration to the end point. The end point is reached when the color of the solution changes from yellow to rose, which is persistent with good mixing. Note and record the volume of $BaCl_2$ solution required to produce the red color.

NOTE 5.—The $AgNO_3$ intensifies the rose color at the end point.

Calculation of Results

8. Calculate the concentration of sulfur in grains per 100 standard cubic feet of gas from the results of the $BaCl_2$ titration, as follows:

$$\text{Sulfur concentration} = \frac{A - 0.2}{V} \times 1.543$$

where:
A = milliliters of $BaCl_2$ solution required for the titration (Section 7(*b*)), and
V = volume of sample burned, in standard cubic feet.

NOTE.—The 0.2 ml subtracted from the $BaCl_2$ titer is a blank allowance for the titration end point.

Precision and Accuracy

9. (*a*) The accuracy of the results of a determination depends on the accuracy with which the sample volume is metered as well as on the accuracy of the titration procedure. With care, when 1 cu ft of gas is burned an absolute precision equivalent to ±0.1 grain of sulfur per 100 cu ft of gas should be attainable in the $BaCl_2$ titration, independent of the total quantity of sulfate present in the absorber. The overall accuracy should therefore be between ±0.1 and ±0.7 grain of sulfur per 100 cu ft, if metering accuracy of ±2 per cent is attained, over the concentration range to which the procedure is adaptable.

APPENDIX

APPARATUS

A1. *Burner.*—A burner of chemically resistant glass that conforms with the dimensions shown in Fig. 1. It consists of a burner tube to which the gas sample is admitted through a side arm and orifice at the lower end. Surrounding the gas orifice tip is a spherical enlargement of the burner tube into which purified primary air for combustion is admitted. The burner tube is provided with a standard-taper glass joint for connection with the chimney. The upper end of the burner tube shall be polished. When connected with the chimney the burner shall be held in position by rubber bands or metal springs stretched between glass hooks on the burner and chimney.

A2. *Chimney.*—A chimney of chemically resistant glass conforming to the dimensions shown in Fig. 2, provided with standard-taper glass joints for connection with the burner and absorber.

A3. *Absorber.*—An absorber of chemically resistant glass conforming to the dimensions shown in Fig. 2, provided with standard-taper glass joints for connection with the chimney and spray trap. A fritted disk with average pore diameter from 150 to 200 μ shall be sealed in the larger of the two bulbs of the absorber. The fritted disk should be of such a permeability that, when 50 ml of water is placed in the absorber and air is passed through at the rate of 3.0 liters per min in the forward direction, the pressure differential between the two sides of the absorber is between 15 and 23 cm of water and the air is dispersed uniformly.

A4. *Spray Trap.*—A spray trap of chemically resistant glass conforming to the dimensions shown in Fig. 2, provided with a standard-taper glass joint for connection with the absorber.

METHOD OF TEST FOR HYDROGEN SULFIDE IN GAS

When the principal sulfur containing gas is hydrogen sulfide, or when this is substantially the only variable sulfur containing component, it may be desirable to determine the amount of this specific component. A method for this determination follows. The test is also used by gas utilities as a control method.

Scope

This method is used for chemical control of tests when the hydrogen sulfide concentration is in excess of 10 grains per 100 cubic feet of gas. Other procedures are available for concentrations below this value.

Principle of Method

A sample of gas, 100 ml or more, is placed in a glass vessel, the pressure is reduced slightly and the hydrogen sulfide is titrated with standard iodine solution.

Apparatus

The apparatus needed is a Tutwiler burette, 100 ml capacity, with a two-way glass stopcock at the bottom and a three-way stopcock at the top connecting with a glass-stoppered cylinder, 10 ml capacity graduated in 0.1 ml subdivisions. Rubber tubing is used to connect the bottom of the burette to a leveling bottle as shown in the accompanying illustration.

Reagents

(a) Iodine Stock Solution, 0.100 N: For each 1000 ml of solution, weigh 12.7 g of iodine in a glass-stoppered weighing bottle and 20 to 25 g of C.P. potassium iodide. Dissolve the KI in as little water as possible; dissolve the iodine in the concentrated KI solution, make up to the proper volume, and store in a glass-stoppered brown glass bottle.

(b) Standard Iodine Solution, 1 ml = 0.00171 gI: Transfer 33.7 ml of the 0.100 N stock solution into a 250 ml volumetric flask; add water to the mark and mix well. Then: 1 ml = 0.00171 gI = 100 grains H_2S per 100 cubic feet of gas, measured at 60°F and 30.0 in. Hg, saturated.

(c) Starch Solution: Rub 10 g of potato starch into a thin paste with a small amount of cold water; pour into one liter of boiling water; stir while boiling; cool and then decant off the clear solution. Make a fresh solution every few days.

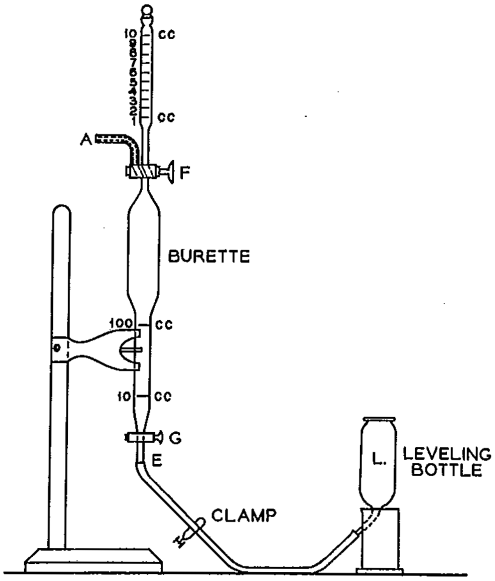

Fig. 43. – Tutwiler Apparatus

Procedure

(a) Fill the leveling bottle (L) with starch solution.

(b) Raise (L), open cock (G), open (F) to (A), and close (F) when the solution begins to run out of gas inlet tube (A). Then close (G).

(c) Purge the gas sampling line and connect it with (A). If the gas contains dust or tarry matter, purge through a tube packed with glass, wool, or absorbent cotton.

(d) Lower (L) and open (F) to (A) and also open (G). When the liquid level is several ml past the 100 ml mark, close (G) and (F) and disconnect the sampling tube at (A).

(e) Open (G) and bring the starch solution to the 100 ml mark by raising (L), then close (G).

(f) Open (F) momentarily to bring the gas in the burette to atmospheric pressure and then close (F).

(g) Open (G), bring the liquid level down to the 10 ml mark by lowering (L). Close (G), clamp the rubber tubing near (E) and disconnect it from the burette.

(h) Rinse the glass-stoppered measuring cylinder at top of burette twice with the standard iodine solution (0.00171 gI per ml); fill the cylinder and record the reading.

(i) Introduce successive small amounts of iodine through (F); shake well after each addition; and continue until a faint permanent blue color is obtained.

(j) Record the reading; subtract from the previous reading and call the difference (X).

(k) With every fresh stock solution, perform a blank test using air instead of gas in the procedure as described above. The amount of iodine used in the blank test is recorded as (Y).

Calculations

Grains H_2S per 100 cubic feet = $100\,[(X)-(Y)]$.

Note: Where the concentration of hydrogen sulfide is low, or where a more precise determination is desired, Tutwiler burette of 500 ml capacity may be used. When warranted, the test result should be corrected for deviation of temperature and pressure from standard conditions.

Dust

It may, sometimes, be necessary to determine the dust concentration in the gas used as fuel. When this is the case, the determination will usually be limited to observation of the dust larger in particle size than 1 micron. The methods for this analysis are those given in the Test Code for Determining Dust Concentration in a Gas Stream (PTC 27). While the methods there given were originally intended for use in determining the dust content of flue gases arising from the combustion of solid fuels either in pulverized form or on stokers, the principles apply to fuel gases when proper precautions are taken for safe disposal of off-gas.

Heat Value

The terms High-Heat Value and Low-Heat Value abbreviated hhv and lhv, as defined in the Performance Test Code on Definitions and Values (PTC 2—1945), are used herein to designate the quantity of heat transmitted in a fuel calorimeter as a result of the complete reaction of unit quantity of fuel with oxygen and the cooling of products to the initial temperature. Heating Value, Heat of Combustion, and Calorific Value are also in common use to designate this characteristic, the last mentioned being favored by the ASTM in its Standard Method of Test.

The heat value which is usually determined for gases is that at constant pressure in which the gas is burned at constant pressure and the products of combustion may expand and thus do work against the ambient pressure. This type of determination is convenient for flow calorimeters which are invariably used to determine the heat value of gas, ut it is also appropriate, since all uses f gas as a fuel for the production of ower and heat have to be compared, ultimately, with a constant pressure standard. There is, however, another method of burning, that at constant volume, which yields a different heat value which may be important for calculation of processes such as those occurring within the cycle of internal-combustion engines and in bomb calorimeters. Constant pressure and constant volume heat values may be reconciled by calculation; further discussion of the constant volume heat value is given in Par. 134 of the Performance Test Code on Definitions and Values (PTC 2—1945).

According to the Code on Definitions and Values:

> The high-heat value at constant pressure of a fuel may be defined as the heat transferred from the products of combustion . . . per unit standard volume of gas fuel, when the products are cooled to the initial temperature of the . . . air-fuel mixture, and includes the enthalpy of vaporization of all the water of combustion from the hydrogen in the fuel. . . . The pressure and temperature may be taken at the prevailing atmospheric values. The low-heat value at constant pressure is defined the same as the high except that the enthalpy of vaporization of the water of combustion is excluded from the heat transferred on the assumption that the water of combustion is not condensed.

Only the high-heat value actually is determined by available calorimetric methods. The low-heat value can be calculated from an experimental determination by reducing the observed value in proportion to the quantity of water formed. This requires knowledge either of the quantity of water formed during combustion of unit quantity of gas, or of the chemical composition of the gas. In the following ASTM Standard the terms "total" and "net calorific value" correspond respectively to high- and low-heat value, with due regard to the differences in standard conditions referred to under Object and Scope—Definitions, paragraph on Standard Conditions and Table 1 (page 2).

Standard Method of Test for

CALORIFIC VALUE OF GASEOUS FUELS BY THE WATER-FLOW CALORIMETER

ASTM Designation: D 900–55

Approved as USA Standard Z68.1–1956

(*Identical with ASTM Procedures*)

Scope

1. (*a*) This method of test is intended for use when water-flow calorimeters[3] are used to determine the total and net calorific values of fuel gases as purchased and sold. The method is restricted to gaseous fuels having total calorific values in the range from 475 to 3300 Btu. per standard cubic foot.

NOTE.—Determination of calorific value of the higher Btu gases within the maximum permissible differences requires careful observation by expert operators of procedures as specified in this method. See Section 20.

(*b*) The subjects covered in this method appear in the following order:

Terminology

2. The most important terms used in connection with the determination of calorific values of gaseous fuels in water-flow calorimetry are as follows:

(*a*) *Standard Temperature.*—The standard temperature is 60 F., based on the international temperature scale.

(*b*) *Standard Pressure.*—The standard pressure is the absolute pressure of a column of pure mercury 30 in. in height at 32 F. and under standard gravity (32.174 ft. per sec. per sec.).

(*c*) *British Thermal Unit.*—A British thermal unit, or Btu., is the quantity of heat that must be added to one avoirdupois pound of pure water to raise its temperature from 58.5 F. to 59.5 F. under standard pressure.

(*d*) *Standard Cubic Foot of Gas.*—A standard cubic foot of gas is the quantity

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[3] Water-flow calorimeters such as those made by the American Meter Co., New York, N. Y., and the Precision Scientific Co., Chicago, Ill., or their equivalent, are considered satisfactory for this test.

of any gas that at standard temperature and under standard pressure will fill a space of 1 cu. ft. when in equilibrium with liquid water.

NOTE.—According to Dalton's Law, this is equivalent to stating that the partial pressure of the gas is:
30 − 0.522 = 29.478 in. of mercury column

(*e*) *Total Calorific Value.*—The total calorific value of a gas is the number of British thermal units evolved by the complete combustion, at constant pressure, of one standard cubic foot of gas with air, the temperature of the gas, air, and products of combustion being 60 F. and all of the water formed by the combustion reaction being condensed to the liquid state.

(*f*) *Net Calorific Value.*—The net calorific value of a gas is the number of British thermal units evolved by the complete combustion, at constant pressure, of one standard cubic foot of gas with air, the temperature of the gas, air, and products of combustion being 60 F. and all of the water formed by the combustion reaction remaining in the vapor state.

NOTE 1.—The net calorific value of a gas is its total calorific value minus the latent heat of evaporation at standard temperature of the water formed by the combustion reaction.

NOTE 2.—The definitions given in Paragraphs (*e*) and (*f*) are for total and net calorific values per standard cubic foot of gas. The definitions corresponding to any other unit quantity of gas are obtained by substituting the name of the desired unit in place of the term "standard cubic foot" in the definitions. Methods of calculating calorific values per cubic foot of gas under any desired conditions of pressure, temperature, and water vapor content are specified in Section 19.

(*g*) *Observed Calorific Value.*—The observed calorific value is the number of British thermal units obtained by multiplying the pounds of water heated in a calorific-value test by its corrected temperature rise in degrees Fahrenheit, and dividing by the number of standard cubic feet of gas burned.

(*h*) *Theoretical Air.*—The theoretical air is the volume of air that contains the quantity of oxygen, in addition to that in the gas itself, consumed in the complete combustion of a given quantity of gas.

NOTE.—By oxygen in the gas is meant any oxygen that may be present, including that from air in air-gas mixtures. For example, if the total amount of oxygen in 1 cu. ft. of an air-gas mixture is equal to that in 0.5 cu. ft. of air, then the theoretical air per cubic foot of the air-gas mixture will be less by 0.5 cu. ft. than that calculated from the combustible constituents of the mixture. Theoretical air may be expressed in various units, such as cubic feet of air per cubic foot of gas, where gas and air are measured under the same conditions, standard cubic feet of air per 100 Btu. of total calorific value, etc.

(*i*) *Excess Air.*—The excess air is the quantity of air passing through the combustion space in excess of theoretical air.

NOTE.—Expressed as a percentage, it is the amount of air in excess of theoretical air, divided by the theoretical air, and multiplied by 100.

(*j*) *Combustion Air.*—The air passing into the combustion space of the calorimeter (theoretical air plus excess air).

(*k*) *Products of Combustion.*—The products of combustion are all substances resulting from the burning of gas with its theoretical air, including the inert constituents of the gas and the theoretical air, but excluding excess air.

(*l*) *Flue Gases.*—The flue gases are the products of combustion remaining in the gaseous state together with the excess air.

(*m*) *Standard Rate of Combustion.*—The standard rate of combustion of any gas in the calorimeter is that which is equivalent to 3000 Btu. per hr. of total calorific value (see Table I).

(*n*) *Humidity-Correction Procedure.*—The humidity-correction procedure for making a calorific value test is that procedure in which the combustion-air drawn into the calorimeter is taken directly from the room, its temperature, pressure, and moisture content are determined at the time of the test, and a so-called humidity correction is applied to the observed calorific value to take account of the heat of vaporization of the difference in the amounts of water vapor entering and leaving the calorimeter.

(*o*) *Humidity-Control Procedure.*—The humidity-control procedure for making a calorific value test is that procedure in which the moisture content of the combustion air is artificially maintained at a value such that the amounts of water vapor entering and leaving the calorimeter are equal (or nearly so) and the humidity correction is zero (or very small).

APPARATUS

Types of Calorimeters

3. (*a*) Two types of water-flow calorimeters,[3] to which the procedures and data given in this method apply, are illustrated in Figs. 1 and 2. The parts of the apparatus illustrated include an 0.1-cu. ft. wet test meter for measuring the volume of gas burned in a test, a calorimeter body in which the gas is burned, and where the heat produced is absorbed in a stream of water, a balance and weights for weighing the water heated in a test, a psychrometer for measuring the humidity of the air, thermometers for measuring temperatures of water, room, gas, and flue gases, a 0.1-cu.-ft. bottle for use in calibrating the wet test meter, a gas pressure regulator, and a graduated cylinder for measuring the water condensed in the calorimeter. Other essential items of equipment, not shown in Figs. 1 and 2, include a barometer for measuring atmospheric pressure, an apparatus for volumetric analysis of gas and flue gases, and a stopwatch, or its equivalent, for measuring the time of revolution of the meter index. A humidifier for use in the humidity-control procedure is illustrated in Fig. 5.

(*b*) A sectional view of a water-flow calorimeter is shown in Fig. 3, which is largely self-explanatory. Water from a storage tank enters at a rate somewhat in excess of that required at the point indicated at the upper left of the figure. The excess flows over the inlet-water weir, and to the drain. The remainder of the entering water flows downward through the inlet-water tube, past the bulb of the inlet-water thermometer which measures its temperature, through the indicating quadrant valve which controls the rate of flow, and enters the calorimeter through a water-circulating ring which distributes the water uniformly around the bottom of the heat-exchange unit. The water then flows upward in contact with the wall of the combustion chamber and the outside of the flue tubes of the heat-exchange unit, over the top of the combustion chamber, past the baffle plates where it is mixed to promote uniformity of temperature, past the bulb of the outlet-water thermometer, and leaves the calorimeter by flowing over the outlet-water weir and through

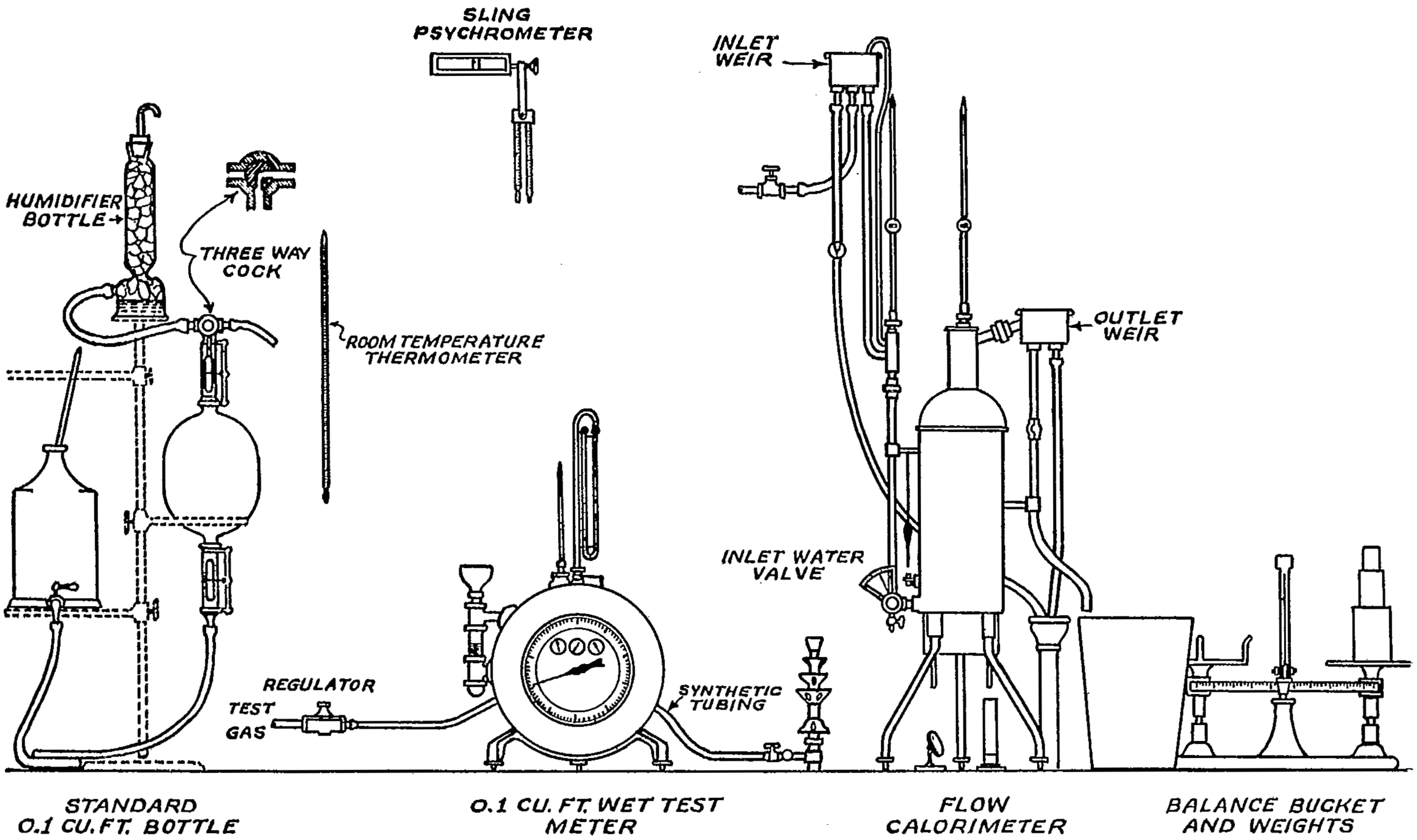

FIG. 1.—Precision Flow Calorimeter Assembly.

the three-way valve to either a weighing bucket or the drain. The constant head of water between the inlet- and outlet-water weirs serves to maintain a constant rate of flow of water through the calorimeter, provided the resistance to such flow remains constant.

Gas is burned at a uniform rate in the combustion chamber. The products of combustion and excess air rise to the top of this chamber, where they are deflected and caused to flow downward through the flue-tubes of the heat exchange unit. A large part of the heat produced by combustion of the gas is transferred to the stream of flowing water, so that the temperature of the flue gases is reduced nearly to that of the inlet water by the time they reach the products chamber. The flue gases are discharged from the calorimeter through the dampered exhaust port.

A large part of the water formed by combustion is condensed to the liquid state and leaves the calorimeter through the condensate drain. A small amount of water stands in the products chamber, forming a seal between the products chamber and combustion chamber, and preventing recirculation of the flue gases with the incoming air.

Detailed Requirements

4. The apparatus shall consist of the following:

(*a*) *Calorimeter Body.*—The calorimeter body shall conform to the following requirements:

(*1*) The damper which regulates the flow of flue gases from the calorimeter shall be adjustable so that the air drawn into the calorimeter can be maintained at 40 per cent in excess of the theoretical air, when any gas having a calorific value in the range from 475 to 3300 Btu. per cu. ft. is being burned in the calorimeter at the standard rate. The setting of the damper shall be definitely indicated by a suitable pointer and scale, or equivalent arrangement.

(*2*) The outer surface of the calorimeter shall be nickel- or chromium-plated and polished.

(*3*) The flue tubes and the space through which the water circulates shall be free from obstructions.

(*4*) There shall be no water leaks from the calorimeter.

(*5*) The burner shall be of the bunsen type, and shall be free from gas leaks. It shall be provided with at least three radiation shields, a suitable flame spreader, and either a set of interchangeable orifices or an adjustable orifice. Burners having adjustable orifices shall be of such construction that gas leaks can be readily detected with the orifice properly adjusted to burn the gas to be tested at the standard rate.

(*6*) The construction of calorimeter and burner shall be such that the burner can be inserted in the calorimeter and

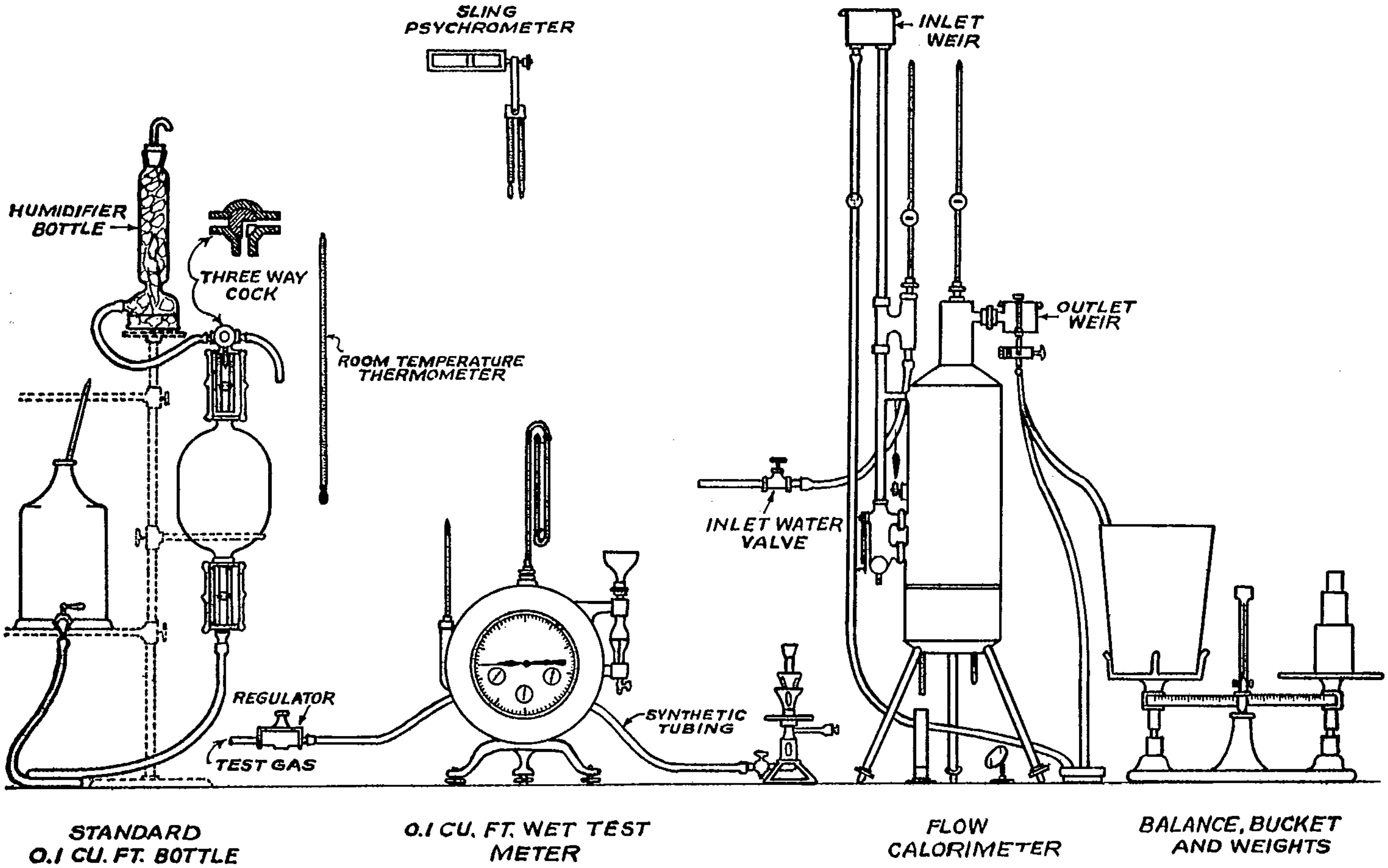

FIG.2.—American Flow Calorimeter Assemby.

clamped in position in such a manner that it is centered in the combustion chamber with the top of the flame spreader at least $1\frac{1}{2}$ in. above the lowest level at which water circulates in the calorimeter.

(*7*) The temperature of the exhaust gases shall not be more than 1 F. above that of the inlet water when gas is being burned in the calorimeter at the standard rate and the rate of water circulation is such that the temperature rise of the water is 15 F.

(*8*) The calorimeter shall be provided with a device for mixing the outlet water so that the fluctuations in its temperature will not exceed 0.2 F. when gas is burned in the calorimeter at a uniform rate.

(*9*) The construction of the products chamber shall be such that all of the flue gases will pass through the dampered port without recirculating with the incoming combustion air.

(*10*) The calorimeter shall be provided with a plumb line and bob for use in leveling the instrument.

(*b*) *Wet Test Meter.*—The meter shall have a capacity of 0.1 cu. ft. per revolution, and shall conform to the following requirements:

(*1*) The meter shall be constructed in such a manner and from such materials that it will have adequate strength and rigidity, and will be resistant to corrosion.

(*2*) The stuffing box on the rotor shaft shall be accessible for repacking.

(*3*) The pressure drop through the meter when gas is flowing through it at a rate of about 7 cu. ft. per hr. shall not exceed 0.2 in. of water.

(*4*) The meter shall be supported by a tripod base provided with three leveling screws, and shall be equipped with fixed spirit levels sufficiently sensitive to detect the tilting of the meter that would be produced by an adjustment of 0.003 in. on one of the leveling screws.

(*5*) The meter shall be provided with a gage glass not less than $\frac{3}{8}$ in. in diameter connected to the meter housing at the top and bottom through openings large enough to permit free passage of gas or water. A metal pin, pointed at the top, shall be located in the gage glass and concentric with it, and shall be so adjustable that the point can be brought to the water level when the capacity of the meter is 0.1 cu. ft. per revolution.

(*6*) The meter shall be provided with an enameled or chromium-plated dial with a circular scale approximately 6 in. in diameter graduated in 100 equal divisions Each fifth graduation mark shall be somewhat longer than the others, and each tenth mark shall be numbered. The large meter index shall be attached to the rotor shaft in such a manner that it can be fixed at any desired orientation relative to the rotor. The index shall extend at least to the middle of the graduations with its end close to the dial. Suitable small dials shall be provided on

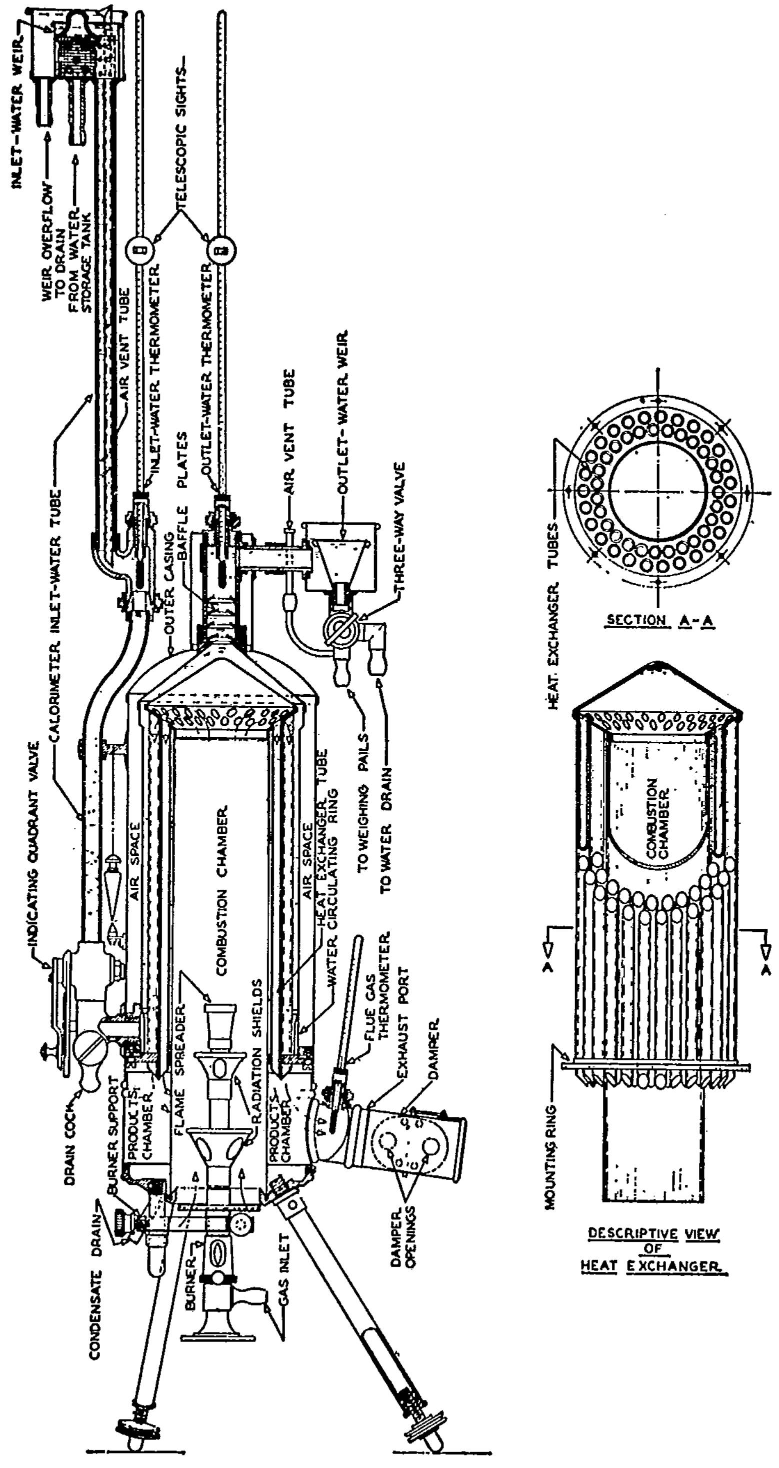

Fig. 3.—Sectional View of a Water-Flow Gas Calorimeter.

the face of the meter to register the number of revolutions of the meter index.

(*7*) The measuring compartments of the drum shall be as nearly as possible equal in size, shape, and mass so that delivered volumes will be approximately proportional to the indicated volumes on the graduated scale and significant fluctuations in water level during the rotation of the drum will be avoided.

(*8*) Provision shall be made for adding and withdrawing water.

(*9*) The meter shall be provided with a suitable thermometer well into which the thermometer specified in Paragraph (*d*) can be inserted so that its bulb will be immersed in the meter water. Provision shall be made for attaching the thermometer armor mentioned in Paragraph (*d*) to the meter at the well in such a manner that the armor will be held rigidly in place, and that the connection will be free from leaks.

(*10*) A U-gage, 6 in. in length with a scale graduated in 0.1 in., shall be connected to the meter.

(*c*) *Pressure Regulator.*—The diaphragm type of pressure regulator is preferable.[4] If the gas pressure on the inlet side of these regulators exceeds 12 in. of water column, a supplementary regulator suitable for reducing the gas pressure to about 12 in. of water column shall be used. Wet-seal prover-type regulators are also satisfactory, but special care must be exercised in their use because they are more subject to leaks and sticking valves.

(*d*) *Wet Test Meter Thermometer.*—A thermometer graduated in intervals of 0.5 F. from 54 to 101 F. and encased in suitable thermometer armor shall be provided for measuring the temperature of the water in the meter. The thermometer shall be held in the armor by means of a suitable cement, or washer, or equivalent arrangement that will prevent leakage of gas from the meter between the thermometer and the armor. The armor shall be of such design that it can be attached to the meter as described in Paragraph (*b*), Item 9. The dimensions of the thermometer and the armor and the position of the thermometer in the armor shall be such that the thermometer bulb will be completely immersed in the water in the meter when the armor is attached to the meter as described in Paragraph (*b*), Item 9, the entire scale of the thermometer will be visible, and the length of one degree on the scale will be not less than 1.5 mm. (0.059 in.). The scale error of the thermometer when standardized shall not exceed 0.5 F. at any point.

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[4] The twin diaphragm regulators of the American Meter Co., ½-in. pipe size, or their equivalent, are satisfactory.

(*e*) *Calorimeter Inlet Thermometer.*—The A.S.T.M. gas calorimeter inlet thermometer shall have a range of 54 to 101 F. and conform to the requirements for Thermometer 50F as prescribed in A.S.T.M. Specifications E 1.[5]

(*f*) *Calorimeter Outlet Thermometer.*—The A.S.T.M. gas calorimeter outlet thermometer shall have a range of 69 to 116 F. and conform to the requirements for Thermometer 51F as prescribed in A.S.T.M. Specifications E 1.[5]

(*g*) *Calorimeter Flue Thermometer.*—The A.S.T.M. gas calorimeter flue thermometer shall be graduated in intervals of 0.5 F. from 54 to 101 F. The dimensions of the thermometer shall be such that when it is inserted in the well in the duct through which the flue gases leave the calorimeter, the bulb can be completely immersed in the stream of flue gases, and the entire scale of the thermometer will then be visible. The length of one degree on the scale shall be not less than 1.5 mm. (0.059 in.). The scale error of the thermometer when standardized shall not exceed 0.5 F.

NOTE.—A thermometer meeting the requirements specified in Paragraph (*d*) for the wet test meter thermometer may be used as the calorimeter flue thermometer if it meets the requirements specified in Paragraph (*g*).

(*h*) *Air-Temperature Thermometer.*—A thermometer graduated in 0.5 F from 54 to 101 F shall be provided for measuring the temperature of the air in the vicinity of the calorimeter. The scale error shall not exceed 0.3 F at any point.

(*i*) *Thermometer Reading Lens.*—A reading lens shall be provided for each calorimeter thermometer. The lenses and their holders shall be constructed so as to avoid parallax errors of 0.01 F. or greater when reading the thermometers.

(*j*) *Psychrometer.*—For determining wet- and dry-bulb temperatures of the combustion air in the humidity-correction procedure a sling psychrometer conforming to the requirements specified in the Standard Method of Determining Relative Humidity (A.S.T.M. Designation: D 337)[5a] shall be used. A suitable psychrometer for use with the humidity-control procedure is illustrated in Fig. 4. The thermometers and wet-bulb wick for this type of psychrometer shall conform to the requirements specified in Method D 337.

(*k*) *Timer.*—A timer shall be used for determining the gas rate. It shall be capable of indicating elapsed time in minutes and seconds. A watch with a second hand is satisfactory.

(*l*) *Equal-Arm Balance.*—The equal-arm balance for determining the weight of water heated during a test shall have a capacity of 10 lb. avoirdupois with a graduated beam reading to 0.001 lb. and sensitive to this amount under full load. One pan holder shall be designed to hold the bucket specified in Paragraph (*n*); the other shall be flat to hold weights.

(*m*) *Set of Brass Weights.*—The set of weights for use with the equal-arm balance should be in a suitable container and shall consist of one 5-lb., two 2-lb., one 1-lb., one 0.5-lb., two 0.2-lb., and one 0.1-lb. weights. The combined weight of any combination of weights and rider shall be accurate to within plus or minus 0.1 per cent when compared with a standard set of class "B" weights certified by the National Bureau of Standards.

(*n*) *Buckets.*—The two buckets required for collecting the water heated in the calorific-value test shall be made of corrosion-resisting material and each shall have a capacity of about 10 lb. of water. They shall be of such a form to fit the pan holder of the balance (Paragraph (*l*)).

(*o*) *Barometer.*—For determining the atmospheric pressure, the mercurial barometer is preferable and shall be of the U. S. Weather Bureau type with a Fortin cistern, and be capable of measuring atmospheric pressure within an accuracy of plus or minus 0.02 in. It shall be provided with a brass scale graduated in 0.1 and 1.0-in. divisions with a vernier reading directly to 0.01 in. A thermometer for indicating the mean temperature of the mercury column within 1 F. shall be attached. The barometer shall be enclosed in a case, with a front opening door, for protection. Proper illumination at the reading points shall be provided.

(*p*) *Gas Analysis Apparatus.*—A gas analysis apparatus[6] shall be used for determining the oxygen requirements of the fuel gas and analyzing the flue gases resulting from its combustion in the calorimeter in order to obtain data for use in adjusting the excess air to its proper value.

(*q*) *Graduated Cylinders.*—For collecting the condensed water formed during combustion, one 25-ml., one 50-ml., and one 100-ml. cylinder, graduated in milliliters and accurate within 0.2 ml. at any point, shall be provided.

(*r*) *Fractional-Cubic-Foot Bottle (0.1-cu. ft.).*—An 0.1-cu.-ft. bottle shall be provided for calibrating the wet test meter. The volume of the bottle between the upper and lower gage marks shall be 0.10000 ± 0.00005 cu. ft. at 70 F.

(*s*) *Water Tank.*—The water tank for tempering and equalizing the temperature of the water shall conform to the following requirements:

(*1*) *Equipment.*—Hot and cold water connections to a mixing manifold in which a thermometer can be inserted; air vent and overflow pipe near the top; water level gage; drain at the bottom; take-off connection at a point near the inlet weir of the calorimeter; suitable stirring device; filter if the tap water contains much sediment; cover to protect from dust and retard evaporation.

(*2*) *Materials of Construction.*—Tank, connecting pipe fittings, stirrer, etc., shall be of corrosion-resistant material such as copper or brass.

(*3*) *Capacity of Water Tank.*—Sufficient to contain an adequate amount of water for several calorific value tests, and the height shall not exceed the shortest horizontal dimension.

(*t*) *Humidity Controller.*—It is frequently desirable to increase the humidity of the combustion air. This may be accomplished either by increasing the humidity of the room or by using a humidity controller (Fig. 5)[7] on the combustion-air supply to the calorimeter. The latter is particularly desirable where (*1*) ambient temperatures are high, (*2*) barometric pressures are low, or (*3*) knowledge of

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[5] 1959 Supplement of Book of ASTM Standards, Part 7.

[5a] 1958 Book of ASTM Standards, Part 10.

[6] A Bureau of Mines Gas Analyzer or its equivalent is satisfactory. Detailed specification requirements for this apparatus are in preparation in Committee D-3.

[7] The apparatus illustrated in Fig. 5, or its equivalent, is satisfactory. The apparatus shown in Fig. 5 is known as the McGlashan Air Humidity and Temperature Controller and was designed by W. A. McGlashan and his associates in the Southern California Gas Co. It was described in the report on "Fuel Gas Calorimetry - Water Flow Method," *Proceedings*, Pacific Coast Gas Association, Supplement to Vol. 32 (1941).

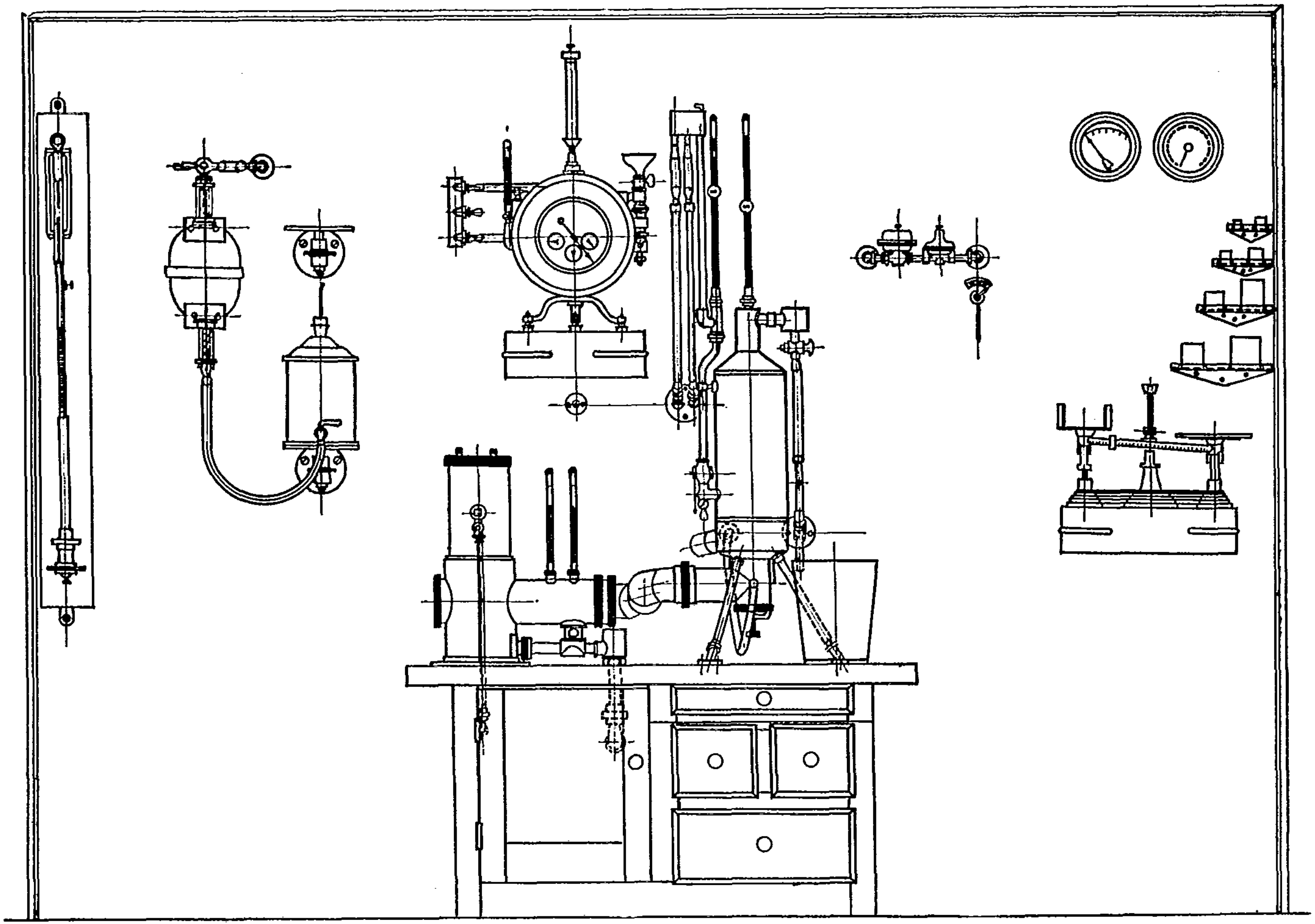

FIG. 4.—Front of Instrument Panel Showing Calorimetric Equipment.

excess air is questionable either due to a lack of knowledge of gas composition or failure to make a proper analysis of the flue gases. The humidity controller shall be capable (*1*) of increasing the minimum normal humidity of the air supply required to burn gas at a rate of 3000 Btu. per hr. to 95 per cent, with the dry-bulb temperature within 2 F. of the inlet water temperature, and (*2*) of regulating the humidity to within plus or minus 1 per cent of any chosen value in the range from 55 to 95 per cent. The controller shall be equipped with dry- and wet-bulb thermometers located in sequence in the stream of combustion air at a point where the cross-sectional area of the duct is between 5 and 10 sq. in., where there is no water spray, and preferably close to the entrance of the calorimeter. The controller should not interfere with the removal of the calorimeter burner.

(*u*) *Test Room.*—The apparatus shall be set up in a room used exclusively for calorimetry in which the temperature is not subject to sudden changes and which is free from drafts, gas contamination, and the direct rays of the sun. The floor space shall be not less than 100 sq. ft. and the ceiling height not less than 8½ ft. Adequate facilities for lighting (25 foot-candles at a 30-in. level), heating, and ventilating without causing drafts shall be provided. Heaters requiring combustion within the room shall not be used. The use of thermostatic control of the heating equipment is desirable. The gas line conveying the gas to the calorimeter shall be as short and direct as practicable, in order to minimize time lag, and shall be free from traps, unnecessary valves, and side connections. The line shall not pass through any location which is subject to extremely high or low temperatures, such as a furnace room or insufficiently covered locations in cold climates. The diameter of the line shall be as small as practicable, consistent with the maintenance of adequate line pressures. If necessary, the line shall be provided with a purging device to assure a sample consistent with the time of the test.

Assembly of Apparatus

5. (*a*) The calorimeter and its accessory appratus shall be mounted as shown in Fig. 4 or on a strong table (about 60 in. in length by 30 in. in width by 24 in. in height). It is desirable to house the calorimeter and its connected accessories in a cabinet. This brings all equipment conveniently close and protects it from dust, accident, corrosion, and unexpected drafts of air.

(*b*) The calorimeter shall be assembled in the following sequence starting at the

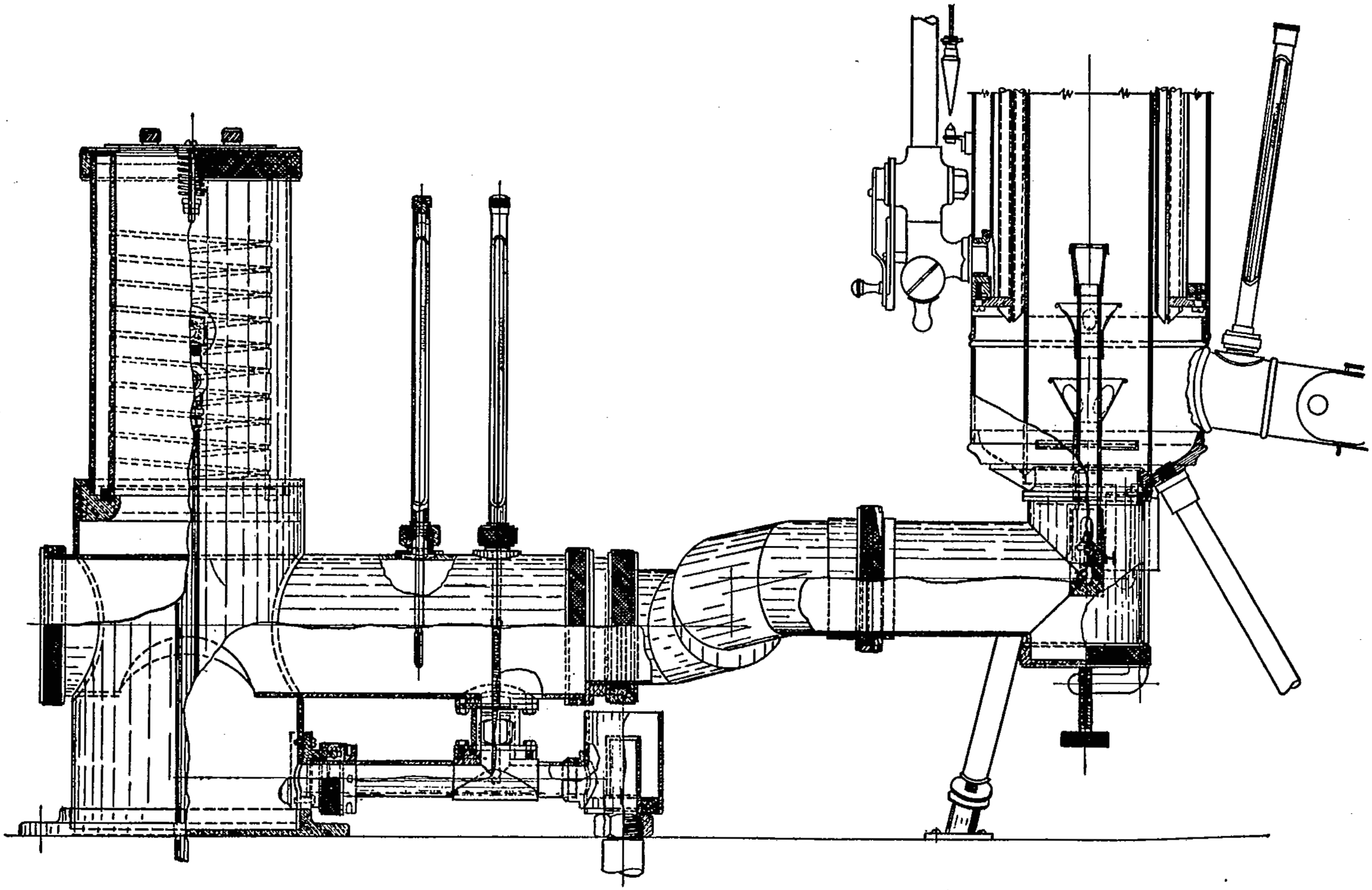

FIG. 5.—Air Humidity and Temperature Controller, Connected in Operating Position to Calorimeter Combustion Chamber.

cock or valve of the sample line:

(*1*) Pressure regulator (one or more depending upon the inlet gas pressure),

(*2*) Wet test meter,

(*3*) Calorimeter, and

(*4*) Humidity controller (if used).

The air-temperature thermometer (Section 4(*h*)) shall be mounted so that its bulb is within a few inches of the calorimeter surface and approximately at the mean height of the calorimeter body. The gas connections shall be made of either flexible metal tubing or a flexible synthetic plastic that will not absorb any of the constituents in the gas (rubber tubing shall be avoided as it will lower the calorific value of gases, particularly those containing higher members of the paraffin series hydrocarbons). The meter shall be located so that it can be observed by the operator while standing in the proper position for reading the calorimeter inlet- and outlet-thermometers, and can be read accurately by him when he operates the water-change-over device. The water collection bucket or buckets shall be placed so that all of the water flowing through the calorimeter during the period of actual test can be collected conveniently and weighed on the equal-arm balance, which shall be placed in a convenient position near the calorimeter proper. A special sight, fitting in the connection from the inlet overflow weir to the drain, will aid in seeing that the flow of water is sufficient.

(*c*) The fractional cubic foot bottle (or aspirator bottle) and gas saturating humidifier either shall be mounted permanently near the wet test meter, or space shall be provided for setting the portable bottle on a rigid base near the meter.

(*d*) The humidity controller, if used, shall be connected to the calorimeter proper and be supplied with water from the calorimeter-water storage tank.

(*e*) The barometer shall be placed in the same room with the calorimeter.

Standardization and Maintenance

6. (*a*) *Calorimeter Inlet and Outlet Thermometers.*—These thermometers should be supplied with certificates from a recognized standardizing laboratory, preferably the National Bureau of Standards, which show the scale corrections at 5 F. intervals to be applied in order to establish the readings to within plus or minus 0.01 F. of the true temperature. If a standard resistance thermometer of the proper accuracy is available, it is more practicable to compare the thermometers at the local testing station. Inasmuch as the certified corrections hold true only for the period of the standardization test, due to volume changes in the bulbs of the thermometers, it is necessary to apply a further correction known as the "differential correction."

NOTE.—The following example illustrates the manner in which the differential correction is determined:

Thermometer A (inlet) has a certificate correction of −0.04 F. at 70 F. and thermometer B (outlet) has a certificate correction of −0.06 F. at 70 F.

The two thermometers were arranged for precise observation, with reading lenses attached, in a well-stirred pail of water, a little below room temperature (70 F.) to secure a rising meniscus and the following readings were made. The thermometers were read alternately, at equal time intervals, beginning and ending with the same thermometer, in order that the means of the two sets of readings might correspond to the same instant of time:

	Thermometer A	Thermometer B
Readings, deg. Fahr.	69.43 69.45 69.46 69.47	69.48 69.49 69.50 ...
Mean	69.45	69.49
Certificate correction	−0.04	−0.06
Corrected readings	69.41	69.43

It will be seen that the corrected reading of thermometer B is 0.02 F. higher than that of thermometer A. A differential correction of −0.02 F. must therefore be applied, in addition to the certificate corrections, to all readings of thermometer B, when the thermometers are both used under conditions essentially the same as those under which the differential correction was determined.

When the differential correction is determined as described in the above note, the bulbs of the inlet- and outlet-water thermometers are subject to the same external pressure. When in use in the calorimeter, the pressure on the bulb of the inlet-water thermometer is greater than that on the outlet-water thermometer by about 18 in. of water. A large number of tests have shown that the effect of external pressure is about 0.2 F. per atmosphere (400 in. of water) for thermometers having cylindrical bulbs 5 to 7 mm. in diameter. The effect of a pressure of 18 in. of water on the bulb of the inlet-water thermometer is therefore an increase of 0.01 F. in the reading of the thermometer. This effect should be taken into account by adding 0.01 F. to the differential correction determined in the manner described above. The data given in the above example then lead to a differential correction of −0.01 F. when the effect of pressure on the inlet-water thermometer bulb is taken into account. The effect of pressure on the inlet-water thermometer reading is taken into account automatically if the differential correction is determined with the thermometers in place in the calorimeter, and with water flowing through the calorimeter, but no gas burning in it. If the correction is determined in this way it is necessary that the inlet-water temperature remain constant during the determination, and that account be taken of the effect of heat transfer between calorimeter and surroundings. This amounts to 2.0 Btu. per hr. per deg. Fahr. difference in temperature between the inlet-water and room.

The differential correction should be determined at intervals of about one month unless experience indicates otherwise. It should be determined at, or very near, some temperature at which the thermometers have been standardized, in order to avoid introducing into the differential correction a constant error resulting from interpolation between two certificate corrections. The differential correction should be determined after both thermometers have been at room temperature for several days. When the thermometers are replaced in the calorimeter, they shall be inserted in their wells to such a depth that the bulbs are completely immersed in the stream of flowing water, that is, so that no part of either bulb is in contact with a pocket of stagnant water or entrapped air.

(*b*) *Thermometer Reading Lens.*—Reading lenses shall be attached to the calorimeter thermometers in such a manner that the observation slot is at right angles to the mercury column and the mercury meniscus and thermometer graduations are equally in focus in the center of the field of view.

(*c*) *Wet Test Meter Thermometer.*—The wet test meter thermometer shall be compared once at each multiple of 10 F. with a calorimeter thermometer in a well-stirred water bath to within plus or minus 0.1 F. and its corrections shall be recorded and used. Subsequent comparisons shall be made once a year at one calibration point.

(*d*) *Flue Thermometer.*—The flue thermometer shall be compared once at each multiple of 10 F. with a calorimeter thermometer in a well-stirred water bath within plus or minus 0.1 F. If its corrections are greater than 0.5 F., it is more convenient to replace it than to supply and use a correction sheet. Subsequent comparisons at one calibration point will show whether the thermometer has changed.

(*e*) *Psychrometer Thermometers.*—The psychrometer and air-temperature thermometers shall be compared once at each multiple of 10 F with a calorimetric thermometer in a well-stirred water bath within plus or minus 0.1 F. If the corrections are greater than 0.25 F, it is more convenient to replace the thermometers than to supply and use correction sheets. The same requirements apply to the humidity-controller thermometers. Subsequent comparisons at one calibration point will show whether the thermometers have changed.

(*f*) *Barometer Thermometer.*—The barometer thermometer shall be compared once at each multiple of 10 F. with a calorimetric thermometer in a well-stirred water bath. If its corrections are greater than 2.5 F., it shall be rejected.

(*g*) *Barometer.*—Barometers shall be corrected to eliminate errors from the following sources:

(*1*) Imperfect vacuum,
(*2*) Capillarity,
(*3*) Scale,
(*4*) Impure mercury,
(*5*) Gravity, and
(*6*) Temperature.

It is not practicable, as a rule, to determine separately the errors due to Items (*1*), (*2*), (*3*), and (*4*). These can be combined conveniently with Item (*5*) and applied as the barometer certified correction. In some cases it may be possible to compensate for all but temperature errors by shifting the scale setting. Proper calibration can be obtained by comparison with a normal barometer at a nearby station of the Weather Bureau. The barometer either can be carefully carried to the station (see "*Circular F*, Barometers and the Measurement of Atmospheric Pressure," W. B. No. 472, U. S. Department of Agriculture) for comparison, or its readings can be compared, *in situ*, with the simultaneous readings of the Weather Bureau station barometer, making any allowances that may be required for differences in level between the two locations, and correcting the readings of the barometer under test to equivalent inches of mercury at 32 F. Table II gives the data for making temperature and gravity corrections.

(*h*) *Apparatus for Weighing the Water.*—The apparatus for weighing the water includes the equal-arm balance, set of brass weights, and two buckets. The two buckets shall be counterbalanced, dry, within 0.001 lb. The balance and weights shall be certified at the local Bureau of Weights and Measures at periodic intervals or if a standardized set of class B weights is available it can be used for comparison. It is more convenient to adjust the weights than to apply corrections. If the balance is not sensitive to 0.001 lb. at maximum load the knife edges shall be replaced or resharpened.

(*i*) *Graduated Cylinders.*—The graduated cylinders shall be calibrated once with a standardized burette within plus or minus 0.2 ml.

(*j*) *Pressure Regulator.*—Having no scale, the pressure regulator cannot be calibrated. It is sufficient to observe, at periodic intervals, if the device is free from leaks and whether it is maintaining the gas pressure without significant change during operation.

(*k*) *Gas Analysis Apparatus.*—The gas analysis apparatus[6] shall be free from leaks. It should contain adequate chemical solutions, and its measuring burette shall be accurate to within plus or minus 0.2 per cent.

(*l*) *Fractional Cubic Foot Bottle* (*0.1-cu.-ft.*, *Capacity*).—The volume of the bottle (0.1 cu. ft.) shall be certified by the National Bureau of Standards to within 0.00001 cu. ft. If one of the gage marks becomes disturbed, if the bottle becomes deformed, or if there is any other reason to suspect its accuracy, it shall be repaired, if necessary, and sent to the National Bureau of Standards for recalibration. Only distilled water shall be used in the bottle and movable reservoir in order to prevent any corrosion or sedimentation from changing the volume of the bottle. Periodic flushing will minimize the chances for this occurrence.

(*m*) *Humidity Controller.*—The controller shall be disassembled periodically for (*1*) inspection and replacement of gaskets when necessary, (*2*) cleaning the water spray orifices and interior surfaces, and (*3*) replacement of the wet-bulb wick of the psychrometer. It is important that this wick be maintained in good condition free from deposited material and, as the psychrometer is in continuous operation, frequent inspection is necessary. The evaporation of water leaves a small quantity of solid material in the wick meshes which in time stiffens the wick so that it does not function properly. The controller inspection frequency will be determined largely by the quality of the water used, as well as the dust content and average moisture content of the air.

(*n*) *Test Room.*—The lighting, heating, and ventilation should be checked periodically in order to ascertain that no error from these sources exists.

(*o*) *Calorimeter.*—Calibration of the calorimeter by a standardizing laboratory is unnecessary except when required by law. The operator should make sure that the requirements prescribed in Section 4 (*a*) are met. The directions given in Items (*1*) to (*6*) below shall be followed, and any defects indicated by the tests specified in these directions shall be remedied in order to insure maintenance of the calorimeter in satisfactory operating condition.

(*1*) If the external surface of the calorimeter has become dull it may be polished with a very mild buffing compound. The polish can be maintained by periodic wiping with a mild soap solution followed by a dry wipe.

(*2*) The heat-exchange unit (and thermometers) shall be removed from the calorimeter periodically, and the flue tubes and surfaces which contact the circulating water shall be cleaned with the brushes provided for this purpose. The nature of the gas, cooling water, etc., will determine the frequency with which this procedure is necessary.

(*3*) After cleaning as described in Item (*2*), the flue tubes, combustion chamber, and products chamber shall be dried, and the calorimeter shall be assembled. The calorimeter shall then be tested for water leaks by filling the water-circulating system with water and allowing the calorimeter to stand for several hours. Leaks will be indicated by an accumulation of water in the products chamber.

(*4*) The burner shall be tested periodically for leaks by removing the mixing tube from the base, and placing the latter under water, after connecting it to the gas supply, with a finger held over the orifice. Leaks will be indicated by bubbles of gas.

(*5*) If the requirements specified in Section 4 (*a*), Item (*6*) are met, excessive differences in temperature between inlet-water and exhaust gases may be due to sediment in the water-circulating system. In this case the condition can be remedied by cleaning the calorimeter as described in Item (*2*).

(*6*) Obviously, the other functioning parts of the calorimeter such as the overflow weirs, indicating quadrant valve, water diverting valve, etc. must be kept in good condition to obtain accurate results.

Calibration of Wet Test Meter.

7. (*a*) The wet test meter shall be calibrated in accordance with procedures described in Sections 16 to 18, inclusive, or Section 19 of the Methods for Measurement of Gaseous Fuel Samples (ASTM Designation: D 1071).[7a] For highest accuracy the procedure described in Section 19 should be followed; the rate of flow of the testing medium should be approximately the same as the rate of flow of gas when the meter is in use in a calorific value test. Air is preferable to gas as the testing medium. If the test of the meter shows a volume per revolution differing from 0.1000 cu ft, the appropriate calibration factor shall be used to calculate the volume of gas burned in a calorific value test.

(*b*) The meter should be calibrated in place at intervals not exceeding three months. Experience may show the need of more frequent calibrations.

TEST PROCEDURE

Adjustments for Humidity-Correction Procedure

8. (*a*) Fill the water tank (*Caution, see Note 1*) and adjust the temperature of water, while stirring it thoroughly to equalize the temperature. The adjusted temperature of the water shall be near enough to that of the room so that inlet-water temperature will not change by more than 0.02 F. during a single calorific value test. This requirement will ordinarily be met if the water temperature is within plus or minus 1 F. of room temperature.

NOTE 1: *Caution.*—Never start a test with a partially filled water tank as there is always the chance that the tank will empty before the end of the test and cause serious damage to the apparatus.

(*b*) Purge gas supply lines of old gas either by discharging through a special vent line to the outside atmosphere or by burning it in an auxiliary burner located some distance from the calorimeter. The best practice is to have the sample line short enough that the normal heating-up period for the calorimeter will provide a proper gas sample.

(*c*) Adjust the gas meter temperature within ±1 F of the room temperature; level the meter with reference to the spirit levels mounted on the top by means of the adjusting screws in the feet; add water, if necessary, to raise the level in the meter somewhat above the pointer in the gage glass; pass a sufficient amount of gas through the meter to saturate the water with gas (Note 2); adjust the water level as described in Section 17(*e*) of Method D 1071.[7a]

NOTE 2.—The amount of gas required to saturate the water in the meter sufficiently for calorimetric purposes probably depends upon the composition of the gas. In the case of a 600 Btu carbureted water gas it has been found that 15 to 20 cu ft of gas must be passed through the meter at about 6 cu ft per hr to saturate the water. In the case of a 600 Btu mixture of carbureted water gas and natural gas about 10 cu ft of gas must be passed through the meter to saturate the water.

(*d*) Test for gas leaks. Remove the burner from the calorimeter and, after passing from 0.1 to 0.2 cu. ft. of gas through the meter to insure that any explosive mixture of gas and air has been removed, light the gas. After the meter has made two or three revolutions, shut off the gas at the base of the burner and immediately after shut off the gas supply to the regulator. If, during an interval of time equal to the duration of the water temperature reading period of the subsequent calorific value test, the index hand does not show a clockwise movement exceeding 0.0001 cu. ft., the leakage may be considered negligible. When waiting for the results of this test, the adjustments described in Paragraph (*e*) may be made.

(*e*) With the indicating quadrant valve set at approximately the position for regular operation, turn on enough water so that some will be discharged to the drain from the inlet-water overflow weir. To promote the escape of air from the water circulation system, quickly open and close the quadrant valve a number of times and, if necessary, loosen the knurled nuts of the thermometer wells so that all of the air and a small amount of water will be forced out. Place the dried water bucket (or buckets) in a convenient position for collection of the effluent water.

(*f*) When it has been determined that no leakage is occurring (Paragraph (*d*)), light the burner and adjust the flow of gas to within ±2 per cent of the standard rate in accordance with the data given in Table I. After the meter has made seven revolutions, adjust the primary air supply to the burner so that the luminous tip of the flame just disappears; it may be necessary to insert an appropriate orifice (Note 3). Open the flue damper wide. Insert the burner in the calorimeter and clamp it in position so that it is at the proper height and is centered in the combustion chamber.

NOTE 3.—It is desirable to use as large an orifice as possible in order that an excessively high gas pressure will not be required to obtain the standard rate of combustion. However, the orifice should not be so large, and the pressure so low, that insufficient primary air will be injected into the burner. Smaller orifices and higher gas pressures may be required for gases of high-calorific value, such as natural gas, propane, butane, etc., and for their mixtures with air than for most manufactured gases. The orifice size, the gas pressure, and the primary air adjustment should be such that the gas under test can be burned in the calorimeter at the standard rate with a flame having no luminous tip, and without producing carbon monoxide when the excess air entering the calorimeter is 40 per cent.

(*g*) Adjust the quadrant indicating valve so that the temperature rise of the flowing heated water is 15 ± 0.5 F.

(*h*) Allow time for the establishment of thermal equilibrium and adjust the damper. Set the adjustable damper in the exhaust port so that the air drawn into the combustion chamber is 40 ± 5 per cent in excess of the theoretical air for the gas being burned. This damper setting shall be determined once for each particular kind of gas. This setting shall be recorded and used whenever calorific

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[7a] 1958 Book of ASTM Standards, Part 8.

value tests are made, provided the observed calorific value of the particular gas is within plus or minus 5 per cent of that existing when the damper setting was established. The damper setting shall be made as follows:

(*1*) After condensate has been dripping from the drain tube at a constant rate for 5 min., thermal equilibrium, that is, constant rate of heat transfer, will have been established. The calorimeter flue thermometer shall then be removed and replaced by a gas sampling tube inserted in the thermometer opening with an airtight fitting. A sample of the flue gas shall be aspirated *slowly* into a sample container or portable gas analysis apparatus at substantially atmospheric pressure in order to avoid contamination of the sample with air drawn in through the joints and to avoid change in the rate of combustion air. The flue gas sample shall be analyzed for its content of carbon dioxide and oxygen.[6]

(*2*) From a complete slow-combustion or explosion analysis[6] of the gas being tested, the theoretical volumes of oxygen consumed and carbon dioxide produced in the complete combustion of the gas can be calculated (Notes 5 and 6).

(*3*) From the data of Items (*1*) and (*2*) the excess air in the flue gases can be calculated (Notes 5 and 6) from the relation:

$$\text{Excess air, per cent} = \frac{R_1}{R_2} \times 100$$

where:

R_1 = ratio of oxygen to carbon dioxide in the flue gas, and

R_2 = ratio of the theoretical volume of oxygen consumed to the volume of carbon dioxide produced in the complete combustion of the gas.

If the value obtained in this way for excess air differs from 40 ± 5 per cent, the damper shall be adjusted accordingly, and the procedures of Items (*1*), (*2*), and (*3*) repeated.

NOTE 4.—Under extreme conditions of high temperature, low barometric pressure, and low relative humidity, it may be desirable to reduce permissible limits of excess air to 40 ± 2 per cent.

(*4*) After the damper has been correctly adjusted, the water flow shall be readjusted, if necessary, so that the temperature rise is 15 ± 0.5 F. The operator shall then proceed with the calorific value test in accordance with Section 10.

NOTE 5: *Example.*—A fuel gas analyzed for its constituents gave the following results:

Constituent	Proportions by Volume, per cent
Carbon dioxide (CO_2)	3.4
Ethylene (C_2H_4)	3.7
Benzene (C_6H_6)	1.5
Oxygen (O_2)	0.3
Carbon Monoxide (CO)	17.4
Hydrogen (H_2)	36.8
Methane (CH_4)	24.9
Nitrogen (N_2)	12.0
Total	100.0

The assumption is made that 1 cu. ft. of this gas is burned completely with the theoretical quantity of air, giving the following data:

Constituent	Cubic Feet per Cubic Foot Dry Gas				
	Amount of Constituent Present in the Fuel Gas	Oxygen Required	Products Formed by Gas During Combustion		
			CO_2	H_2O	N_2
CO_2	0.034	...	0.034	...	...
C_2H_4	0.037	0.1110	0.074	0.074	...
C_6H_6	0.015	0.1125	0.090	0.045	...
O_2	0.003	−0.0030	...	...	...
CO	0.174	0.0870	0.174	...	...
H_2	0.368	0.1840	...	0.368	...
CH_4	0.249	0.4980	0.249	0.498	...
N_2	0.120	...	...	...	0.120
Total	1.000	0.9895	0.621	0.985	0.120

The analysis of the flue gas from the calorimeter gave the following results:

Constituent	Proportions by Volume, per cent
CO_2	10.0
O_2	5.9
N_2	84.1
Total	100.0

Then by definition (Section 8(*h*)):

$$\text{Excess air in flue gas} = \frac{R_1}{R_2} \times 100 =$$

$$\left(\frac{5.9}{10.0} \div \frac{0.9895}{0.621}\right) \times 100 = 37.0 \text{ per cent}$$

Although this falls within the specified range of 40 ± 5 per cent, it is desirable to set the damper to yield 40 ± 1 per cent because greater variations in the following factors can be tolerated before the limiting tolerances are reached and another adjustment is required:

(*1*) Rate of gas flow,
(*2*) Constituents of the gas,
(*3*) Ambient temperature,
(*4*) Atmospheric pressure,
(*5*) Water vapor in the air, and
(*6*) Condition of the calorimeter flue passages.

In the example cited, the damper would have to be opened slightly to increase the excess air to 40 per cent. In some cases the amount of excess air is too great, even with the damper in the closed position. In this event, the holes in the damper valve shall be partially covered with a small copper or brass plate soldered in position.

NOTE 6.—A complete analysis of the gas is not necessary in order to evaluate the ratio, R_2. All that is required is a determination of the oxygen (O_2) consumed (in addition to that in the gas itself) and the carbon dioxide (CO_2) formed (including that in the gas) in the complete combustion of a given amount of gas. The ratio R_2 is then calculated as follows:

$$R_2 = \frac{O_2}{CO_2}$$

Adjustments for Humidity Control Procedure

9. (*a*) Prior to determination of calorific value by the humidity control procedure, make the adjustments described in Section 8 (*a*) to (*d*). Continue in accordance with the following Paragraphs (*b*) to (*g*).

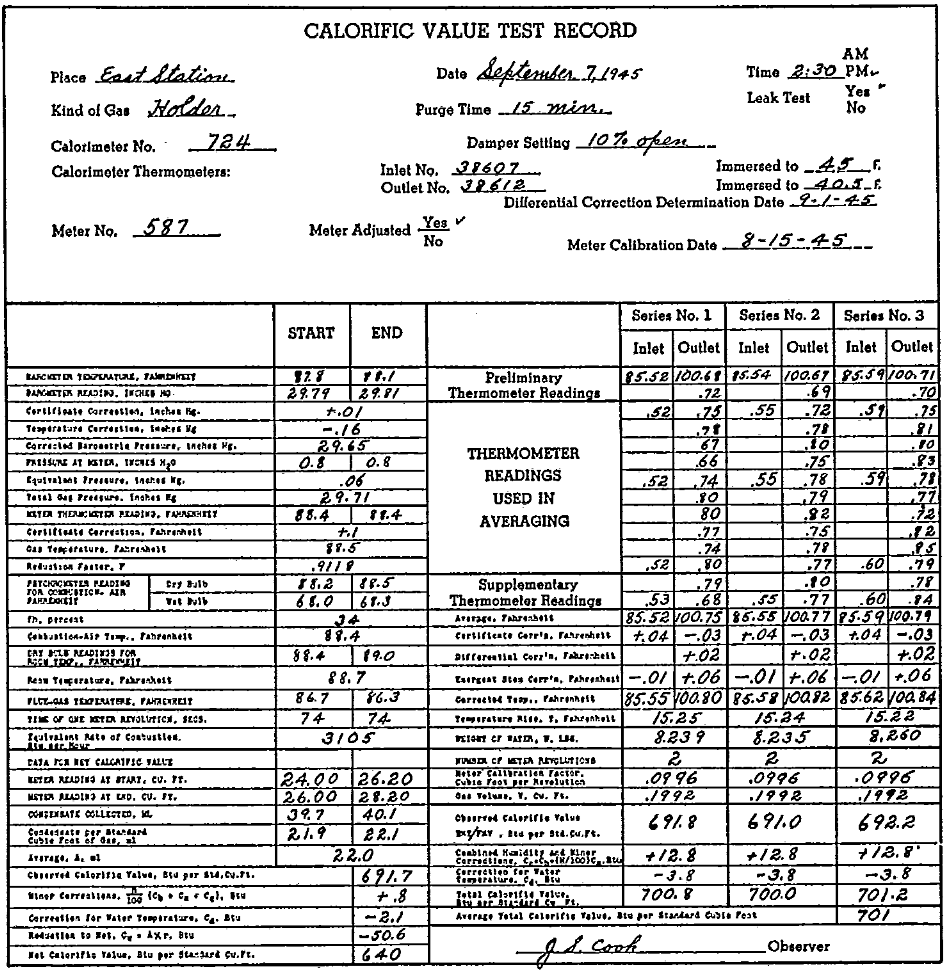
(*b*) With the indicating quadrant valve set at approximately the position for regular operation, turn on enough water so that some will be discharged to the drain from the inlet-water overflow weir. To promote the escape of air from the water circulation system, quickly open and close the quadrant valve a number of times and, if necessary, loosen the knurled nuts of the thermometer wells so that all of the air and a small amount of water will be forced out. Place the dried water bucket (or buckets) in a convenient position for collection of the effluent water. Start the flow of water through the humidity controller by opening the supply valve to its maximum position.

(*c*) When it has been determined that no leakage is occurring, as described in Section 8 (*d*), light the burner and adjust the flow of gas to 1.4 times the standard rate in accordance with Table I. After the meter has made seven revolutions, adjust the primary air supply to the burner so that the luminous tip of the flame just disappears. It may be necessary to insert an appropriate orifice (Note 3, Section 8). Open the flue damper wide.

(*d*) Attach the special housing enclosing the burner to the calorimeter as shown in Fig. 5, with the burner at its proper height and concentric with the wall of the combustion chamber. Connect the humidity controller to the special burner housing.

(*e*) After 5 min. have elapsed from the time the lighted burner was inserted into the calorimeter, thermal equilibrium, that is, constant rate of heat transfer, will have been established. Close the flue damper slowly until the outlet-water temperature begins to drop or until odors appear in the flue products. Then reduce the gas flow to within plus or minus 10 per cent of the standard rate in accordance with Table I. Adjust the humidity controller by manipulating the shutters so as to maintain the value of the product *f* × (relative humidity) for tolerances specified in Table VII, equal to that given under fh_0 in Table VIII.

(*f*) After these adjustments have been made, the operator shall proceed with the calorific value test in accordance with Section 10.



CALORIFIC VALUE TEST RECORD

Place East Station
Date September 7, 1945
Time 2:30 AM [✓ PM]
Kind of Gas Holder
Purge Time 15 min.
Leak Test [✓ Yes] No
Calorimeter No. 724
Damper Setting 10% open
Calorimeter Thermometers:
Inlet No. 38607 Immersed to 45 F.
Outlet No. 38612 Immersed to 40.5 F.
Differential Correction Determination Date 9-1-45
Meter No. 587
Meter Adjusted [✓ Yes] No
Meter Calibration Date 8-15-45

		START	END
Barometer Temperature, Fahrenheit		87.8	88.1
Barometer Reading, Inches Hg		29.79	29.81
Certificate Correction, Inches Hg.		+.01	
Temperature Correction, Inches Hg		−.16	
Corrected Barometric Pressure, Inches Hg.		29.65	
Pressure at Meter, Inches H_2O		0.8	0.8
Equivalent Pressure, Inches Hg.		.06	
Total Gas Pressure, Inches Hg		29.71	
Meter Thermometer Reading, Fahrenheit		88.4	88.4
Certificate Correction, Fahrenheit		+.1	
Gas Temperature, Fahrenheit		88.5	
Reduction Factor, F		.9118	
Psychrometer Reading for Combustion Air Fahrenheit	Dry Bulb	88.2	88.5
	Wet Bulb	68.0	68.3
fh, percent		34	
Combustion-Air Temp., Fahrenheit		88.4	
Dry Bulb Readings for Room Temp., Fahrenheit		88.4	89.0
Room Temperature, Fahrenheit		88.7	
Flue-Gas Temperature, Fahrenheit		86.7	86.3
Time of One Meter Revolution, Secs.		74	74
Equivalent Rate of Combustion, Btu per Hour		3105	
Data for Net Calorific Value			
Meter Reading at Start, Cu. Ft.		24.00	26.20
Meter Reading at End, Cu. Ft.		26.00	28.20
Condensate Collected, ml		39.7	40.1
Condensate per Standard Cubic Feet of Gas, ml		21.9	22.1
Average, A, ml		22.0	
Observed Calorific Value, Btu per Std.Cu.Ft.			691.7
Minor Corrections, $\frac{H}{100}(C_b + C_s + C_g)$, Btu			+.8
Correction for Water Temperature, C_w, Btu			−2.1
Reduction to Net, $C_n = A \times r$, Btu			−50.6
Net Calorific Value, Btu per Standard Cu.Ft.			640

	Series No. 1		Series No. 2		Series No. 3	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
Preliminary Thermometer Readings	85.52	100.68	85.54	100.67	85.59	100.71
		.72		.69		.70
THERMOMETER READINGS USED IN AVERAGING	.52	.75	.55	.72	.59	.75
		.78		.78		.81
		67		.80		.80
		.66		.75		.83
	.52	.74	.55	.78	.59	.78
		.80		.79		.77
		80		.82		.72
		.77		.75		.82
		.74		.78		.85
	.52	.80		.77	.60	.79
Supplementary Thermometer Readings		.79		.80		.78
	.53	.68	.55	.77	.60	.84
Average, Fahrenheit	85.52	100.75	86.55	100.77	85.59	100.79
Certificate Corr'n, Fahrenheit	+.04	−.03	+.04	−.03	+.04	−.03
Differential Corr'n, Fahrenheit		+.02		+.02		+.02
Emergent Stem Corr'n, Fahrenheit	−.01	+.06	−.01	+.06	−.01	+.06
Corrected Temp., Fahrenheit	85.55	100.80	85.58	100.82	85.62	100.84
Temperature Rise, T, Fahrenheit	15.25		15.24		15.22	
Weight of Water, W, Lbs.	8.239		8.235		8.260	
Number of Meter Revolutions	2		2		2	
Meter Calibration Factor, Cubic Foot per Revolution	.0996		.0996		.0996	
Gas Volume, V, Cu. Ft.	.1992		.1992		.1992	
Observed Calorific Value WT/FAV, Btu per Std.Cu.Ft.	691.8		691.0		692.2	
Combined Humidity and Minor Corrections, $C_h + (H/100)C_s$, Btu	+12.8		+12.8		+12.8	
Correction for Water Temperature, C_w, Btu	−3.8		−3.8		−3.8	
Total Calorific Value, Btu per Standard Cu. Ft.	700.8		700.0		701.2	
Average Total Calorific Value, Btu per Standard Cubic Foot					701	

J. S. Cook Observer

FIG. 6.—Form for Humidity Correction Procedure.

Procedure for Determination of Calorific Value by Either Humidity-Correction or Humidity-Control Procedure

10. (*a*) *Test Record.*—Prepare the calorific value test record. A suitable data sheet shall be used for recording the observations made by the operator during a calorific value test. The form of the sheet will depend upon local conditions, operator's choice, etc. (Note).

NOTE.—The two calorific value test record forms shown in Figs. 6 and 7 are examples found to be suitable. The test example in Fig. 6 was made by following the humidity correction procedure, while that in Fig. 7 was made by following the humidity control procedure.

It is desirable that all data sheets, and particularly those which may have to be submitted to the review of others, shall contain sufficient data to identify completely all major test conditions and equipment, such as the following:

(*1*) Place of test,
(*2*) Date and time gas sample was burned,
(*3*) Gas; kind and purging time,
(*4*) Calorimeter; kind and serial number,
(*5*) Wet test meter; kind, serial number, level adjustment, and last calibration date,
(*6*) Inlet- and outlet-water thermometers; serial numbers, temperatures to which immersed, and date of last determination of differential correction,
(*7*) Damper setting,
(*8*) Leak test, and
(*9*) Signature of observer.

These observations may be made and recorded during the adjustment period described in Section 8 (*h*) or 9 (*e*).

(*b*) *Preliminary Observations.*—Make the following preliminary test observations:

(*1*) The barometric pressure to the nearest 0.01 in.

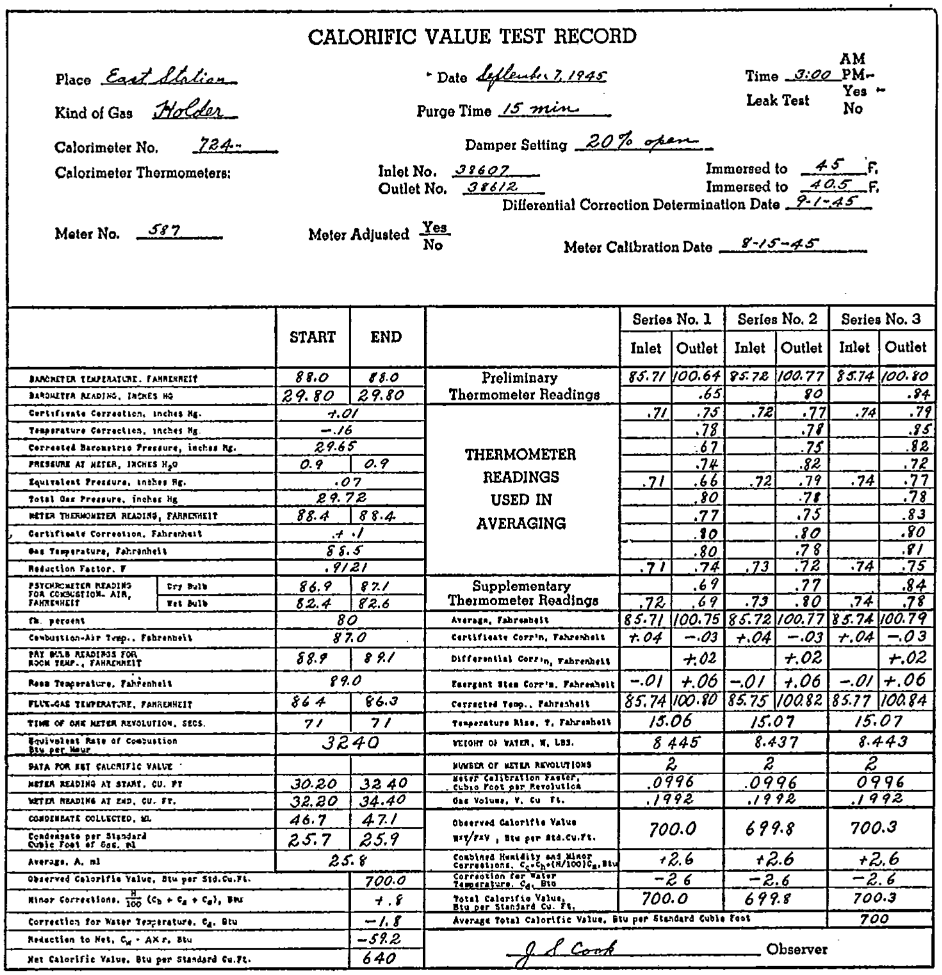
(*2*) The temperature of the barometer to the nearest 1 F.

(*3*) The readings of the wet- and dry-bulb thermometers of the sling psychrometer or the stationary psychrometer included in the humidity controller, to the nearest 0.1 F. The combustion-air temperature is the reading of the air-temperature thermometer when using the humidity correction procedure, or the reading of the dry bulb of the included psychrometer when using the humidity control procedure. Sometimes there is a significant difference between the ambient *room temperature* and the combustion-air temperature. Determine the room temperature by reading the air-temperature thermometer mounted near the calorimeter as described in Section 5(*b*).

(*4*) The time, in seconds, per revolution of the meter index.

(*5*) The pressure at the wet meter to the nearest 0.1 in. water column.

(*6*) The temperature of the water in



CALORIFIC VALUE TEST RECORD

Place East Station
Date September 7, 1945
Time 3:00 AM [✓ PM]
Kind of Gas Holder
Purge Time 15 min
Leak Test [✓ Yes] No
Calorimeter No. 724
Damper Setting 20% open
Calorimeter Thermometers: Inlet No. 38607 Immersed to 45 F.
Outlet No. 38612 Immersed to 40.5 F.
Differential Correction Determination Date 9-1-45
Meter No. 587
Meter Adjusted Yes / No
Meter Calibration Date 8-15-45

		START	END
Barometer Temperature, Fahrenheit		88.0	88.0
Barometer Reading, Inches Hg		29.80	29.80
Certificate Correction, inches Hg.		+.01	
Temperature Correction, inches Hg.		−.16	
Corrected Barometric Pressure, inches Hg.		29.65	
Pressure at Meter, Inches H_2O		0.9	0.9
Equivalent Pressure, inches Hg.		.07	
Total Gas Pressure, inches Hg		29.72	
Meter Thermometer Reading, Fahrenheit		88.4	88.4
Certificate Correction, Fahrenheit		+.1	
Gas Temperature, Fahrenheit		88.5	
Reduction Factor, F		.9121	
Psychrometer Reading for Combustion Air, Fahrenheit	Dry Bulb	86.9	87.1
	Wet Bulb	82.4	82.6
Rh. percent		80	
Combustion-Air Temp., Fahrenheit		87.0	
Dry Bulb Readings for Room Temp., Fahrenheit		88.9	89.1
Room Temperature, Fahrenheit		89.0	
Flue-Gas Temperature, Fahrenheit		86.4	86.3
Time of One Meter Revolution, Secs.		71	71
Equivalent Rate of Combustion Btu per Hour		3240	
Data for Net Calorific Value			
Meter Reading at Start, Cu. Ft		30.20	32.40
Meter Reading at End, Cu. Ft.		32.20	34.40
Condensate Collected, ml		46.7	47.1
Condensate per Standard Cubic Foot of Gas, ml		25.7	25.9
Average, A, ml		25.8	
Observed Calorific Value, Btu per Std.Cu.Ft.			700.0
Minor Corrections, $\frac{H}{100}(C_b + C_a + C_e)$, Btu			+.8
Correction for Water Temperature, C_d, Btu			−1.8
Reduction to Net, $C_w \cdot A \times r$, Btu			−59.2
Net Calorific Value, Btu per Standard Cu.Ft.			640

	Series No. 1		Series No. 2		Series No. 3	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
Preliminary Thermometer Readings	85.71	100.64	85.72	100.77	85.74	100.80
		.65		80		.84
THERMOMETER READINGS USED IN AVERAGING	.71	.75	.72	.77	.74	.79
		.78		.78		.85
		.67		.75		.82
		.74		.82		.72
	.71	.66	.72	.79	.74	.77
		.80		.78		.78
		.77		.75		.83
		.80		.80		.80
		.80		.78		.81
	.71	.74	.73	.72	.74	.75
Supplementary Thermometer Readings		.69		.77		.84
	.72	.69	.73	.80	.74	.78
Average, Fahrenheit	85.71	100.75	85.72	100.77	85.74	100.79
Certificate Corr'n, Fahrenheit	+.04	−.03	+.04	−.03	+.04	−.03
Differential Corr'n, Fahrenheit		+.02		+.02		+.02
Emergent Stem Corr'n, Fahrenheit	−.01	+.06	−.01	+.06	−.01	+.06
Corrected Temp., Fahrenheit	85.74	100.80	85.75	100.82	85.77	100.84
Temperature Rise, T, Fahrenheit	15.06		15.07		15.07	
Weight of Water, W, Lbs.	8 445		8.437		8.443	
Number of Meter Revolutions	2		2		2	
Meter Calibration Factor, Cubic Foot per Revolution	.0996		.0996		0996	
Gas Volume, V, Cu Ft.	.1992		.1992		.1992	
Observed Calorific Value WT/FXV, Btu per Std.Cu.Ft.	700.0		699.8		700.3	
Combined Humidity and Minor Corrections, $C_c = C_h + (H/100)C_a$, Btu	+2.6		+2.6		+2.6	
Correction for Water Temperature, C_d, Btu	−2 6		−2.6		−2.6	
Total Calorific Value, Btu per Standard Cu. Ft.	700.0		699.8		700.3	
Average Total Calorific Value, Btu per Standard Cubic Feet					700	

J S Cook Observer

FIG. 7.—Form for Humidity Control Procedure.

the wet test meter to the nearest 0.1 F.

(*7*) The temperature of the flue gases to the nearest 0.1 F. This temperature indicates the limits for good calorimeter operating conditions. Normally it should not differ by more than about 1 F. from the inlet-water temperature when the water and gas passages within the calorimeter are clean, when the rates of flow of gas and water are correctly adjusted, and when the room temperature is substantially equal to the inlet-water temperature.

(*c*) *First Determination.*—Make the first determination as follows:

(*1*) Start the collection of condensate if a net calorific value test is to be made. At the instant the meter hand crosses the zero mark, place the proper size graduated cylinder under the condensate drain tube of the calorimeter and record the meter reading.

(*2*) Adjust the position of the thermometer reading lenses and make and record one or two preliminary readings of the inlet- and outlet-water thermometers. Note whether the temperature rise has remained at 15 ± 0.5 F.

(*3*) At the instant the meter index crosses the zero mark, shift the changeover device to divert the effluent heated water to the weighing bucket. The operations of shifting the changeover device, to and from the bucket, shall be made in the same manner and with the greatest care so that the time interval between the two operations shall be as nearly as possible equal to that defined by the passages of the meter index past the zero position of the dial. An electrically operated device may be used to perform automatically the changeover operation at the proper time, although care shall be taken that the device is maintained in satisfactory operating condition.

(*4*) Make and record three readings of the inlet-water thermometer and at least ten readings of the outlet-water thermometer (Note 1). The readings of each thermometer shall be made at approximately equal time intervals during two revolutions of the meter index when testing gases having calorific values in the range 300 to 1300 Btu. per cu. ft., or during one revolution of the meter index when testing gases having calorific values above 1300 Btu. per cu. ft. The readings may be timed by making them at the times the meter index passes suitably chosen graduations on the dial, as indicated by the following schedules:

THERMOMETER READING SCHEDULES.

Meter Reading	Read Thermometer	
	Inlet	Outlet
For Gases Having Calorific Values Below 1300 Btu per cu. ft.		
90	1st	
0[a]		
10		1st
30		2nd
50		3rd
70		4th
90		5th
0	2nd	
10		6th
30		7th
50		8th
70		9th
90		10th
0[b]		
10	3rd	
For Gases Having Calorific Values Above 1300 Btu. per cu. ft.		
95	1st	
0[a]		
5		1st
15		2nd
25		3rd
35		4th
45		5th
50	2nd	
55		6th
65		7th
75		8th
85		9th
95		10th
0[b]		
5	3rd	

[a] Initial zero meter reading at which effluent water is diverted to weighing bucket (see Item (*3*)).

[b] Final zero meter reading at which effluent water is diverted to drain (see Item (*5*)).

NOTE 1.—It is preferable to make an estimate of the average reading of the outlet-water thermometer during each interval and to record this average as the reading rather than to record the readings observed at certain instants. The observer shall estimate the thermometer readings to one tenth of the smallest graduation interval, that is, to 0.01 F. To avoid errors due to parallax, the line of sight must be perpendicular to the thermometer stem, a condition which will be secured with a properly constructed reading lens, so located that the mercury meniscus is in the center of the field of view (Section 6(*b*)). An error of 0.02 F. in the determination of the average temperature of either the inlet- or outlet-water or a combined error of 0.02 F. in the two temperatures will cause an error of over 0.1 per cent when operating with a 15 F. temperature rise. To minimize the fluctuations in the reading of the outlet water thermometer, due to drafts and air currents, the calorimeter should be shielded from drafts and the observer should move about as little as possible while taking the thermometer readings.

(*5*) At the instant the index of the meter passes through the zero mark at the end of the second revolution (end of the first revolution for gases above 1300 Btu. per cu. ft.) after the effluent water was diverted to the weighing buckets, shift the changeover device to divert the water back into the drain. When testing gases having calorific values between 650 and 1300 Btu. per cu. ft., the amount of water heated during two revolutions of the meter index will be greater than the capacity of a single weighing bucket. In such cases the stream of effluent water must be diverted to the second bucket at some convenient time during the second revolution. Make and record one or two supplementary readings of inlet- and outlet-water thermometers, and verify the recorded integral values of the temperatures.

(*6*) Weigh the water collected in the bucket or buckets and record the weight (*W* on the calorific value test record, Fig. 6 or 7) to the nearest 0.001 lb.

(*d*) *Second and Third Determinations.*—Take the second (and third) series of observations as soon as convenient after the first series is complete. The full set of observations, (Items (*2*) to (*6*) of Paragraph (*c*) of this section) shall be repeated.

(*e*) *Collection of Condensate.*—Stop the collection of condensate if the net calorific value is being determined. After the meter index has made at least ten revolutions since the collection of condensate was started, remove the graduate from under the drain tube of the calorimeter at the instant the meter index passes the zero of the scale. Note and record the meter reading. Read and record the volume of condensate collected to the nearest 0.1 ml. If the net calorific value is to be determined with the same accuracy as the total calorific value, make another collection of condensate similar to the first.

(*f*) *Preliminary Observations Repeated.*—Repeat the preliminary observations prescribed in Paragraph (*b*). This shall be done on the general principle that no single observation should be accepted without verification and because it enables the operator to decide whether the determination should be repeated either because of a mistake in the observations or on account of a significant change in test conditions.

(*g*) *Shut Down of Apparatus.*—Shut down the calorimeter equipment in the following sequence:

Close gas valve at supply before the meter,

Remove burner from calorimeter (*Caution*, see Note 2),

Close water valve from supply tank, and

Refill the water supply tank.

NOTE 2: *Caution.*—Great care shall always be taken never to leave gas burning in the calorimeter when the apparatus is unattended, because when the water tank becomes empty the lighted burner will soon cause serious damage.

THEORY OF CALCULATIONS AND CORRECTIONS TO BE APPLIED

Observed Calorific Value

11. The first approximation to the calorific value of the gas tested is given by the following expression:

Observed Calorific Value,

$$\text{Btu. per standard cu. ft.} = \frac{WT}{VF}$$

where:

W = number of pounds of heated water collected in the buckets.

T = temperature rise of water in degrees Fahrenheit. This is the difference between the averages of the inlet- and outlet-thermometer readings after the following corrections have been applied to each: the certificate correction, the differential correction, and the emergent stem correction.

V = observed gas volume in cubic feet. This is the number of revolutions made by the index hand during the collection of the heated water *multiplied* by the meter calibration factor (usually 0.1000).

F = reduction factor to correct the observed gas volume V to standard conditions. The reduction factors for the corrected absolute pressure and temperature conditions of test are given in Table IV.

Corrections to Observed Calorific Value

12. A number of corrections must be applied to the observed calorific value to obtain the true total or net calorific value of the gas. These corrections include the following:

(*a*) A correction, C_b, for the buoyant effect of the air on the observed weight of water heated during the test.

(*b*) A correction, C_s, to account for the fact that the specific heat of water is not always exactly 1.000 under test conditions.

(*c*) A correction, C_e, for heat loss from the calorimeter when the inlet water is at combustion air temperature.

(*d*) A correction, C_d, to account for any difference between the temperatures of inlet water, combustion air, and room. This correction includes the effects of:

(*1*) The change in the mean specific heat of water between the temperatures $t_c + 7.5$ and $t_i + 7.5$, where t_c and t_i represent the temperatures, in degrees Fahrenheit, of combustion air and inlet water, respectively.

(*2*) The difference in the amount of heat lost from the surface of the calorimeter because the average temperature of the surface is higher or lower than it would be if inlet water were at combustion-air temperature. (In calculating this correction it is assumed that the temperatures of combustion air and room are equal.)

(*3*) The different amount of sensible heat carried out by the flue gases and condensed water, because their temperature is higher or lower than it would be if the inlet water were at combustion-air temperature.

(*4*) The latent heat of vaporization of the different amount of water vapor carried out by the flue gases due to their higher or lower temperature.

(*5*) The increase or decrease in the amount of heat lost from the surface of the calorimeter if combustion-air and room temperatures are not equal, as they are assumed to be in calculating the correction for heat loss from the calorimeter surface due only to inlet-water temperature, as described in Item (*2*).

(*e*) A correction C_t, to refer the results of the test to the standard temperature of 60 F. defined in Section 2 (*a*).

(*f*) A correction, C_h, (applied only in calculating total calorific value) to account for the fact that, in general, the amount of water vapor entering the calorimeter is not equal to that leaving it.

(*g*) A correction C_w, (applied only in calculating net calorific value) equal to the heat of vaporization of the water condensed in the calorimeter per standard cubic foot of gas burned.

Minor Correction Term C_m

13. The corrections C_b, C_s, C_e, and C_t are usually lumped together in a single "minor correction" term, C_m. The values of the minor corrections C_m, shown in Table XI, have been calculated with the following assumptions:

(*a*) C_b was calculated for a pressure of 30 in. for each temperature given.

(*b*) C_s was calculated for a water temperature rise of 15 F.

(*c*) C_e was found to be approximately 0.2 per cent of the observed heating value for the American and Precision type calorimeters when operated with inlet water at room temperature and at a gas burning rate of 3000 Btu. per hr. This average value of 0.2 per cent may be used only for calorimeters of these types.

(*d*) C_t was calculated from the difference in the heat capacity of the combustion products and the reactants (gas and air), and the difference between combustion-air temperature and 60 F.

Correction for Density of Hard Water.

14. With very few exceptions, public water supplies are pure enough to be used as calorimeter water without correction for dissolved matter. In a few cases of extreme salinity or hardness, it may be desirable to have measurements made of the density of the water and to subtract 2 per cent from the observed calorific value of the gas for each 1 per cent by which the density of the water used exceeds that of pure water.

Correction for Humidty

15. (*a*) The humidity correction takes account of the fact that the amounts of water vapor entering and leaving a calorimeter are not equal, in general. Usually more water vapor leaves the calorimeter than enters it, and a quantity of heat equal to the heat of vaporization of the excess therefore is not measured by the calorimeter, although it is, by definition, a part of the total calorific value of the gas. The calculation of the humidity correction is discussed in National Bureau of Standards *Circular 464*, where it is shown that the humidity correction is given by the following expressions:

$$C_h = \frac{LW}{F}\left[(r-1)\,V_o + V_p - 1 - \frac{fh}{100}\,r\,V_o\right] \quad \ldots\ldots\ldots(1)$$

$$= \frac{H}{100}\,\frac{LW}{F}\left[N_o - \frac{fh}{100}\,(N_o - N_1)\right] \quad \ldots\ldots(2)$$

$$= \frac{HS}{100P}\left[N_o - \frac{fh}{100}\,(N_o - N_1)\right] \quad \ldots\ldots(3)$$

where:

$$f = \frac{30 - w_t}{30 - \frac{h}{100}w_t}$$

V_p = volume of air-free products of combustion of 1 cu. ft. of gas, both measured saturated at the same temperature and pressure,

F = factor for reducing volume of saturated gas to standard conditions (Table IV),

L = latent heat of vaporization of water in British thermal units per pound,

P = pressure in inches of mercury,

H = total calorific value of gas in British thermal units per standard cubic foot,

$N = \dfrac{\left(r - \frac{fh}{100}r - 1\right)V_o + V_p - 1}{H/100}$ standard cubic feet per 100 Btu.,

$N_o = \dfrac{(r-1)\,V_o + V_p - 1}{H/100}$ = value of N when $fh = 0$

$N_1 = \dfrac{-V_o + V_p - 1}{H/100}$

= value of N when $fh = 100$ per cent,

C_h = humidity correction in British thermal units per standard cubic foot of gas,

W = weight of water, in pounds, required to saturate a space of 1 cu. ft.,

V_o = volume of air, in cubic feet, required to burn 1 cu. ft. of gas, when air and gas are measured under the same conditions,

V_a = $r\,V_o$ = volume of air, reduced to saturated condition, entering calorimeter per cubic foot of saturated gas, where r = ratio of combustion air to theoretical air,

h = relative humidity of air entering the calorimeter, expressed as a percentage, as defined in the Standard Method of Determining Relative Humidity (**A.S.T.M. Designation: D 337**),[5a] and

w_t = vapor pressure of water at the temperature t.

It will be seen from Eq. 3 above that the humidity correction will be zero if fh has the value

$$fh_o = \frac{N_o}{N_o - N_1}\,100$$

The above formulas are valid for any value of the ratio, r, of combustion air to theoretical air, provided the air entering the calorimeter is sufficient to ensure complete combustion of the gas. Values of N_o, N_1, and fh_o for various gases, calculated using the standard value $r = 1.40$, are given in Table VIII.

(*b*) A great majority of determinations of calorific value are made in connection with the periodic testing of gaseous fuels which vary only moderately in composition. The approximate calorific value of the gas is known in advance and the pressure at which the gas is measured depends mainly upon altitude and is nearly constant. Constant values of H and P corresponding to local conditions may therefore be inserted in Eq. 3 and a single value of N for each value of fh may be chosen depending upon the character of the gas being tested. A single table of humidity corrections similar to those in Table X therefore can be made up readily for local use by means of Eq. 3 using values of S from Table IX and values of N_0 and N_1 calculated from measured values of V_e and V_p for the gas being tested, or the values of N_0 and N_1 taken from Table VIII. For mixtures of two or more gases of the types covered in Table VIII, the value of N corresponding to any value of fh can be computed from the corresponding values of N for the individual gases by means of the relation:

$$N = \frac{N_a H_a X_a + N_b H_b X_b \cdots}{H_a X_a + H_b X_b \cdots} \ldots\ldots (4)$$

where X_a, X_b, . . . are the volume fractions of the gases a, b, . . . in the mixture and H_a, H_b, . . . are the calorific values of the gases a, b, . . . in British thermal units per standard cubic foot.

Corrections for Local Use (Preparation of Tables)

16. (*a*) When preparing a table for local use, the corrections for humidity shall be combined with the minor corrections given in Table XI. In Table VIII values of N_0, N_1, $N_0 - N_1$, and fh_0 are given for typical gases of different calorific values. These values may also be calculated by means of Eq. 1, using values of V_p and V_e obtained from combustion analysis, and this procedure should be followed whenever gases of unusual composition are encountered.

Note: *Example.*—The calculation of values of N for a typical gas mixture is illustrated by the following example:

Suppose the gas under consideration is a mixture of 550-Btu. carburetted water gas and 1100-Btu. natural gas and the approximate calorific value of the mixture is 700 Btu. Let X_a and X_b represent the volume fractions of the carburetted water gas and natural gas, respectively, in the mixture. Then since the calorific value of the mixture is 700 Btu., the following relation must hold:

$$550\,X_a + 1100\,X_b = 700 \ldots\ldots\ldots (5)$$

also since $X_a + X_b = 1$,

$$550\,X_a + 550\,X_b = 550 \ldots\ldots\ldots (6)$$

Subtracting Eq. 6 from Eq. 5,

$$550\,X_b = 150$$
$$X_b = 0.273$$

Substituting X_b in $X_a + X_b = 1$,

$$X_a = 0.727$$

The values of N_0 and N_1 for the two constituent gases are found from Table VIII to have the following values:

Gas	N_0	N_1
550-Btu. carburetted water..	0.99	−0.22
1100-Btu. natural..........	1.16	−0.18

Using these values, the values of N_0 and N_1 for the mixed 700-Btu. gas may be computed by means of Eq. 4. as follows:

$$N_0 = \frac{0.99 \times 0.727 \times 550 + 1.16 \times 0.273 \times 1100}{700} = 1.063$$

$$N_1 = -\frac{0.22 \times 0.727 \times 550 + 0.18 \times 0.273 \times 1100}{700} = -0.203$$

From these values of N_0 and N_1, the following values of N were calculated by linear interpolation:

h, per cent	N, standard cu. ft. per 100 Btu.
0	1.06
10	0.94
20	0.81
30	0.68
40	0.56
50	0.43
60	0.30
70	0.18
80	0.05
90	−0.08
100	−0.20

(*b*) Table X illustrates the computation of humidity corrections, C_h, for the mixed 550- and 1100- Btu. gases for an average local barometric pressure of 28 in. of mercury. The values of S were taken from Table IX, while the values of N are those given in the final tabulation of the Note under Paragraph (*a*). Also given in Table X are values of

$$\frac{H}{100} C_m = 7.00\,C_m = 7.00(C_b + C_s + C_e + C_t)$$

calculated from the values of C_m (expressed in percentage of total calorific value) given in Table XI, and the combined corrections:

$$C_c = C_h + 7.00\,C_m$$

(*c*) The part of the correction, C_d, which takes account of the effects listed in Section 12 (*d*), Items (*1*) to (*4*) is practically independent of barometric pressure and relative humidity. It depends to some extent upon the composition of the gas, but if the temperature difference between inlet-water and combustion air is kept within 1 or 2 F., the magnitude of the correction will be so small that its variation with gas composition can be neglected, and a single value of the correction (in percentage of total calorific value per degree Fahrenheit) for each temperature can be used for all fuel gases. Values of the correction calculated on this basis are given in Table XII. In footnote *b* to Table XII are given directions for calculating the part of C_d due to increase or decrease in heat loss from the surface of the calorimeter when combustion-air and room temperatures are not equal (see Section 12 (*d*), Item (*5*)).

Calculation of Total Calorific Value

17. (*a*) Two sample calorific value tests are illustrated. Figure 6 shows results from the humidity-correction method and Fig. 7 shows results from the humidity-control method. The *total* calorific value shall be calculated as shown in Paragraphs (*b*) to (*e*). (See Section 12.)

(*b*) (*1*) Correct the observed barometric heights by adding the certificate correction and the proper temperature and gravity correction shown in Table II. Record the average corrected barometric height. Convert the average gas pressure at the meter, by means of Table III, from observed inches of water column to equivalent inches of mercury column, and record. The total gas pressure is the sum of the corrected barometric height and the gas pressure at meter.

(*2*) Apply the certificate correction, if any, to the meter thermometer reading and record the average meter temperature.

(*3*) Enter from Table IV the gas reduction factor F corresponding to the total gas pressure and meter temperature.

(*4*) From Table V enter on the record the value of the product fh corresponding to the recorded *wet-bulb* and *dry bulb* temperatures.

(*5*) Average and record the test readings (not the preliminary or supplementary) of the inlet and outlet calorimeter water thermometers for each series separately. Enter the certificate corrections corresponding to the average readings of the inlet and outlet calorimeter water thermometers from a table such as shown in Fig. 8. Enter the *differential correction* from a table such as shown in Fig. 8. Enter the emergent stem corrections for the average readings of the inlet and outlet calorimeter water thermometers from Table VI. Apply the certificate, differential, and emergent stem corrections to the observed average inlet and outlet water thermometer readings to obtain the corrected temperatures.

(*6*) Subtract the corrected average temperature of the inlet water from the corrected average temperature of the outlet water to obtain the temperature rise T, and record.

(*7*) Correct the observed weight of water heated W if calibration of the balance and weights has shown it to be necessary.

(*8*) Calculate and record the volume of gas burned V by multiplying the observed number of revolutions of the meter index by the meter calibration constant.

(*9*) Record the observed calorific value calculated as follows:

$$\text{Observed calorific value, Btu. per standard cu. ft} = \frac{WT}{VF}$$

(*c*) (*1*) From the table of combined corrections (similar to Table X) for the gas being tested and for average local barometric pressure, take the value of C_e corresponding to the values of fh and combustion-air temperature observed during the test and enter as correction for humidity, etc.

(*2*) If the inlet water temperature differs from the combustion-air temperature, obtain from Table XII the tabulated part of the correction C_d corresponding to the mean value of the inlet water and combustion-air temperatures. If the combustion-air temperature differs from room temperature, calculate the additional part of the correction, C_d, as described in Footnote *b* of Table XII (Note). Combine this with the tabulated part of the correction, and enter the result on the record as correction for water temperature.

Note.—The calculation of the correction C_d is illustrated in the following example:

Observed calorific value....	700 Btu. per cu. ft.
Inlet water temperature........	71.1 F.
Room temperature............	68.8 F.
Combustion-air temperature....	69.8 F.

The mean of the combustion-air and inlet-water temperature is:

$$\frac{69.8 + 71.1}{2} = 70.5\text{ F.}$$

From Table XII (total calorific value column), the tabulated part of C_d corresponding to 70.5 is 0.147 per cent per degree Fahrenheit. This part of the correction for the 700-Btu. gas therefore is given by:

$$(71.1 - 69.8)\ 0.00147 \times 700 = +1.34\text{ Btu.}$$

and the correction for difference between combustion-air temperature and room temperature is:

$$(69.8 - 68.8)\ 0.00068 \times 700 = +0.48\text{ Btu.}$$

The total correction, C_d, therefore is:

$$C_d = 1.34 + 0.48 = +1.8\text{ Btu.}$$

(*3*) Obtain the ***total calorific value***, H, by applying the corrections C_e and C_d to the observed calorific value. Calculate the ***average total calorific value*** and enter it on the record.

(*d*) Calculate and record the equivalent gas rate in British thermal units per hour from the following expression:

$$\text{Equivalent gas rate, Btu. per hr.} = \frac{0.1\,FH\,3600}{S_m}$$

where:

$0.1\,F$ = the volume, in standard cubic feet, of gas burned per revolution of the meter,
H = the total calorific value,
$3600/S_m$ = the number of revolutions of the meter per hour, and
S_m = seconds per revolution.

Note.—The operator usually can adjust S_m so well that the equivalent gas rate will be within the allowable tolerance of plus or minus 5 per cent and the test will not need to be rerun.

Calculation of Net Calorific Value

18. (*a*) Two sample calorific value tests are illustrated in Fig. 6 for humidity correction procedure and in Fig. 7 for humidity control procedure. The calculation of the net calorific value differs from that of the total calorific value only as explained in Paragraphs (*b*) to (*e*).

(*b*) (*1*) Subtract the meter reading at the start from the meter reading at the

CERTIFICATE CORRECTIONS FOR INLET OR OUTLET CALORIMETER THERMOMETER

Maker ....

Maker's No. .... National Bureau of Standards No. ....

Date Tested at National Bureau of Standards ....

The following corrections are taken from the original

National Bureau of Standards Certificate Report No. ....

Thermometer Reading, deg. Fahr.	Correction, deg. Fahr.	Thermometer Reading, deg. Fahr.	Correction, deg. Fahr.	Thermometer Reading, deg. Fahr.	Correction, deg. Fahr.
40...........	—	65...........	—	90...........	—
41...........	—	66...........	—	91...........	—
42...........	—	67...........	—	92...........	—
43...........	—	68...........	—	93...........	—
44...........	—	69...........	—	94...........	—
45...........	—	70...........	—	95...........	—
46...........	—	71...........	—	96...........	—
47...........	—	72...........	—	97...........	—
48...........	—	73...........	—	98...........	—
49...........	—	74...........	—	99...........	—
50...........	—	75...........	—	100...........	—
51...........	—	76...........	—		
52...........	—	77...........	—		
53...........	—	78...........	—		
54...........	—	79...........	—		
55...........	—	80...........	—		
56...........	—	81...........	—		
57...........	—	82...........	—		
58...........	—	83...........	—		
59...........	—	84...........	—		
60...........	—	85...........	—		
61...........	—	86...........	—		
62...........	—	87...........	—		
63...........	—	88...........	—		
64...........	—	89...........	—		

Differential Correction

Determined with Inlet Outlet Thermometer No. ....

Date	Determined at, deg. Fahr.	Difference in Degrees Fahrenheit To Apply to Outlet Thermometer
——	—	——
——	—	——
——	—	——

Fig. 8.—Illustration of Certificate Corrections for Calorimeter Thermometer.

end of the collection of condensate. This difference gives approximately the number of cubic feet of gas, measured at meter temperature, and under a pressure equal to that entered above as total gas pressure, burned during the collection of the recorded milliliters of condensate. Multiply the difference by the meter calibration factor and by the reduction factor F to find the volume of gas in standard cubic feet; divide the milliliters of condensate collected by this product and enter the resulting quotient on the record as the condensate per standard cubic foot of gas.

(*2*) Record the average of the *observed calorific values.*

(*c*) (*1*) Record the minor correction, C_m, for specific heat of water, buoyancy, and heat loss as obtained from Table XI (net calorific value column). The correction for atmospheric humidity is not used in calculating the net calorific value (see Section 2 (*f*)).

(*2*) Obtain the tabulated part of the correction, C_d, from the net heating value column of Table XII. If combustion-air and room temperatures differ, calculate the additional part of C_d as described in Footnote *b*, of Table XII. Combine this with the tabulated part of the correction and record the result as correction for water temperature.

(*3*) Multiply the milliliters of condensate per standard cubic foot of gas, entered opposite A in the record (Figs. 6 and 7), by the latent heat r of water in British thermal units per milliliter from Table XIII and record the product as the reduction to net Ar.

(*d*) To the average observed calorific value, apply the corrections described in Paragraph (*c*) and record the result as the *net calorific value.*

(*e*) The values contained in Table X, Fig. 6, and Fig. 7 illustrate the test values that would have been obtained in testing the mixed 550-Btu. carburetted water gas and 1100-Btu. natural gas under the selected test conditions. The values in Table X are not to be used unless the gas being tested and the local barometric pressure are identical in all respects to the example. Correct values to suit local conditions shall be incorporated into a similar table (or tables) for each gas to be tested.

Conversion of Calorific Value per Standard Cubic Foot to Basis of Measurement Used in Field

19. (*a*) The test procedure described in this method involves measurement of the gas sample under saturation conditions and expression of the results of calorific value tests in terms of the standard cubic foot of gas, that is, a cubic foot of gas saturated with water vapor at standard temperature and pressure. Sometimes it is desired to have the calorific value of the gas in terms of a cubic foot under the conditions of measurement for sale or use, and these conditions will differ, in general, from the standard conditions. The calorific value under the conditions of measurement can be calculated by multiplying the calorific value under standard conditions by a factor which depends upon the observed conditions of temperature, pressure, and humidity of the gas at the time it is measured. In general, it is incorrect to assume that gas introduced into a low-pressure distribution system will maintain its original condition of humidity until metered, and the humidity of the gas as well as its temperature and pressure should always be determined at the time and place at which the gas is measured.

(*b*) The amount of water vapor in the gas can usually be determined best by the use of a dew-point apparatus. The partial pressure of water vapor in the gas corresponding to the mean of the temperatures at which dew appears and disappears, can be read from Table XIII, which shows the vapor pressure of water in inches of mercury at various temperatures.

(*c*) Three cases will be considered. In the first and second it is assumed that the gas has been measured by displacement meters of the diaphragm, rotary, or proportional types which give readings directly in cubic feet of gas under the conditions of pressure, temperature, and humidity actually existing in the meter. In the first case, it is assumed that the dew point of the gas has been determined at the pressure existing in the meter; in the second case that the dew point has been observed after the gas has expanded to a lower pressure. In the third case, it is assumed that the gas is measured by an orifice meter or some other type of "rate-of-flow" meter. Such meters do not, in general, give data directly in cubic feet, but the volume metered must be calculated from observations of other physical quantities. It is customary to use formulas which give the quantity of gas measured in terms of cubic feet at 60 F. and 30 in. of mercury pressure, but without taking account of any change which would occur in the percentage of water vapor in the gas if brought to saturation at 60 F. For this class of meters, corrections for temperature and pressure have already been made when the volume of gas is first expressed in cubic feet, and only the correction for humidity remains. The factors for conversion of calorific value per standard cubic foot to basis of measurement used in the field are as follows:

Case 1.—The calorific value of the gas at its temperature, pressure, and humidity in the meter is to be determined, and the dew point of the gas has been observed at the meter pressure. Multiply the calorific value under standard conditions, determined in the usual way, by the factor:[8]

$$\frac{(P - D)(60 + 460)}{(30 - 0.5218)(t + 460)} = 17.640 \frac{P - D}{t + 460}$$

where:

P = total pressure (barometric plus gage) of the gas in the meter in inches of mercury,

t = temperature in degrees Fahrenheit, and

D = vapor pressure of water at the observed dew point.

The product multiplied by the number of cubic feet registered by the meter will give the total quantity of heat produced by combustion of the gas measured.

Case 2.—The calorific value of the gas under the conditions in the meter is to be determined as in Case 1, but the dew point has been observed in gas expanded to pressure p. Multiply the calorific value under standard conditions by the factor:[8]

$$\frac{P - \frac{DP}{p}(60 + 460)}{(30 - 0.5218)(t + 460)} = 17.640 \frac{P(p - D)}{p(t + 460)}$$

---

[8] The accepted absolute temperature corresponding to 0 F. is 459.7 deg. In cases where absolute temperatures appear as factors in both numerator and denominator of a fraction, no appreciable error is involved in the use of the rounded value "460" instead of the more nearly exact value.

where P, D, and t represent the same values as given in Case 1, and p is the total pressure of the gas in which the dew point is taken.

Again, the product multiplied by the number of cubic feet registered gives the total quantity of heat produced by combustion of the gas measured.

Case 3.—The volume of gas metered has been reduced as though it were dry to the volume it would occupy if dry under otherwise standard conditions, and the dew point was measured at pressure p. The calorific value at standard temperature and pressure is to be determined as though no water were added or removed. (The amount of water contained may be sufficient to condense at 60 F., but the problem is to be treated as though it remained in vapor form.) Multiply the calorific value under standard conditions by the factor:

$$1.018\,\frac{p - D}{p}$$

where p and D represent the same values as given in Case 2.

The product, multiplied by the number of cubic feet at standard temperature and pressure, gives the total quantity of heat produced by combustion of the gas measured.

REPRODUCIBILITY OF RESULTS

Reproducibility of Results

20. For manufactured gases of about 540 Btu, natural gases of about 1050 Btu, and liquefied petroleum gases such as propane and butane of about 2400 to 3200 Btu, the maximum permissible difference between the results of duplicate determinations of total calorific value of a given sample of gas by the same observer using a single set of apparatus is 0.3 per cent. The maximum permissible difference between results of determinations of calorific value of a given sample of gas by different observers using different apparatus is 0.5 per cent.

Caution—In order to obtain the indicated reproducibility it is necessary to follow very carefully the procedures specified in this method. This statement applies particularly to gases of high calorific values, for example those consisting largely of propane or butane or mixtures thereof.

NOTE: For summarized operating directions for water flow calorimeters see the Appendix (p. 79).

TABLE I.—TIME PER REVOLUTION OF A 0.1-CU. FT. METER HAND CORRESPONDING TO TOTAL CALORIFIC VALUE OF 3000 BTU. PER HR.

Approximate Calorific Value of Gas, Btu. per standard cu. ft.	Time per Revolution, sec.[a]
300	36
400	48
500	60
600	72
700	84
800	96
900	108
1000	120
1100	132
1200	144
1300	156
1400	168
1500	180
1750	210
2000	240
2500	300
3000	360
3500	420

[a] Allowable tolerance in rate:
For humidity correction procedure........ ±2 per cent
For humidity control procedure.......... ±10 per cent

If the test conditions differ from standard conditions (60 F., 30 in. of mercury) so that the correction factor F given in Table IV differs from unity, multiply the tabulated values of time per revolution by F.

TABLE III.—EQUIVALENT PRESSURES, INCHES OF WATER COLUMN *versus* INCHES OF MERCURY COLUMN.[a]

Water Column, in.	Mercury Column, in.	Water Column, in.	Mercury Column, in.
0.0	0.00	1.8	0.13
0.1	0.01	1.9	0.14
0.2	0.01	2.0	0.15
0.3	0.02	2.1	0.15
0.4	0.03	2.2	0.16
0.5	0.04	2.3	0.17
0.6	0.04	2.4	0.18
0.7	0.05	2.5	0.18
0.8	0.06	2.6	0.19
0.9	0.07	2.7	0.20
1.0	0.07	2.8	0.21
1.1	0.08	2.9	0.21
1.2	0.09	3.0	0.22
1.3	0.10	3.1	0.23
1.4	0.10	3.2	0.24
1.5	0.11	3.3	0.24
1.6	0.12	3.4	0.25
1.7	0.12	3.5	0.26

[a] A pressure equivalent to 13.609 in. H_2O at 62 F. is equivalent to 1 in. of mercury at 32 F.

TABLE II.—CORRECTIONS FOR REDUCTION OF OBSERVED BAROMETRIC HEIGHTS TO STANDARD CONDITIONS.[a,b]

(*a*) CORRECTION TO BE SUBTRACTED FROM THE OBSERVED BAROMETRIC HEIGHT TO OBTAIN THE HEIGHT WITH THE MERCURY AT 32 F.

Temperature o Barometer, deg. Fahr.	Observed Barometric Height, in.			
	24.0	26.0	28.0	30.0
40	0.03	0.03	0.03	0.03
45	0.04	0.04	0.04	0.05
50	0.05	0.05	0.05	0.06
55	0.06	0.06	0.07	0.07
60	0.07	0.07	0.08	0.09
65	0.08	0.09	0.09	0.10
70	0.09	0.10	0.11	0.11
75	0.10	0.11	0.12	0.13
80	0.11	0.12	0.13	0.14
85	0.12	0.13	0.14	0.15
90	0.13	0.14	0.16	0.17
95	0.14	0.16	0.17	0.18
100	0.15	0.17	0.18	0.19

(*b*) CORRECTION TO BE SUBTRACTED FROM THE OBSERVED BAROMETRIC HEIGHT FOR LATITUDES BELOW 45 DEG. AND ADDED FOR LATITUDES ABOVE 45 DEG. TO REDUCE THE READING TO THAT CORRESPONDING TO GRAVITY AT LATITUDE 45 DEG.[c]

Latitude, deg.	Observed Barometric Height, in.			
	24.0	26.0	28.0	30.0
	Subtract			
24	0.04	0.05	0.05	0.05
26	0.04	0.04	0.05	0.05
28	0.04	0.04	0.04	0.05
30	0.03	0.04	0.04	0.04
32	0.03	0.03	0.03	0.04
34	0.02	0.03	0.03	0.03
36	0.02	0.02	0.02	0.03
38	0.02	0.02	0.02	0.02
40	0.01	0.01	0.01	0.02
42	0.01	0.01	0.01	0.01
44	0.00	0.00	0.00	0.00
	Add			
46	0.00	0.00	0.00	0.00
48	0.01	0.01	0.01	0.01
50	0.01	0.01	0.01	0.01

(*c*) CORRECTION TO BE SUBTRACTED FROM THE OBSERVED BAROMETRIC HEIGHT TO COMPENSATE FOR THE DECREASE IN GRAVITY WITH INCREASE IN ALTITUDE.[c]

Height above Sea Level, ft.	Observed Barometric Height, in.			
	24.0	26.0	28.0	30.0
0	0.00	0.00	0.00	0.00
1000	0.00	0.00	0.00	0.00
2000	0.00	0.01	0.01	0.01
3000	0.01	0.01	0.01	....
4000	0.01	0.01	0.01	....
5000	0.01	0.01	.....	....
6000	0.01	0.01	....	....
7000	0.02	....	....	....

[a] These corrections have been calculated for a mercury-in-glass barometer with a brass measuring scale correct at 62 F.

[b] For convenience, the corrections for temperature, latitude, and altitude can be combined in one table to suit local conditions.

[c] Corrections for latitude and for altitude are illustrated in the following example:

Location	Barometric Pressure, in.	Latitude	Altitude, ft.	Correction, in.		
				For Latitude	For Altitude	Total
Denver	25	39° 40′	4900	−0.01	−0.01	−0.02
El Paso	26	31° 6′	3438	−0.03	−0.01	−0.04

TABLE IV.—CORRECTION FACTOR *F* FOR GAS VOLUME.[a, b]

Temperature, deg. Fahr.	Total Gas Pressure, in. of mercury									
	24.0	24.1	24.2	24.3	24.4	24.5	24.6	24.7	24.8	24.9
46	0.8258	0.8293	0.8328	0.8363	0.8398	0.8433	0.8468	0.8502	0.8537	0.8572
47	0.8238	0.8272	0.8307	0.8342	0.8377	0.8412	0.8446	0.8481	0.8516	0.8551
48	0.8217	0.8252	0.8287	0.8321	0.8356	0.8391	0.8426	0.8460	0.8495	0.8530
49	0.8196	0.8231	0.8266	0.8300	0.8335	0.8370	0.8404	0.8439	0.8474	0.8508
50	0.8176	0.8210	0.8245	0.8280	0.8314	0.8349	0.8383	0.8418	0.8453	0.8487
51	0.8155	0.8189	0.8224	0.8258	0.8293	0.8328	0.8362	0.8397	0.8431	0.8466
52	0.8134	0.8169	0.8203	0.8238	0.8272	0.8307	0.8341	0.8376	0.8410	0.8445
53	0.8113	0.8147	0.8182	0.8216	0.8251	0.8285	0.8319	0.8354	0.8388	0.8423
54	0.8092	0.8127	0.8161	0.8195	0.8230	0.8264	0.8298	0.8333	0.8367	0.8401
55	0.8072	0.8106	0.8140	0.8174	0.8209	0.8243	0.8277	0.8311	0.8346	0.8380
56	0.8050	0.8084	0.8119	0.8153	0.8187	0.8221	0.8255	0.8289	0.8324	0.8358
57	0.8029	0.8063	0.8097	0.8132	0.8166	0.8200	0.8234	0.8268	0.8302	0.8336
58	0.8008	0.8042	0.8076	0.8110	0.8144	0.8178	0.8212	0.8246	0.8280	0.8314
59	0.7986	0.8020	0.8054	0.8088	0.8122	0.8156	0.8190	0.8224	0.8258	0.8292
60	0.7965	0.7998	0.8032	0.8066	0.8100	0.8134	0.8168	0.8202	0.8236	0.8270
61	0.7943	0.7977	0.8011	0.8045	0.8079	0.8112	0.8146	0.8180	0.8214	0.8248
62	0.7921	0.7955	0.7989	0.8022	0.8056	0.8090	0.8124	0.8158	0.8191	0.8225
63	0.7899	0.7933	0.7967	0.8000	0.8034	0.8068	0.8102	0.8135	0.8169	0.8203
64	0.7877	0.7911	0.7944	0.7978	0.8012	0.8045	0.8079	0.8113	0.8146	0.8180
65	0.7855	0.7889	0.7922	0.7956	0.7990	0.8023	0.8057	0.8090	0.8124	0.8158
66	0.7833	0.7866	0.7900	0.7933	0.7967	0.8000	0.8034	0.8067	0.8101	0.8134
67	0.7810	0.7844	0.7877	0.7911	0.7944	0.7978	0.8011	0.8045	0.8078	0.8112
68	0.7787	0.7821	0.7854	0.7887	0.7921	0.7954	0.7988	0.8021	0.8055	0.8088
69	0.7765	0.7798	0.7832	0.7865	0.7898	0.7932	0.7965	0.7998	0.8032	0.8065
70	0.7742	0.7775	0.7808	0.7841	0.7875	0.7908	0.7941	0.7975	0.8008	0.8041
71	0.7719	0.7752	0.7785	0.7818	0.7852	0.7885	0.7918	0.7951	0.7984	0.8018
72	0.7696	0.7729	0.7762	0.7795	0.7828	0.7861	0.7894	0.7928	0.7961	0.7994
73	0.7672	0.7705	0.7738	0.7771	0.7804	0.7838	0.7871	0.7904	0.7937	0.7970
74	0.7648	0.7682	0.7715	0.7748	0.7781	0.7814	0.7847	0.7880	0.7913	0.7946
75	0.7625	0.7658	0.7691	0.7724	0.7757	0.7790	0.7823	0.7856	0.7889	0.7921
76	0.7600	0.7633	0.7666	0.7699	0.7732	0.7765	0.7798	0.7831	0.7864	0.7897
77	0.7577	0.7609	0.7642	0.7675	0.7708	0.7741	0.7774	0.7806	0.7839	0.7872
78	0.7552	0.7585	0.7618	0.7651	0.7684	0.7716	0.7749	0.7782	0.7815	0.7848
79	0.7528	0.7560	0.7593	0.7626	0.7659	0.7691	0.7724	0.7757	0.7790	0.7822
80	0.7503	0.7536	0.7568	0.7601	0.7634	0.7666	0.7699	0.7732	0.7764	0.7797
81	0.7478	0.7510	0.7543	0.7576	0.7608	0.7641	0.7673	0.7706	0.7739	0.7771
82	0.7452	0.7485	0.7518	0.7550	0.7583	0.7615	0.7648	0.7680	0.7713	0.7745
83	0.7427	0.7459	0.7492	0.7524	0.7557	0.7589	0.7622	0.7654	0.7687	0.7719
84	0.7401	0.7434	0.7466	0.7499	0.7531	0.7564	0.7596	0.7628	0.7661	0.7693
85	0.7375	0.7407	0.7440	0.7472	0.7505	0.7537	0.7569	0.7602	0.7634	0.7666
86	0.7349	0.7381	0.7414	0.7446	0.7478	0.7511	0.7543	0.7575	0.7608	0.7640
87	0.7322	0.7354	0.7387	0.7419	0.7451	0.7483	0.7516	0.7548	0.7580	0.7612
88	0.7296	0.7328	0.7360	0.7392	0.7424	0.7456	0.7489	0.7521	0.7553	0.7585
89	0.7269	0.7301	0.7333	0.7365	0.7397	0.7429	0.7461	0.7493	0.7526	0.7558
90	0.7241	0.7273	0.7305	0.7337	0.7370	0.7402	0.7434	0.7466	0.7498	0.7530
91	0.7213	0.7246	0.7278	0.7310	0.7342	0.7374	0.7406	0.7438	0.7470	0.7502
92	0.7186	0.7218	0.7250	0.7282	0.7314	0.7346	0.7378	0.7410	0.7441	0.7473
93	0.7157	0.7189	0.7221	0.7253	0.7285	0.7317	0.7349	0.7381	0.7413	0.7444
94	0.7129	0.7161	0.7193	0.7224	0.7256	0.7288	0.7320	0.7352	0.7384	0.7416
95	0.7100	0.7132	0.7164	0.7195	0.7227	0.7259	0.7291	0.7322	0.7354	0.7386
96	0.7071	0.7103	0.7135	0.7166	0.7198	0.7230	0.7261	0.7293	0.7325	0.7357
97	0.7041	0.7073	0.7105	0.7136	0.7168	0.7200	0.7231	0.7263	0.7295	0.7326
98	0.7012	0.7043	0.7075	0.7107	0.7138	0.7170	0.7201	0.7233	0.7265	0.7296
99	0.6981	0.7013	0.7044	0.7076	0.7107	0.7139	0.7170	0.7202	0.7234	0.7265
100	0.6951	0.6983	0.7014	0.7046	0.7077	0.7109	0.7140	0.7172	0.7203	0.7235

[a] Correction factor, $F = \frac{519.7}{459.7 + t} \times \frac{P - w_t}{29.4782}$

where:

P = total gas pressure in inches of mercury,
w_t = saturated vapor pressure of water, at temperature t, in inches of mercury, and
t = gas temperature in degrees Fahrenheit.

[b] This table has been taken from the National Bureau of Standards *Circular C464.*

TABLE IV.—CORRECTION FACTOR *F* FOR GAS VOLUME (*Continued*).

Temperature, deg. Fahr.	Total Gas Pressure, in. of mercury									
	25.0	25.1	25.2	25.3	25.4	25.5	25.6	25.7	25. 8	25.9
46.......	0.8607	0.8642	0.8677	0.8712	0.8746	0.8781	0.8816	0.8851	0.8886	0.8921
47.......	0.8586	0.8620	0.8655	0.8690	0.8725	0.8759	0.8794	0.8829	0.8864	0.8899
48.......	0.8564	0.8599	0.8634	0.8669	0.8703	0.8738	0.8773	0.8807	0.8842	0.8877
49.......	0.8543	0.8578	0.8612	0.8647	0.8682	0.8716	0.8751	0.8786	0.8820	0.8855
50.......	0.8522	0.8556	0.8591	0.8626	0.8660	0.8695	0.8729	0.8764	0.8799	0.8833
51.......	0.8500	0.8535	0.8569	0.8604	0.8638	0.8673	0.8707	0.8742	0.8776	0.8811
52.......	0.8479	0.8513	0.8548	0.8582	0.8617	0.8651	0.8686	0.8720	0.8755	0.8789
53.......	0.8457	0.8491	0.8526	0.8560	0.8594	0.8629	0.8663	0.8698	0.8732	0.8766
54.......	0.8436	0.8470	0.8504	0.8538	0.8573	0.8607	0.8641	0.8676	0.8710	0.8744
55.......	0.8414	0.8448	0.8483	0.8517	0.8551	0.8585	0.8620	0.8654	0.8688	0.8723
56.......	0.8392	0.8426	0.8460	0.8495	0.8529	0.8563	0.8597	0.8631	0.8666	0.8700
57.......	0.8370	0.8405	0.8439	0.8473	0.8507	0.8541	0.8575	0.8609	0.8643	0.8677
58.......	0.8348	0.8382	0.8416	0.8450	0.8484	0.8518	0.8552	0.8586	0.8621	0.8655
59.......	0.8326	0.8360	0.8394	0.8428	0.8462	0.8496	0.8530	0.8564	0.8598	0.8632
60.......	0.8304	0.8338	0.8372	0.8406	0.8439	0.8473	0.8507	0.8541	0.8575	0.8609
61.......	0.8282	0.8316	0.8349	0.8383	0.8417	0.8451	0.8485	0.8519	0.8553	0.8586
62.......	0.8259	0.8293	0.8327	0.8360	0.8394	0.8428	0.8462	0.8496	0.8529	0.8563
63.......	0.8237	0.8270	0.8304	0.8338	0.8371	0.8405	0.8439	0.8473	0.8506	0.8540
64.......	0.8214	0.8247	0.8281	0.8315	0.8348	0.8382	0.8416	0.8449	0.8483	0.8517
65.......	0.8191	0.8225	0.8258	0.8292	0.8326	0.8359	0.8393	0.8426	0.8460	0.8494
66.......	0.8168	0.8201	0.8235	0.8269	0.8302	0.8336	0.8369	0.8403	0.8436	0.8470
67.......	0.8145	0.8178	0.8212	0.8245	0.8279	0.8312	0.8346	0.8379	0.8413	0.8446
68.......	0.8121	0.8155	0.8188	0.8222	0.8255	0.8288	0.8322	0.8355	0.8389	0.8422
69.......	0.8098	0.8132	0.8165	0.8198	0.8232	0.8265	0.8298	0.8332	0.8365	0.8398
70.......	0.8074	0.8108	0.8141	0.8174	0.8208	0.8241	0.8274	0.8307	0.8341	0.8374
71.......	0.8051	0.8084	0.8117	0.8151	0.8184	0.8217	0.8250	0.8283	0.8317	0.8350
72.......	0.8027	0.8060	0.8093	0.8127	0.8160	0.8193	0.8226	0.8259	0.8292	0.8326
73.......	0.8003	0.8036	0.8069	0.8102	0.8135	0.8169	0.8202	0.8235	0.8268	0.8301
74.......	0.7979	0.8012	0.8045	0.8078	0.8111	0.8144	0.8177	0.8210	0.8243	0.8276
75.......	0.7954	0.7987	0.8020	0.8053	0.8086	0.8119	0.8152	0.8185	0.8218	0.8251
76.......	0.7929	0.7962	0.7995	0.8028	0.8061	0.8094	0.8127	0.8160	0.8193	0.8226
77.......	0.7905	0.7938	0.7971	0.8004	0.8036	0.8069	0.8102	0.8135	0.8168	0.8201
78.......	0.7880	0.7913	0.7946	0.7979	0.8011	0.8044	0.8077	0.8110	0.8143	0.8175
79.......	0.7855	0.7888	0.7920	0.7953	0.7986	0.8019	0.8051	0.8084	0.8117	0.8150
80.......	0.7830	0.7862	0.7895	0.7928	0.7960	0.7993	0.8026	0.8058	0.8091	0.8124
81.......	0.7804	0.7836	0.7869	0.7902	0.7934	0.7967	0.7999	0.8032	0.8065	0.8097
82.......	0.7778	0.7810	0.7843	0.7876	0.7908	0.7941	0.7973	0.8006	0.8038	0.8071
83.......	0.7752	0.7784	0.7817	0.7849	0.7882	0.7914	0.7947	0.7979	0.8011	0.8044
84.......	0.7726	0.7758	0.7791	0.7823	0.7855	0.7888	0.7920	0.7953	0.7985	0.8018
85.......	0.7699	0.7731	0.7763	0.7796	0.7828	0.7861	0.7893	0.7925	0.7958	0.7990
86.......	0.7672	0.7705	0.7737	0.7769	0.7801	0.7834	0.7866	0.7898	0.7931	0.7963
87.......	0.7645	0.7677	0.7709	0.7741	0.7774	0.7806	0.7838	0.7870	0.7903	0.7935
88.......	0.7617	0.7650	0.7682	0.7714	0.7746	0.7778	0.7811	0.7843	0.7875	0.7907
89.......	0.7590	0.7622	0.7654	0.7686	0.7718	0.7750	0.7783	0.7815	0.7847	0.7879
90.......	0.7562	0.7594	0.7626	0.7658	0.7690	0.7722	0.7754	0.7787	0.7819	0.7851
91.......	0.7534	0.7566	0.7598	0.7630	0.7662	0.7694	0.7726	0.7758	0.7790	0.7822
92.......	0.7505	0.7537	0.7569	0.7601	0.7633	0.7665	0.7697	0.7729	0.7761	0.7793
93.......	0.7476	0.7508	0.7540	0.7572	0.7604	0.7636	0.7668	0.7700	0.7731	0.7763
94.......	0.7447	0.7479	0.7511	0.7543	0.7575	0.7607	0.7638	0.7670	0.7702	0.7734
95.......	0.7418	0.7450	0.7481	0.7513	0.7545	0.7577	0.7608	0.7640	0.7672	0.7704
96.......	0.7388	0.7420	0.7452	0.7483	0.7515	0.7547	0.7579	0.7610	0.7642	0.7674
97.......	0.7358	0.7390	0.7421	0.7453	0.7485	0.7516	0.7548	0.7580	0.7611	0.7643
98.......	0.7328	0.7359	0.7391	0.7423	0.7454	0.7486	0.7517	0.7549	0.7581	0.7612
99.......	0.7297	0.7328	0.7360	0.7391	0.7423	0.7454	0.7486	0.7518	0.7549	0.7581
100.......	0.7266	0.7298	0.7329	0.7361	0.7392	0.7424	0.7455	0.7487	0.7518	0.7550

TABLE IV.—CORRECTION FACTOR *F* FOR GAS VOLUME (*Continued*).

Temperature, deg. Fahr.	Total Gas Pressure, in, of mercury									
	26.0	26.1	26.2	26.3	26.4	26.5	26.6	26.7	26.8	26.9
46......	0.8956	0.8990	0.9025	0.9060	0.9095	0.9130	0.9165	0.9200	0.9235	0.9269
47......	0.8933	0.8968	0.9003	0.9038	0.9073	0.9107	0.9142	0.9177	0.9212	0.9247
48......	0.8912	0.8946	0.8981	0.9016	0.9051	0.9085	0.9120	0.9155	0.9189	0.9224
49......	0.8890	0.8924	0.8959	0.8993	0.9028	0.9063	0.9097	0.9132	0.9167	0.9201
50......	0.8868	0.8902	0.8937	0.8971	0.9006	0.9041	0.9075	0.9110	0.9144	0.9179
51......	0.8845	0.8880	0.8914	0.8949	0.8983	0.9018	0.9052	0.9087	0.9121	0.9156
52......	0.8824	0.8858	0.8892	0.8927	0.8961	0.8996	0.9030	0.9065	0.9099	0.9134
53......	0.8801	0.8835	0.8870	0.8904	0.8938	0.8973	0.9007	0.9042	0.9076	0.9110
54......	0.8779	0.8813	0.8847	0.8882	0.8916	0.8950	0.8985	0.9019	0.9053	0.9088
55......	0.8757	0.8791	0.8825	0.8860	0.8894	0.8928	0.8962	0.8997	0.9031	0.9065
56......	0.8734	0.8768	0.8802	0.8836	0.8871	0.8905	0.8939	0.8973	0.9007	0.9042
57......	0.8712	0.8746	0.8780	0.8814	0.8848	0.8882	0.8916	0.8950	0.8985	0.9019
58......	0.8689	0.8723	0.8757	0.8791	0.8825	0.8859	0.8893	0.8927	0.8961	0.8995
59......	0.8666	0.8700	0.8734	0.8768	0.8802	0.8836	0.8870	0.8904	0.8938	0.8972
60......	0.8643	0.8677	0.8711	0.8745	0.8779	0.8813	0.8847	0.8880	0.8914	0.8948
61......	0.8620	0.8654	0.8688	0.8722	0.8756	0.8790	0.8823	0.8857	0.8891	0.8925
62......	0.8597	0.8631	0.8664	0.8698	0.8732	0.8766	0.8800	0.8833	0.8867	0.8901
63......	0.8574	0.8608	0.8641	0.8675	0.8709	0.8742	0.8776	0.8810	0.8844	0.8877
64......	0.8550	0.8584	0.8618	0.8651	0.8685	0.8719	0.8752	0.8786	0.8820	0.8853
65......	0.8527	0.8561	0.8594	0.8628	0.8662	0.8695	0.8729	0.8762	0.8796	0.8830
66......	0.8503	0.8537	0.8570	0.8604	0.8637	0.8671	0.8705	0.8738	0.8772	0.8805
67......	0.8480	0.8513	0.8547	0.8580	0.8614	0.8647	0.8681	0.8714	0.8747	0.8781
68......	0.8455	0.8489	0.8522	0.8556	0.8589	0.8622	0.8656	0.8689	0.8723	0.8756
69......	0.8432	0.8465	0.8498	0.8532	0.8565	0.8598	0.8632	0.8665	0.8699	0.8732
70......	0.8407	0.8441	0.8474	0.8507	0.8540	0.8574	0.8607	0.8640	0.8674	0.8707
71......	0.8383	0.8416	0.8450	0.8483	0.8516	0.8549	0.8582	0.8616	0.8649	0.8682
72......	0.8359	0.8392	0.8425	0.8458	0.8491	0.8524	0.8558	0.8591	0.8624	0.8657
73......	0.8334	0.8367	0.8400	0.8433	0.8466	0.8499	0.8533	0.8566	0.8599	0.8632
74......	0.8309	0.8342	0.8375	0.8408	0.8441	0.8474	0.8507	0.8540	0.8573	0.8606
75......	0.8284	0.8317	0.8350	0.8383	0.8416	0.8449	0.8482	0.8515	0.8548	0.8581
76......	0.8259	0.8291	0.8324	0.8357	0.8390	0.8423	0.8456	0.8489	0.8522	0.8555
77......	0.8234	0.8266	0.8299	0.8332	0.8365	0.8398	0.8431	0.8463	0.8496	0.8529
78......	0.8208	0.8241	0.8274	0.8307	0.8339	0.8372	0.8405	0.8438	0.8471	0.8503
79......	0.8182	0.8215	0.8248	0.8280	0.8313	0.8346	0.8379	0.8411	0.8444	0.8477
80......	0.8156	0.8189	0.8222	0.8254	0.8287	0.8320	0.8352	0.8385	0.8418	0.8450
81......	0.8130	0.8162	0.8195	0.8228	0.8260	0.8293	0.8325	0.8358	0.8391	0.8423
82......	0.8103	0.8136	0.8168	0.8201	0.8234	0.8266	0.8299	0.8331	0.8364	0.8396
83......	0.8076	0.8109	0.8141	0.8174	0.8206	0.8239	0.8271	0.8304	0.8336	0.8369
84......	0.8050	0.8082	0.8115	0.8147	0.8180	0.8212	0.8244	0.8277	0.8309	0.8342
85......	0.8022	0.8055	0.8087	0.8119	0.8152	0.8184	0.8217	0.8249	0.8281	0.8314
86......	0.7995	0.8028	0.8060	0.8092	0.8125	0.8157	0.8189	0.8221	0.8254	0.8286
87......	0.7967	0.7999	0.8032	0.8064	0.8096	0.8128	0.8161	0.8193	0.8225	0.8257
88......	0.7939	0.7972	0.8004	0.8036	0.8068	0.8100	0.8132	0.8165	0.8197	0.8229
89......	0.7911	0.7943	0.7975	0.8008	0.8040	0.8072	0.8104	0.8136	0.8168	0.8200
90......	0.7883	0.7915	0.7947	0.7979	0.8011	0.8043	0.8075	0.8107	0.8139	0.8171
91......	0.7854	0.7886	0.7918	0.7950	0.7982	0.8014	0.8046	0.8078	0.8110	0.8142
92......	0.7825	0.7857	0.7889	0.7921	0.7953	0.7985	0.8017	0.8049	0.8081	0.8113
93......	0.7795	0.7827	0.7859	0.7891	0.7923	0.7955	0.7987	0.8019	0.8050	0.8082
94......	0.7766	0.7798	0.7829	0.7861	0.7893	0.7925	0.7957	0.7989	0.8020	0.8052
95......	0.7736	0.7767	0.7799	0.7831	0.7863	0.7895	0.7926	0.7958	0.7990	0.8022
96......	0.7706	0.7737	0.7769	0.7801	0.7832	0.7864	0.7896	0.7928	0.7959	0.7991
97......	0.7675	0.7706	0.7738	0.7770	0.7801	0.7833	0.7865	0.7896	0.7928	0.7960
98......	0.7644	0.7676	0.7707	0.7739	0.7770	0.7802	0.7834	0.7865	0.7897	0.7928
99......	0.7612	0.7644	0.7675	0.7707	0.7738	0.7770	0.7802	0.7833	0.7865	0.7896
100......	0.7581	0.7613	0.7644	0.7676	0.7707	0.7739	0.7770	0.7802	0.7833	0.7865

TABLE IV.—CORRECTION FACTOR *F* FOR GAS VOLUME (*Continued*).

Temperature, deg Fahr.	Total Gas Pressure, in. of mercury									
	27.0	27.1	27.2	27.3	27.4	27.5	27.6	27.7	27.8	27.9
46	0.9304	0.9339	0.9374	0.9409	0.9444	0.9479	0.9513	0.9548	0.9583	0.9618
47	0.9281	0.9316	0.9351	0.9386	0.9421	0.9455	0.9490	0.9525	0.9560	0.9595
48	0.9259	0.9294	0.9328	0.9363	0.9398	0.9433	0.9467	0.9502	0.9537	0.9571
49	0.9236	0.9271	0.9305	0.9340	0.9375	0.9409	0.9444	0.9479	0.9513	0.9548
50	0.9214	0.9248	0.9283	0.9317	0.9352	0.9387	0.9421	0.9456	0.9490	0.9525
51	0.9191	0.9225	0.9260	0.9294	0.9329	0.9363	0.9398	0.9432	0.9467	0.9501
52	0.9168	0.9203	0.9237	0.9271	0.9306	0.9340	0.9375	0.9409	0.9444	0.9478
53	0.9145	0.9179	0.9213	0.9248	0.9282	0.9317	0.9351	0.9385	0.9420	0.9454
54	0.9122	0.9156	0.9191	0.9225	0.9259	0.9294	0.9328	0.9362	0.9396	0.9431
55	0.9099	0.9134	0.9168	0.9202	0.9236	0.9271	0.9305	0.9339	0.9373	0.9408
56	0.9076	0.9110	0.9144	0.9178	0.9212	0.9247	0.9281	0.9315	0.9349	0.9383
57	0.9053	0.9087	0.9121	0.9155	0.9189	0.9223	0.9258	0.9292	0.9326	0.9360
58	0.9029	0.9063	0.9097	0.9131	0.9165	0.9199	0.9234	0.9268	0.9302	0.9336
59	0.9006	0.9040	0.9074	0.9108	0.9142	0.9176	0.9210	0.9244	0.9278	0.9312
60	0.8982	0.9016	0.9050	0.9084	0.9118	0.9152	0.9186	0.9220	0.9254	0.9288
61	0.8959	0.8993	0.9027	0.9060	0.9094	0.9128	0.9162	0.9196	0.9230	0.9264
62	0.8935	0.8969	0.9002	0.9036	0.9070	0.9104	0.9138	0.9171	0.9205	0.9239
63	0.8911	0.8945	0.8979	0.9012	0.9046	0.9080	0.9114	0.9147	0.9181	0.9215
64	0.8887	0.8921	0.8954	0.8988	0.9022	0.9055	0.9089	0.9123	0.9156	0.9190
65	0.8863	0.8897	0.8930	0.8964	0.8998	0.9031	0.9065	0.9098	0.9132	0.9166
66	0.8839	0.8872	0.8906	0.8939	0.8973	0.9006	0.9040	0.9073	0.9107	0.9141
67	0.8814	0.8848	0.8881	0.8915	0.8948	0.8982	0.9015	0.9049	0.9082	0.9116
68	0.8790	0.8823	0.8856	0.8890	0.8923	0.8957	0.8990	0.9023	0.9057	0.9090
69	0.8765	0.8799	0.8832	0.8865	0.8899	0.8932	0.8965	0.8999	0.9032	0.9065
70	0.8740	0.8773	0.8807	0.8840	0.8873	0.8906	0.8940	0.8973	0.9006	0.9040
71	0.8715	0.8749	0.8782	0.8815	0.8848	0.8881	0.8915	0.8948	0.8981	0.9014
72	0.8690	0.8723	0.8757	0.8790	0.8823	0.8856	0.8889	0.8922	0.8956	0.8989
73	0.8665	0.8698	0.8731	0.8764	0.8797	0.8830	0.8864	0.8897	0.8930	0.8963
74	0.8639	0.8673	0.8706	0.8739	0.8772	0.8805	0.8838	0.8871	0.8904	0.8937
75	0.8614	0.8647	0.8680	0.8713	0.8746	0.8779	0.8812	0.8845	0.8878	0.8911
76	0.8588	0.8621	0.8653	0.8686	0.8719	0.8752	0.8785	0.8818	0.8851	0.8884
77	0.8562	0.8595	0.8628	0.8661	0.8693	0.8726	0.8759	0.8792	0.8825	0.8858
78	0.8536	0.8569	0.8602	0.8634	0.8667	0.8700	0.8733	0.8766	0.8798	0.8831
79	0.8510	0.8542	0.8575	0.8608	0.8640	0.8673	0.8706	0.8739	0.8771	0.8804
80	0.8483	0.8516	0.8548	0.8581	0.8614	0.8646	0.8679	0.8712	0.8744	0.8777
81	0.8456	0.8488	0.8521	0.8554	0.8586	0.8619	0.8652	0.8684	0.8717	0.8749
82	0.8429	0.8461	0.8494	0.8526	0.8559	0.8592	0.8624	0.8657	0.8689	0.8722
83	0.8401	0.8434	0.8466	0.8499	0.8531	0.8564	0.8596	0.8629	0.8661	0.8694
84	0.8374	0.8407	0.8439	0.8471	0.8504	0.8536	0.8569	0.8601	0.8634	0.8666
85	0.8346	0.8378	0.8411	0.8443	0.8476	0.8508	0.8540	0.8573	0.8605	0.8637
86	0.8318	0.8351	0.8383	0.8415	0.8448	0.8480	0.8512	0.8545	0.8577	0.8609
87	0.8290	0.8322	0.8354	0.8386	0.8419	0.8451	0.8483	0.8515	0.8548	0.8580
88	0.8261	0.8293	0.8326	0.8358	0.8390	0.8422	0.8454	0.8487	0.8519	0.8551
89	0.8232	0.8265	0.8297	0.8329	0.8361	0.8393	0.8425	0.8457	0.8489	0.8522
90	0.8203	0.8236	0.8268	0.8300	0.8332	0.8364	0.8396	0.8428	0.8460	0.8492
91	0.8174	0.8206	0.8238	0.8270	0.8302	0.8334	0.8366	0.8398	0.8430	0.8462
92	0.8144	0.8176	0.8208	0.8240	0.8272	0.8304	0.8336	0.8368	0.8400	0.8432
93	0.8114	0.8146	0.8178	0.8210	0.8242	0.8274	0.8306	0.8338	0.8369	0.8401
94	0.8084	0.8116	0.8148	0.8180	0.8212	0.8243	0.8275	0.8307	0.8339	0.8371
95	0.8053	0.8085	0.8117	0.8149	0.8181	0.8212	0.8244	0.8276	0.8308	0.8339
96	0.8023	0.8055	0.8086	0.8118	0.8150	0.8181	0.8213	0.8245	0.8277	0.8308
97	0.7991	0.8023	0.8055	0.8086	0.8118	0.8150	0.8181	0.8213	0.8245	0.8276
98	0.7960	0.7992	0.8023	0.8055	0.8086	0.8118	0.8150	0.8181	0.8213	0.8245
99	0.7928	0.7959	0.7991	0.8022	0.8054	0.8086	0.8117	0.8149	0.8180	0.8212
100	0.7896	0.7928	0.7959	0.7991	0.8022	0.8054	0.8085	0.8117	0.8148	0.8180

TABLE IV.—CORRECTION FACTOR *F* FOR GAS VOLUME (*Continued*).

Temperature, deg. Fahr.	Total Gas Pressure, in. of mercury									
	28.0	28.1	28.2	28.3	28.4	28.5	28.6	28.7	28.8	28.9
46.......	0.9653	0.9688	0.9723	0.9757	0.9792	0.9827	0.9862	0.9897	0.9932	0.9967
47.......	0.9629	0.9664	0.9699	0.9734	0.9768	0.9803	0.9838	0.9873	0.9908	0.9942
48.......	0.9606	0.9641	0.9676	0.9710	0.9745	0.9780	0.9815	0.9849	0.9884	0.9919
49.......	0.9583	0.9617	0.9652	0.9687	0.9721	0.9756	0.9791	0.9825	0.9860	0.9895
50.......	0.9560	0.9594	0.9629	0.9663	0.9698	0.9732	0.9767	0.9802	0.9836	0.9871
51.......	0.9536	0.9570	0.9605	0.9639	0.9674	0.9708	0.9743	0.9777	0.9812	0.9846
52.......	0.9513	0.9547	0.9582	0.9616	0.9650	0.9685	0.9719	0.9754	0.9788	0.9823
53.......	0.9489	0.9523	0.9557	0.9592	0.9626	0.9660	0.9695	0.9729	0.9764	0.9798
54.......	0.9465	0.9499	0.9534	0.9568	0.9602	0.9637	0.9671	0.9705	0.9740	0.9774
55.......	0.9442	0.9476	0.9510	0.9545	0.9579	0.9613	0.9647	0.9682	0.9716	0.9750
56.......	0.9418	0.9452	0.9486	0.9520	0.9554	0.9589	0.9623	0.9657	0.9691	0.9725
57.......	0.9394	0.9428	0.9462	0.9496	0.9531	0.9565	0.9599	0.9633	0.9667	0.9701
58.......	0.9370	0.9404	0.9438	0.9472	0.9506	0.9540	0.9574	0.9608	0.9642	0.9676
59.......	0.9346	0.9380	0.9414	0.9448	0.9482	0.9516	0.9550	0.9584	0.9618	0.9652
60.......	0.9321	0.9355	0.9389	0.9423	0.9457	0.9491	0.9525	0.9559	0.9593	0.9627
61.......	0.9297	0.9331	0.9365	0.9399	0.9433	0.9467	0.9501	0.9534	0.9568	0.9602
62.......	0.9273	0.9307	0.9340	0.9374	0.9408	0.9442	0.9476	0.9509	0.9543	0.9577
63.......	0.9248	0.9282	0.9316	0.9350	0.9383	0.9417	0.9451	0.9485	0.9518	0.9552
64.......	0.9224	0.9257	0.9291	0.9325	0.9358	0.9392	0.9426	0.9459	0.9493	0.9527
65.......	0.9199	0.9233	0.9266	0.9300	0.9334	0.9367	0.9401	0.9434	0.9468	0.9502
66.......	0.9174	0.9208	0.9241	0.9275	0.9308	0.9342	0.9375	0.9409	0.9442	0.9476
67.......	0.9149	0.9183	0.9216	0.9250	0.9283	0.9317	0.9350	0.9383	0.9417	0.9450
68.......	0.9124	0.9157	0.9190	0.9224	0.9257	0.9291	0.9324	0.9357	0.9391	0.9424
69.......	0.9099	0.9132	0.9165	0.9199	0.9232	0.9265	0.9299	0.9332	0.9365	0.9399
70.......	0.9073	0.9106	0.9139	0.9173	0.9206	0.9239	0.9273	0.9306	0.9339	0.9372
71.......	0.9048	0.9081	0.9114	0.9147	0.9180	0.9214	0.9247	0.9280	0.9313	0.9346
72.......	0.9022	0.9055	0.9088	0.9121	0.9154	0.9188	0.9221	0.9254	0.9287	0.9320
73.......	0.8996	0.9029	0.9062	0.9095	0.9128	0.9161	0.9194	0.9228	0.9261	0.9294
74.......	0.8970	0.9003	0.9036	0.9069	0.9102	0.9135	0.9168	0.9201	0.9234	0.9267
75.......	0.8944	0.8977	0.9010	0.9043	0.9076	0.9108	0.9141	0.9174	0.9207	0.9240
76.......	0.8917	0.8950	0.8983	0.9015	0.9048	0.9081	0.9114	0.9147	0.9180	0.9213
77.......	0.8890	0.8923	0.8956	0.8989	0.9022	0.9055	0.9088	0.9120	0.9153	0.9186
78.......	0.8864	0.8897	0.8930	0.8962	0.8995	0.9028	0.9061	0.9094	0.9126	0.9159
79.......	0.8837	0.8870	0.8902	0.8935	0.8968	0.9000	0.9033	0.9066	0.9099	0.9131
80.......	0.8810	0.8842	0.8875	0.8908	0.8940	0.8973	0.9006	0.9038	0.9071	0.9104
81.......	0.8782	0.8815	0.8847	0.8880	0.8912	0.8945	0.8978	0.9010	0.9043	0.9075
82.......	0.8754	0.8787	0.8819	0.8852	0.8884	0.8917	0.8950	0.8982	0.9015	0.9047
83.......	0.8726	0.8759	0.8791	0.8824	0.8856	0.8889	0.8921	0.8954	0.8986	0.9019
84.......	0.8698	0.8731	0.8763	0.8796	0.8828	0.8861	0.8893	0.8925	0.8958	0.8990
85.......	0.8670	0.8702	0.8734	0.8767	0.8799	0.8832	0.8864	0.8896	0.8929	0.8961
86.......	0.8641	0.8674	0.8706	0.8738	0.8771	0.8803	0.8835	0.8868	0.8900	0.8932
87.......	0.8612	0.8644	0.8677	0.8709	0.8741	0.8773	0.8806	0.8838	0.8870	0.8902
88.......	0.8583	0.8615	0.8648	0.8680	0.8712	0.8744	0.8776	0.8808	0.8841	0.8873
89.......	0.8554	0.8586	0.8618	0.8650	0.8682	0.8714	0.8746	0.8779	0.8811	0.8843
90.......	0.8524	0.8556	0.8588	0.8620	0.8652	0.8685	0.8717	0.8749	0.8781	0.8813
91.......	0.8494	0.8526	0.8558	0.8590	0.8622	0.8654	0.8686	0.8718	0.8750	0.8782
92.......	0.8464	0.8496	0.8528	0.8560	0.8592	0.8624	0.8656	0.8688	0.8720	0.8752
93.......	0.8433	0.8465	0.8497	0.8529	0.8561	0.8593	0.8625	0.8656	0.8688	0.8720
94.......	0.8403	0.8434	0.8466	0.8498	0.8530	0.8562	0.8594	0.8625	0.8657	0.8689
95.......	0.8371	0.8403	0.8435	0.8467	0.8498	0.8530	0.8562	0.8594	0.8626	0.8657
96.......	0.8340	0.8372	0.8404	0.8435	0.8467	0.8499	0.8530	0.8562	0.8594	0.8626
97.......	0.8308	0.8340	0.8371	0.8403	0.8435	0.8466	0.8498	0.8530	0.8561	0.8593
98.......	0.8276	0.8308	0.8339	0.8371	0.8403	0.8434	0.8466	0.8497	0.8529	0.8561
99.......	0.8243	0.8275	0.8306	0.8338	0.8370	0.8401	0.8433	0.8464	0.8496	0.8527
100.......	0.8211	0.8243	0.8274	0.8306	0.8337	0.8369	0.8400	0.8432	0.8463	0.8495

TABLE IV.—CORRECTION FACTOR *F* FOR GAS VOLUME (*Continued*).

Temperature, deg. Fahr.	Total Gas Pressure, in. of mercury									
	29.0	29.1	29.2	29.3	29.4	29.5	29.6	29.7	29.8	29.9
46.......	1.0001	1.0036	1.0071	1.0106	1.0141	1.0176	1.0211	1.0246	1.0280	1.0315
47.......	0.9977	1.0012	1.004	1.0082	1.0116	1.0151	1.0186	1.0221	1.0256	1.0290
48.......	0.9953	0.9988	1.0023	1.0058	1.0092	1.0127	1.0162	1.0196	1.0231	1.0266
49.......	0.9929	0.9964	0.9998	1.0033	1.0068	1.0102	1.0137	1.0172	1.0206	1.0241
50.......	0.9905	0.9940	0.9975	1.0009	1.0044	1.0078	1.0113	1.0148	1.0182	1.0217
51.......	0.9881	0.9915	0.9950	0.9984	1.0019	1.0054	1.0088	1.0123	1.0157	1.0192
52.......	0.9857	0.9892	0.9926	0.9961	0.9995	1.0029	1.0064	1.0098	1.0133	1.0167
53.......	0.9832	0.9867	0.9901	0.9936	0.9970	1.0004	1.0039	1.0073	1.0107	1.0142
54.......	0.9808	0.9843	0.9877	0.9911	0.9946	0.9980	1.0014	1.0049	1.0083	1.0117
55.......	0.9784	0.9819	0.9853	0.9887	0.9921	0.9956	0.9990	1.0024	1.0058	1.0093
56.......	0.9759	0.9794	0.9828	0.9862	0.9896	0.9930	0.9965	0.9999	1.0033	1.0067
57.......	0.9735	0.9769	0.9803	0.9838	0.9872	0.9906	0.9940	0.9974	1.0008	1.0042
58.......	0.9710	0.9744	0.9778	0.9812	0.9846	0.9881	0.9915	0.9949	0.9983	1.0017
59.......	0.9686	0.9720	0.9754	0.9788	0.9822	0.9856	0.9890	0.9924	0.9958	0.9992
60.......	0.9661	0.9695	0.9729	0.9762	0.9796	0.9830	0.9864	0.9898	0.9932	0.9966
61.......	0.9636	0.9670	0.9704	0.9738	0.9772	0.9805	0.9839	0.9873	0.9907	0.9941
62.......	0.9611	0.9644	0.9678	0.9712	0.9746	0.9780	0.9813	0.9847	0.9881	0.9915
63.......	0.9586	0.9619	0.9653	0.9687	0.9721	0.9754	0.9788	0.9822	0.9856	0.9889
64.......	0.9560	0.9594	0.9628	0.9661	0.9695	0.9729	0.9762	0.9796	0.9830	0.9863
65.......	0.9535	0.9569	0.9602	0.9636	0.9670	0.9703	0.9737	0.9770	0.9804	0.9838
66.......	0.9509	0.9543	0.9576	0.9610	0.9644	0.9677	0.9711	0.9744	0.9778	0.9811
67.......	0.9494	0.9517	0.9551	0.9584	0.9618	0.9651	0.9685	0.9718	0.9752	0.9785
68.......	0.9458	0.9491	0.9524	0.9558	0.9591	0.9625	0.9658	0.9692	0.9725	0.9758
69.......	0.9432	0.9465	0.9499	0.9532	0.9566	0.9599	0.9632	0.9666	0.9699	0.9732
70.......	0.9406	0.9439	0.9472	0.9506	0.9539	0.9572	0.9605	0.9639	0.9672	0.9705
71.......	0.9380	0.9413	0.9446	0.9479	0.9513	0.9546	0.9579	0.9612	0.9645	0.9679
72.......	0.9353	0.9387	0.9420	0.9453	0.9486	0.9519	0.9552	0.9586	0.9619	0.9652
73.......	0.9327	0.9360	0.9393	0.9426	0.9459	0.9492	0.9525	0.9559	0.9592	0.9625
74.......	0.9300	0.9333	0.9366	0.9399	0.9432	0.9465	0.9498	0.9531	0.9564	0.9597
75.......	0.9273	0.9306	0.9339	0.9372	0.9405	0.9438	0.9471	0.9504	0.9537	0.9570
76.......	0.9246	0.9279	0.9312	0.9345	0.9377	0.9410	0.9443	0.9476	0.9509	0.9542
77.......	0.9219	0.9252	0.9285	0.9318	0.9350	0.9383	0.9416	0.9449	0.9482	0.9515
78.......	0.9192	0.9225	0.9257	0.9290	0.9323	0.9356	0.9389	0.9421	0.9454	0.9487
79.......	0.9164	0.9197	0.9230	0.9262	0.9295	0.9328	0.9361	0.9393	0.9426	0.9459
80.......	0.9136	0.9169	0.9202	0.9234	0.9267	0.9300	0.9332	0.9365	0.9398	0.9430
81.......	0.9108	0.9141	0.9173	0.9206	0.9238	0.9271	0.9304	0.9336	0.9369	0.9401
82.......	0.9080	0.9112	0.9145	0.9177	0.9210	0.9242	0.9275	0.9308	0.9340	0.9373
83.......	0.9051	0.9083	0.9116	0.9148	0.9181	0.9213	0.9246	0.9278	0.9311	0.9343
84.......	0.9023	0.9055	0.9088	0.9120	0.9152	0.9185	0.9217	0.9250	0.9282	0.9315
85.......	0.8993	0.9026	0.9058	0.9090	0.9123	0.9155	0.9188	0.9220	0.9252	0.9285
86.......	0.8965	0.8997	0.9029	0.9061	0.9094	0.9126	0.9158	0.9191	0.9223	0.9255
87.......	0.8935	0.8967	0.8999	0.9031	0.9064	0.9096	0.9128	0.9160	0.9193	0.9225
88.......	0.8905	0.8937	0.8969	0.9002	0.9034	0.9066	0.9098	0.9130	0.9163	0.9195
89.......	0.8875	0.8907	0.8939	0.8971	0.9004	0.9036	0.9068	0.9100	0.9132	0.9164
90.......	0.8845	0.8877	0.8909	0.8941	0.8973	0.9005	0.9037	0.9069	0.9101	0.9134
91.......	0.8814	0.8846	0.8878	0.8910	0.8942	0.8974	0.9006	0.9038	0.9070	0.9102
92.......	0.8784	0.8816	0.8848	0.8879	0.8911	0.8943	0.8975	0.9007	0.9039	0.9071
93.......	0.8752	0.8784	0.8816	0.8848	0.8880	0.8912	0.8944	0.8975	0.9007	0.9039
94.......	0.8721	0.8753	0.8785	0.8816	0.8848	0.8880	0.8912	0.8944	0.8976	0.9008
95.......	0.8689	0.8721	0.8753	0.8784	0.8816	0.8848	0.8880	0.8912	0.8943	0.8975
96.......	0.8657	0.8689	0.8721	0.8753	0.8784	0.8816	0.8848	0.8879	0.8911	0.8943
97.......	0.8625	0.8656	0.8688	0.8720	0.8751	0.8783	0.8815	0.8846	0.8878	0.8910
98.......	0.8592	0.8624	0.8655	0.8687	0.8719	0.8750	0.8782	0.8814	0.8845	0.8877
99.......	0.8559	0.8590	0.8622	0.8653	0.8685	0.8717	0.8748	0.8780	0.8811	0.8843
100.......	0.8526	0.8558	0.8589	0.8621	0.8652	0.8684	0.8715	0.8747	0.8778	0.8810

TABLE IV.—CORRECTION FACTOR *F* FOR GAS VOLUME (*Concluded*).

Temperature, deg. Fahr.	Total Gas Pressure, in. of mercury									
	30.0	30.1	30.2	30.3	30.4	30.5	30.6	30.7	30.8	30.9
46.......	1.0350	1.0385	1.0420	1.0455	1.0490	1.0524	1.0559	1.0594	1.0629	1.0664
47.......	1.0325	1.0360	1.0395	1.0430	1.0464	1.0499	1.0534	1.0569	1.0604	1.0638
48.......	1.0301	1.0335	1.0370	1.0405	1.0440	1.0474	1.0509	1.0544	1.0578	1.0613
49.......	1.0276	1.0310	1.0345	1.0380	1.0414	1.0449	1.0484	1.0518	1.0553	1.0588
50.......	1.0251	1.0286	1.0320	1.0355	1.0390	1.0424	1.0459	1.0493	1.0528	1.0563
51.......	1.0226	1.0261	1.0295	1.0330	1.0364	1.0399	1.0433	1.0468	1.0502	1.0537
52.......	1.0202	1.0236	1.0271	1.0305	1.0340	1.0374	1.0408	1.0443	1.0477	1.0512
53.......	1.0176	1.0211	1.0245	1.0279	1.0314	1.0348	1.0383	1.0417	1.0451	1.0486
54.......	1.0151	1.0186	1.0220	1.0254	1.0289	1.0323	1.0357	1.0392	1.0426	1.0460
55.......	1.0127	1.0161	1.0195	1.0230	1.0264	1.0298	1.0332	1.0367	1.0401	1.0435
56.......	1.0101	1.0135	1.0170	1.0204	1.0238	1.0272	1.0306	1.0341	1.0375	1.0409
57.......	1.0076	1.0111	1.0145	1.0179	1.0213	1.0247	1.0281	1.0315	1.0349	1.0384
58.......	1.0051	1.0085	1.0119	1.0153	1.0187	1.0221	1.0255	1.0289	1.0323	1.0357
59.......	1.0026	1.0060	1.0094	1.0128	1.0162	1.0196	1.0230	1.0264	1.0298	1.0332
50.......	1.0000	1.0034	1.0068	1.0102	1.0136	1.0170	1.0203	1.0237	1.0271	1.0305
61.......	0.9975	1.0009	1.0042	1.0076	1.0110	1.0144	1.0178	1.0212	1.0246	1.0279
62.......	0.9949	0.9982	1.0016	1.0050	1.0084	1.0118	1.0151	1.0185	1.0219	1.0253
63.......	0.9923	0.9957	0.9990	1.0024	1.0058	1.0092	1.0125	1.0159	1.0193	1.0227
64.......	0.9897	0.9931	0.9964	0.9998	1.0032	1.0065	1.0099	1.0133	1.0166	1.0200
65.......	0.9871	0.9905	0.9938	0.9972	1.0006	1.0039	1.0073	1.0106	1.0140	1.0174
66.......	0.9845	0.9878	0.9912	0.9945	0.9979	1.0012	1.0046	1.0080	1.0113	1.0147
67.......	0.9819	0.9852	0.9886	0.9919	0.9953	0.9986	1.0019	1.0053	1.0086	1.0120
68.......	0.9792	0.9825	0.9859	0.9892	0.9925	0.9959	0.9992	1.0026	1.0059	1.0092
69.......	0.9766	0.9799	0.9832	0.9866	0.9899	0.9932	0.9966	0.9999	1.0032	1.0066
70.......	0.9739	0.9772	0.9805	0.9838	0.9872	0.9905	0.9938	0.9972	1.0005	1.0038
71.......	0.9712	0.9745	0.9778	0.9812	0.9845	0.9878	0.9911	0.9944	0.9978	1.0011
72.......	0.9685	0.9718	0.9751	0.9784	0.9818	0.9851	0.9884	0.9917	0.9950	0.9983
73.......	0.9658	0.9691	0.9724	0.9757	0.9790	0.9823	0.9856	0.9889	0.9923	0.9956
74.......	0.9630	0.9664	0.9697	0.9730	0.9763	0.9796	0.9829	0.9862	0.9895	0.9928
75.......	0.9603	0.9636	0.9669	0.9702	0.9735	0.9768	0.9801	0.9834	0.9867	0.9900
76.......	0.9575	0.9608	0.9641	0.9674	0.9707	0.9739	0.9772	0.9805	0.9838	0.9871
77.......	0.9547	0.9580	0.9613	0.9646	0.9679	0.9712	0.9745	0.9777	0.9810	0.9843
78.......	0.9520	0.9553	0.9585	0.9618	0.9651	0.9684	0.9716	0.9749	0.9782	0.9815
79.......	0.9491	0.9524	0.9557	0.9590	0.9622	0.9655	0.9688	0.9721	0.9753	0.9786
80.......	0.9463	0.9496	0.9528	0.9561	0.9594	0.9626	0.9659	0.9692	0.9724	0.9757
81.......	0.9434	0.9467	0.9499	0.9532	0.9564	0.9597	0.9630	0.9662	0.9695	0.9728
82.......	0.9405	0.9438	0.9470	0.9503	0.9535	0.9568	0.9600	0.9633	0.9666	0.9698
83.......	0.9376	0.9408	0.9441	0.9473	0.9506	0.9538	0.9571	0.9603	0.9636	0.9668
84.......	0.9347	0.9379	0.9412	0.9444	0.9477	0.9509	0.9542	0.9574	0.9606	0.9639
85.......	0.9317	0.9349	0.9382	0.9414	0.9447	0.9479	0.9511	0.9544	0.9576	0.9608
86.......	0.9288	0.9320	0.9352	0.9385	0.9417	0.9449	0.9481	0.9514	0.9546	0.9578
87.......	0.9257	0.9289	0.9322	0.9354	0.9386	0.9418	0.9451	0.9483	0.9515	0.9547
88.......	0.9227	0.9259	0.9291	0.9324	0.9356	0.9388	0.9420	0.9452	0.9484	0.9517
89.......	0.9196	0.9228	0.9261	0.9293	0.9325	0.9357	0.9389	0.9421	0.9453	0.9485
90.......	0.9166	0.9198	0.9230	0.9262	0.9294	0.9326	0.9358	0.9390	0.9422	0.9454
91.......	0.9134	0.9166	0.9198	0.9230	0.9262	0.9294	0.9326	0.9358	0.9390	0.9422
92.......	0.9103	0.9135	0.9167	0.9199	0.9231	0.9263	0.9295	0.9327	0.9359	0.9391
93.......	0.9071	0.9103	0.9135	0.9167	0.9199	0.9231	0.9263	0.9294	0.9326	0.9358
94.......	0.9039	0.9071	0.9103	0.9135	0.9167	0.9199	0.9230	0.9262	0.9294	0.9326
95.......	0.9007	0.9039	0.9070	0.9102	0.9134	0.9166	0.9198	0.9229	0.9261	0.9293
96.......	0.8975	0.9006	0.9038	0.9070	0.9102	0.9133	0.9165	0.9197	0.9228	0.9260
97.......	0.8941	0.8973	0.9005	0.9036	0.9068	0.9100	0.9131	0.9163	0.9195	0.9226
98.......	0.8908	0.8940	0.8972	0.9003	0.9035	0.9066	0.9098	0.9130	0.9161	0.9193
99.......	0.8874	0.8906	0.8937	0.8969	0.9001	0.9032	0.9064	0.9095	0.9127	0.9158
100.......	0.8841	0.8873	0.8904	0.8936	0.8967	0.8999	0.9030	0.9062	0.9093	0.9125

TABLE V.—VALUES OF THE PRODUCT *fh* FROM WET- AND DRY-BULB TEMPERATURES.[a]

VALUES OF *fh* FOR HUMIDITY CORRECTION PROCEDURE[b]

Dry-Bulb Temperature, deg. Fahr.	Difference Between Wet-Bulb and Dry-Bulb Temperatures, deg. Fahr.																																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
40.......	92	83	75	68	60	52	45	37	29	22	15	7																												
45.......	93	86	78	71	64	57	51	44	38	31	25	18	12	6																										
50.......	93	87	80	74	67	61	55	49	43	38	32	27	21	16	10	5																								
55.......	94	88	82	76	70	65	59	54	49	43	38	33	28	23	19	14	9	5																						
60.......	94	89	83	78	73	68	63	58	53	48	43	39	34	30	26	21	17	13	9	5																				
65.......	95	90	85	80	75	70	65	60	56	51	47	43	39	35	30	26	23	20	16	12	9	5	2																	
70.......	95	90	85	81	76	71	67	63	58	54	50	47	43	39	35	32	28	25	22	19	15	12	9	6	3															
75.......	96	91	86	82	77	73	69	65	61	57	53	50	46	43	39	36	33	29	26	23	20	17	14	11	9	7	4													
80.......	96	91	87	83	78	75	71	67	63	60	56	53	49	46	43	40	37	34	31	28	25	22	19	17	14	12	10	7	5											
85.......	96	92	88	84	80	76	72	69	65	62	58	55	52	49	46	43	40	37	35	32	29	26	24	21	19	16	14	12	10	8	6									
90.......	96	92	88	84	80	77	73	70	67	64	60	57	54	51	48	46	43	40	38	35	33	30	28	25	23	21	18	16	14	12	10	8	7							
95.......	96	93	89	85	82	78	75	72	68	65	62	59	57	54	51	49	46	43	41	38	36	34	31	29	27	24	22	20	18	16	14	12	11	9	7	6				
100.......	96	93	89	85	82	79	76	72	69	66	63	60	57	54	52	49	47	44	42	39	37	35	33	31	29	27	25	23	21	19	18	16	14	12	11	9	8	7	5	

VALUES OF *fh* FOR HUMIDITY CONTROL PROCEDURE[c]

Dry-Bulb Temperature, deg. Fahr.	Difference Between Wet- and Dry-Bulb Temperatures, deg. Fahr.												
	1	2	3	4	5	6	7	8	9	10	11	12	13
50........	91	84	76	68	59	51							
55........	91	85	78	71	64	57	50						
60........	92	86	80	73	68	62	55	49					
65........	93	87	82	76	71	66	61	56	51				
70........	93	88	83	78	73	68	63	59	55	51			
75........	94	89	84	80	75	71	66	63	59	55	51		
80........	94	90	85	81	76	72	68	64	61	57	54	51	
85........	94	90	86	82	78	74	69	66	62	59	56	53	
90........	95	91	87	83	79	75	71	67	64	61	58	55	53
95........	96	92	88	84	80	76	73	70	66	63	60	57	55
100........	96	92	89	85	81	78	75	72	69	65	62	59	56

[a] The product *fh* is equal to the ratio of the mass of water vapor mixed with a given mass of air to the mass of water vapor which would be mixed with the same mass of air if it were saturated at the same temperature and total pressure.

$$f = \frac{30 - w_t}{30 - \frac{h}{100} w_t}$$, where w_t = vapor pressure of water at the temperature t F.

h = relative humidity, per cent, as defined in the Standard Method of Determining Relative Humidity (A.S.T.M. Designation: D 337).[5a]

[b] These values of *fh* are from wet- and dry-bulb temperatures for psychrometer in air moving with a velocity not less than 900 ft. per min., and under a barometric pressure of 30 in. of mercury. The values of *h* for calculating *fh* for the humidity correction procedure are taken from Report No.235, U. S. Weather Bureau, Department of Agriculture (1937). If the barometric pressure is below 27 in. of mercury, the tabulated values will be in error by significant amounts for certain values of temperature and wet-bulb depression. If average local barometric pressure is below 27 in. of mercury, a special tabulation of values of *fh* for the humidity correction procedure, corresponding to local conditions, should be prepared.

[c] These values of *fh* are from wet- and dry-bulb temperatures for psychrometer in air moving with a velocity of 8 to 10 ft. per min. The values of *h* for calculating *fh* for the humidity control procedure are from a revision of the values given in "Fuel Gas Calorimetry—Water-Flow Method," Supplement to Vol. 32, *Proceedings*, Pacific Coast Gas Association. The revised data were supplied by Guy Corfield, Chairman, Calorimetry Committee, Pacific Coast Gas Association.

TABLE VI.—EMERGENT STEM CORRECTIONS FOR THERMOMETERS.

EMERGENT STEM CORRECTIONS[a] TO READINGS OF OUTLET-WATER THERMOMETER FOR A 15 F. RISE IN TEMPERATURE OF WATER WHEN TEMPERATURES OF INLET WATER AND ROOM ARE APPROXIMATELY EQUAL, IN DEGREES FAHRENHEIT

NOTE.—This table is applicable when the temperature of the inlet water is within 2 F. of room temperature. The temperature of the emergent stem of the outlet thermometer is slightly above that of the surrounding air, and allowance has been made for this in the table. The thermometer is assumed to be immersed to the top of the nut holding it in place in the calorimeter. The correction is positive and is to be added to the observed reading.

Graduation to Which Outlet-Water Thermometer is Immersed, deg. Fahr.	Temperature of Inlet Water or Room, deg. Fahr.					
	50	60	70	80	90	100
30......	0.04	0.05	0.06	0.07	0.09	0.10
40......	0.03	0.04	0.05	0.06	0.08	0.09
50......	0.02	0.03	0.04	0.05	0.07	0.08
60......	0.00	0.01	0.03	0.04	0.05	0.06

TABLE VI *(Cont.)*

EMERGENT STEM CORRECTIONS[a] IN DEGREES FAHRENHEIT FOR INLET- AND OUTLET-WATER THERMOMETERS

NOTE.—Individual corrections are to be applied to each of the averaged thermometer readings. This correction is positive, and is to be added to the observed reading, when the water temperature is higher than the room-air temperature. It is negative, and is to be subtracted from the observed reading, when the room-air temperature is higher than the water temperature. Each thermometer is assumed to be immersed to the top of the nut holding it in place in the calorimeter.

Number of Fahrenheit Degrees Emergent	Water Temperature *minus* Room-Air Temperature, deg. Fahr.								
	0	5	10	15	20	25	30	35	40
0......	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5......	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.02
10......	0.00	0.00	0.01	0.01	0.02	0.02	0.03	0.03	0.03
15......	0.00	0.01	0.01	0.02	0.03	0.03	0.04	0.04	0.05
20......	0.00	0.01	0.02	0.03	0.03	0.04	0.05	0.06	0.07
25......	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.09
30......	0.00	0.01	0.03	0.04	0.05	0.06	0.08	0.09	0.10
35......	0.00	0.01	0.03	0.04	0.06	0.07	0.09	0.10	0.12
40......	0.00	0.02	0.03	0.05	0.07	0.09	0.10	0.12	0.14
45......	0.00	0.02	0.04	0.06	0.08	0.10	0.11	0.13	0.15
50......	0.00	0.02	0.04	0.06	0.09	0.11	0.13	0.15	0.17
55......	0.00	0.02	0.05	0.07	0.09	0.12	0.14	0.16	0.19
60......	0.00	0.03	0.05	0.08	0.10	0.13	0.15	0.18	0.20

[a] Based on the value 0.000085 per deg. Fahr. for the relative coefficient of expansion of mercury in glass.

TABLE VII.—ERROR IN THE VALUE OF THE PRODUCT *fh* FOR THE COMBUSTION AIR CORRESPONDING TO AN ERROR OF 0.05 PER CENT IN A TOTAL CALORIFIC VALUE DETERMINATION WITH 40 PER CENT EXCESS AIR

Combustion-Air Temperature, deg. Fahr.	Allowable Error in *fh*, per cent[a]
40.............	10.0
50.............	6.0
60.............	5.0
70.............	3.5
80.............	2.5
90.............	2.0
100.............	1.0

[a] These tolerances apply to the determination of *fh* for either humidity correction or humidity control procedures. The use of a humidity correction corresponding to too high a value of *fh* for the combustion air will result in too low a calorific value for the gas being tested.

TABLE VIII.—AVERAGE VALUES OF N_0, N_1, N_0-N_1, AND fh_0 FOR VARIOUS GASES.

Type of Gas	Total Calorific Value, Btu. per standard cu. ft.	N_0, standard cu. ft. per 100 Btu.	N_1, standard cu. ft. per 100 Btu.	$N_0 - N_1$, standard cu. ft. per 100 Btu.	fh_0,[a] per cent
Butane-air and propane-air	3000	1.24	−0.11	1.35	92
	1500	1.20	−0.11	1.31	92
	1000	1.15	−0.11	1.26	91
	800	1.11	−0.11	1.22	91
	700	1.09	−0.11	1.20	91
	600	1.05	−0.11	1.16	90
	500	1.00	−0.11	1.11	90
Carburetted water	1000	1.11	−0.19	1.30	85
	800	1.08	−0.20	1.28	84
	700	1.05	−0.20	1.25	84
	600	1.02	−0.21	1.23	83
	500	0.96	−0.23	1.19	81
	400	0.88	−0.26	1.14	77
	300	0.73	−0.33	1.06	69
Coal, coke-oven, oil, and refinery	2000	1.22	−0.13	1.35	90
	1500	1.20	−0.14	1.34	90
	1100	1.14	−0.17	1.31	87
	900	1.10	−0.20	1.30	85
	800	1.07	−0.21	1.28	84
	700	1.03	−0.23	1.26	82
	600	0.98	−0.26	1.24	79
	500	0.92	−0.29	1.21	76
Natural	1300	1.18	−0.17	1.35	87
	1100	1.16	−0.18	1.34	87
	900 or under	1.14	−0.20	1.34	85

[a] The value fh_0 is the value of the product fh for the combustion air for zero humidity correction.

TABLE IX.—VALUE OF THE FUNCTION S AT VARIOUS TEMPERATURES

Combustion-Air Temperature, deg. Fahr.	Value of S
40	13
42	14
44	15
46	16
48	17
50	18
52	19
54	21
56	23
58	24
60	26
62	28
64	30
66	32
68	35
70	37
72	40
74	43
76	45
78	49
80	53
82	56
84	60
86	64
88	68
90	73
92	77
94	82
96	88
98	93
100	100

TABLE X.—COMBINED CORRECTIONS C_c FOR ILLUSTRATIVE LOCAL CONDITIONS WHEN CALCULATING TOTAL CALORIFIC VALUE.*

Values of $\frac{fh}{100}$			0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Values of N			1.06	0.94	0.81	0.68	0.56	0.43	0.30	0.18	0.05	−0.08	−0.20
Combustion Air Temperature (Dry-Bulb), deg. Fahr.	Value of S	Corrections	Btu. per Standard cu. ft.										
40	13	7.00 $NS/28$	3.4	3.1	2.6	2.2	1.8	1.4	1.0	0.6	0.2	−0.3	−0.7
		7.00 (C_m)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
		C_c	6.4	6.1	5.6	5.2	4.8	4.4	4.0	3.6	3.2	2.7	2.3
45	15	7.00 $NS/28$	4.0	3.5	3.0	2.6	2.1	1.6	1.1	0.7	0.2	−0.3	−0.8
		7.00 (C_m)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
		C_c	6.5	6.0	5.5	5.1	4.6	4.1	3.6	3.2	2.7	2.2	1.7
50	18	7.00 $NS/28$	4.8	4.2	3.6	3.1	2.5	1.9	1.4	0.8	0.2	−0.4	−0.9
		7.00 (C_m)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
		C_c	6.8	6.2	5.6	5.1	4.5	3.9	3.4	2.8	2.2	1.6	1.1
55	22	7.00 $NS/28$	5.8	5.2	4.5	3.7	3.1	2.4	1.7	1.0	0.3	−0.4	−1.1
		7.00 (C_m)	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
		C_c	7.4	6.8	6.1	5.3	4.7	4.0	3.3	2.6	1.9	1.2	0.5
60	26	7.00 $NS/28$	6.9	6.1	5.3	4.4	3.6	2.8	2.0	1.2	0.3	−0.5	−1.3
		7.00 (C_m)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
		C_c	8.4	7.6	6.8	5.9	5.1	4.3	3.5	2.7	1.8	1.0	0.2
65	31	7.00 $NS/28$	8.2	7.3	6.3	5.3	4.3	3.3	2.3	1.4	0.4	−0.6	−1.6
		7.00 (C_m)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
		C_c	9.7	8.8	7.8	6.8	5.8	4.8	3.8	2.9	1.9	0.9	−0.1
70	37	7.00 $NS/28$	9.8	8.7	7.5	6.3	5.2	4.0	2.8	1.7	0.5	−0.7	−1.9
		7.00 (C_m)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
		C_c	11.3	10.2	9.0	7.8	6.7	5.5	4.3	3.2	2.0	0.8	−0.4
75	44	7.00 $NS/28$	11.7	10.3	8.9	7.5	6.2	4.7	3.3	2.0	0.6	−0.9	−2.2
		7.00 (C_m)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
		C_c	13.2	11.8	10.4	9.0	7.7	6.2	4.8	3.5	2.1	0.6	−0.7
80	53	7.00 $NS/28$	14.0	12.5	10.7	9.0	7.4	5.7	4.0	2.4	0.7	−1.1	−2.7
		7.00 (C_m)	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
		C_c	15.6	14.1	12.3	10.6	9.0	7.3	5.6	4.0	2.3	0.5	−1.1
85	62	7.00 $NS/28$	16.4	14.6	12.6	10.5	8.7	6.7	4.7	2.8	0.8	−1.2	−3.1
		7.00 (C_m)	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
		C_c	18.1	16.3	14.3	12.2	10.4	8.4	6.4	4.5	2.5	0.5	−1.4
90	73	7.00 $NS/28$	19.3	17.2	14.8	12.4	10.2	7.8	5.5	3.3	0.9	−1.4	−3.7
		7.00 (C_m)	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
		C_c	21.2	19.1	16.7	14.3	12.1	9.7	7.4	5.2	2.8	0.5	−1.8
95	86	7.00 $NS/28$	22.8	20.2	17.4	14.6	12.0	9.3	6.5	3.9	1.1	−1.7	−4.3
		7.00 (C_m)	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
		C_c	24.9	22.3	19.5	16.7	14.1	11.4	8.6	6.0	3.2	0.4	−2.2
100	100	7.00 $NS/28$	26.5	23.5	20.3	17.0	14.0	10.8	7.5	4.5	1.3	−2.0	−5.0
		7.00 (C_m)	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
		C_c	28.9	25.9	22.7	19.4	16.4	13.2	9.9	6.9	3.7	0.4	−2.6

---

* It is assumed that the gas is a mixture of 550-Btu. carburetted water gas and 1100-Btu. natural gas, the heating value of the mixture being 700 Btu. It is also assumed that the local barometric pressure is 28 in. of mercury. Then the combined correction equals

$$C_c = \frac{HNS}{100\,P} + \left(\frac{H}{100}\right)(C_b + C_s + C_e + C_t)$$

or

$$C_c = \frac{7.00\,NS}{28} + 7.00(C_m)$$

H is the anticipated total calorific value of the mixture in British thermal units and P is the average local barometric pressure in inches of mercury. The values of S were taken from Table IX and the values of N were calculated as described in Section 16 of the method, using data taken from Table VIII. Values of C_m were taken from Table XI.

TABLE XI.—MINOR CORRECTIONS, C_m, TO BE ADDED TO THE OBSERVED CALORIFIC VALUE.

Combustion-Air Temperature, deg. Fahr.	Corrections[a] to be Added, percentage of anticipated total calorific value					
	C_b	C_s	C_e	C_t	Sum = C_m	
					Total Calorific Value ($C_b + C_s + C_e + C_t$)	Net Calorific Value ($C_b + C_s + C_e$)
40.......	0.11	0.22	0.20	−0.10	0.43	0.53
45.......	0.11	0.11	0.20	−0.07	0.35	0.42
50.......	0.11	0.03	0.20	−0.05	0.29	0.34
55.......	0.11	−0.04	0.20	−0.02	0.25	0.27
60.......	0.11	−0.09	0.20	0.00	0.22	0.22
65.......	0.11	−0.12	0.20	0.02	0.21	0.19
70.......	0.11	−0.15	0.20	0.05	0.21	0.16
75.......	0.11	−0.16	0.20	0.07	0.22	0.15
80.......	0.10	−0.17	0.20	0.10	0.23	0.13
85.......	0.10	−0.18	0.20	0.12	0.24	0.12
90.......	0.10	−0.18	0.20	0.15	0.27	0.12
95.......	0.10	−0.17	0.20	0.17	0.30	0.13
100.......	0.10	−0.16	0.20	0.20	0.34	0.14

[a] The significance of the individual corrections C_b, C_s, C_e, and C_t is as follows:

C_b corrects for the buoyancy of air affecting the weight of the water collected. The values shown are for a barometric pressure of 30 in. of standard mercury column. If the barometric pressure differs significantly from 30 in., the tabulated values shall be multiplied by $\frac{P}{30}$, where P is the average local barometric height in inches of mercury.

C_s corrects for variation of the specific heat of pure water with temperature. The temperature rise of the water is taken as 15 F.

C_e corrects for heat lost by the calorimeter by radiation and convection, and is an average figure for American and Precision type calorimeters.

C_t corrects for the difference in the heat capacity of the combustion products and the reactants (gas and air) at temperatures above and below 60 F. as related to the total calorific value. The temperature coefficients for net calorific value are much smaller and can be neglected. The tabulated values of C_t apply for all fuel gases except blue water gas. For blue water gas one half of the tabulated values of C_t should be used.

TABLE XII.—VALUES OF CORRECTION C_d FOR DIFFERENCE BETWEEN INLET-WATER AND COMBUSTION-AIR TEMPERATURES.[a, b]

Mean of Inlet-Water and Combustion-Air Temperature, deg. Fahr.	For Calculating Total Calorific Value, percentage of anticipated total calorific value per deg. Fahr. difference	For Calculating Net Calorific Value, percentage of anticipated total calorific value per deg. Fahr. difference
40.......	0.094	0.074
45.......	0.102	0.079
50.......	0.110	0.083
55.......	0.119	0.087
60.......	0.128	0.090
65.......	0.136	0.092
70.......	0.146	0.094
75.......	0.155	0.095
80.......	0.167	0.097
85.......	0.180	0.098
90.......	0.194	0.099
95.......	0.209	0.099
100.......	0.228	0.100

[a] The correction is added if the inlet-water temperature is higher than combustion-air temperature, and is subtracted if the inlet-water temperature is lower.

[b] The values are based on the assumption that the temperature of the combustion air and the air surrounding the calorimeter are identical, but sometimes these temperatures are different. In this event, an additional correction is necessary to take account of the fact that the part of C_d which is for heat loss from the surface of the calorimeter should be based on room temperature rather than on combustion air temperature. This additional correction amounts to 0.068 per cent of the observed calorific value per deg. Fahr. difference and is added if the temperature of the room air is lower than that of the combustion air and subtracted if it is higher. This correction is to be applied in calculating both total and net calorific values.

TABLE XIII.—LATENT HEAT OF VAPORIZATION AND VAPOR PRESSURE OF WATER.

Combustion-Air Temperature, deg. Fahr.	Heat of Vaporization, r, Btu. per ml.[a]	Vapor Pressure, in. of Mercury
40..........	2.36	0.248
45..........	2.36	0.300
50..........	2.35	0.363
55..........	2.34	0.436
60..........	2.34	0.522
65..........	2.33	0.622
70..........	2.32	0.739
75..........	2.31	0.875
80..........	2.31	1.032
85..........	2.30	1.213
90..........	2.29	1.422
95..........	2.28	1.660
100..........	2.27	1.933

[a] The values given in this column are in British thermal units per milliliter at the corresponding temperature. They are for use in reducing observed to net calorific values.

APPENDIX

SUMMARIZED OPERATING DIRECTIONS FOR WATER-FLOW CALORIMETERS

A1. The following summarized directions may be of use to those who are sufficiently familiar with the complete directions for this method and may desire only a reminder of the principal operations involved. They are not to be considered as a substitute for the detailed directions given in the test of the method, which should be followed in all cases. References to the detailed directions are given for each of the items below:

(a) *Adjustments for Humidity-Correction Procedure:*

(*1*) Fill water supply tank and adjust temperature of water (Section 8 (*a*)),

(*2*) Purge gas lines (Section 8 (*b*)),

(*3*) Adjust meter for temperature, level, water level, and saturation of water with gas (Section 8(*c*)),

(*4*) Test for gas leaks (Section 8 (*d*)),

(*5*) Start flow of water through system and expel air (Section 8 (*e*)),

(*6*) Light gas, adjust rate of gas flow, adjust primary air supply, and insert burner in calorimeter (Section 8 (*f*)),

(*7*) Adjust water flow to give proper temperature rise (Section 8 (*g*)), and

(*8*) Allow time for attainment of a steady thermal state and adjust damper (Section 8 (*h*)).

(*b*) *Adjustment for Humidity Control Procedure:*

(*1*) Make adjustments described in Items (*1*) to (*4*) of Paragraph (*a*),

(*2*) Start flow of water through calorimeter and through humidity controller (Section 9 (*b*)),

(*3*) Light gas, adjust rate of gas flow, adjust primary air supply, and open flue damper wide (Section 9 (*c*)),

(*4*) Attach special housing containing burner to calorimeter, then connect the humidity controller to the special burner housing (Section 9 (*d*)),

(*5*) Allow time for the attainment of a steady thermal state. Close flue damper until evidence of incomplete combustion is observed. Reduce gas flow to standard rate. Adjust humidity controller so as to maintain the proper value of *fh*. Adjust water flow in calorimeter to give the proper temperature rise (Section 9 (*e*)).

(*c*) *Procedure for Calorific Value Determination:*

(*1*) Prepare test record sheet, and make preliminary observations of barometric pressure and temperature, pressure and temperature of gas in meter, wet- and dry-bulb thermometer readings, temperature of flue gases, and time of one revolution of meter (Section 10 (*a*) and (*b*)),

(*2*) Start collection of condensate and record meter reading (Section 10 (*c*), Item (*1*)),

(*3*) Take first series of observations as follows: Make preliminary notation of water temperatures; shift water; observe series of water temperatures; shift water; make supplemental notation of water temperatures; and weigh water (Section 10 (*c*), Items (*2*) to (*6*)),

(*4*) Take second and third series of observations (Section 10 (*d*)),

(*5*) Stop collection of condensate and record meter reading and amount of condensate (Section 10 (*e*)),

(*6*) Repeat preliminary observations of Item (*1*) above (Section 10 (*f*)), and

(*7*) Turn off gas and then turn off water (Section 10 (*g*)).

HIGH-HEAT VALUE OF GASES IN NATURAL GAS RANGE

The high-heat value of gases in the natural gas range may also be determined by means of a continuous recording gas calorimeter where one is correctly installed and maintained. In the use of this instrument, it is of special importance that the gas sampling and instrument connections be connected directly to the equipment. When changing gases, the calorimeter must be operated for a sufficient time after the change to provide equilibrium conditions of the gas in contact with the equipment.

Standard Method of Test for

CALORIFIC VALUE OF GASES IN NATURAL GAS RANGE BY CONTINUOUS RECORDING CALORIMETER

ASTM Designation: D 1826–64

Approved as USA Standard Z68.2–1966

(Paragraph and table to obtain factors to change results from "Standard" to other temperature and pressure bases is omitted. See Table I, page 2.)

Scope

1. (*a*) This method covers a procedure for determining with the continuous recording calorimeter (Note 1) the total calorific value of fuel gas produced or sold in the natural gas range of 900 to 1200 Btu per standard cubic foot.

Note 1.—An extensive investigation of the accuracy of the Cutler-Hammer recording gas calorimeter, when used with gases of high heating value, was made by the National Bureau of Standards in 1957 under a research project sponsored by the American Gas Association.

(*b*) The subjects covered in this method appear in the following sections:

	Sections
Air - Gas Ratio Test	10
Apparatus	4
Basis of Measurement	13
Cold Balance Test	9
Compensation of Complicating Factors	12
Condition of Gas Sample	6
Definitions	3
Installation of Apparatus	5
Maintenance, Appendix I	A1 to A4
Operating Precautions, Appendix II	B1 and B2
Operation and Checking of Apparatus	8
Precision	14
Scope	1
Standardization of Calorimeter	11
Standardization, Preliminary, of Calorimeter by Hydrogen	7
Summary of Method	2

Summary of Method

2. (*a*) The heating value is determined by imparting all of the heat obtained from the combustion of the test gas to a stream of air and measuring the rise in temperature of the air. The streams of test gas and heat absorbing air are maintained in fixed volumetric proportion to each other by metering devices similar to the ordinary wet test meters, geared together and driven from a common electric motor. The meters are mounted in a tank of water, the level of which is maintained and the temperature of which determines the temperature of the entering gas and air.

(*b*) The flue gas resulting from combustion of the gas (combustion products plus excess combustion air) is kept separate from the heat absorbing air, and is cooled to a few degrees above the initial temperature of gas and air. The water formed in the combustion is practically all condensed to the liquid state. Consequently, the temperature rise produced in the heat absorbing air is directly proportional to the heating value of the gas. Since all the heat from the combustion of the test gas sample, including the latent heat of vaporization of the water vapor formed in the combustion, is imparted to the heat absorbing air, the calorimeter makes a direct determination of total heating value. The temperature rise is measured by nickel resistance thermometers and is translated into Btu per standard cubic foot.

Definitions

3. The most important terms used in connection with the determination of the calorific value of gaseous fuels in recording calorimetry are as follows:

(*a*) *British Thermal Unit.*—A British thermal unit, or Btu, is the quantity of heat that must be added to one avoirdupois pound of pure water to raise its temperature from 58.5 to 59.5 F under standard pressure.

Note.—From the National Bureau of Standards data: One British thermal unit, or Btu, is equivalent to 1055.07 absolute joules.

(*b*) *Combustion Air.*—The air used for combustion, a total of the portion mixed with the gas as primary air and the air supplied around the burner tube as secondary air (theoretical air plus excess air).

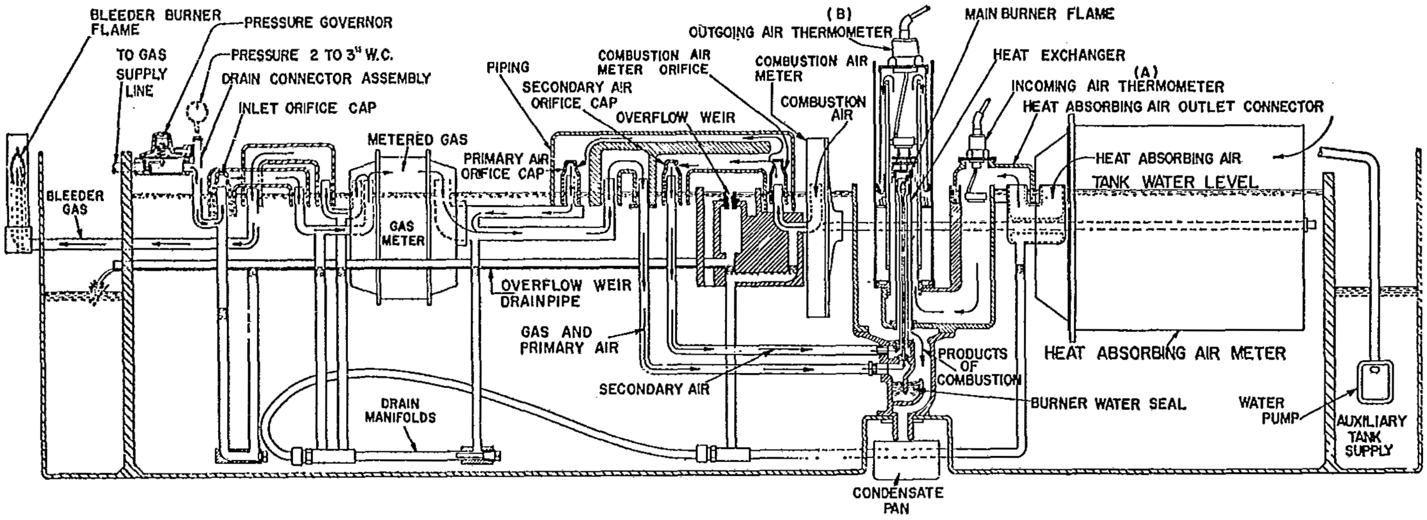


FIG. 1.—Calorimeter—Schematic Flow Diagram.

(*c*) *Flue Gases.*—The flue gases are the products of combustion remaining in the gaseous state, together with any excess air.

(*d*) *Heat-Absorbing Air.*—The heat-absorbing air is the heat exchange medium used to absorb the heat of combustion derived from the burning of gaseous fuel.

(*e*) *Saturated Basis.*—The expressed total calorific value of a gas when it is saturated with water vapor at standard temperature and pressure; 1 cu ft of this gas is equivalent in dry gas content to 0.9826 cu ft of dry gas at the temperature and pressure.

NOTE.—The definitions given in Paragraphs (*e*) and (*i*) are for total calorific values per standard cubic foot of gas. The definitions corresponding to any other unit quantity of gas are obtained by substituting the name of the desired unit in place of the term "standard cubic foot" in the definitions. Methods of calculating calorific values per cubic foot of gas under any desired conditions of pressure, temperature, and water vapor content are specified in Section 13.

(*f*) *Standard Cubic Foot of Gas.*—A standard cubic foot of gas is the quantity of any gas that at standard temperature and under standard pressure will fill a space of 1 cu ft when in equilibrium with liquid water.

NOTE.—According to Dalton's law, this is equivalent to stating that the partial pressure of the gas is:

$30 - 0.522 = 29.478$ in. of mercury column

(*g*) *Standard Pressure.*—The standard pressure is the absolute pressure of a column of pure mercury 30 in. in height at 32 F and under standard gravity (32.174 ft per sec per sec).

(*h*) *Standard Temperature.*—The standard temperature is 60 F, based on the international temperature scale.

(*i*) *Total Calorific Value.*—The total calorific value of a gas is the number of British thermal units evolved by the complete combustion at constant pressure of one standard cubic foot of gas with air, the temperature of the gas, air, and products of combustion being 60 F, and all the water formed by the combustion reaction being condensed to the liquid state.

Apparatus

4. The recording calorimeter (Note 2) consists of two major units: the tank unit or calorimeter proper, Figs. 1, 2, and 3, in which the heating value of the test gas sample is measured; and the recording unit which translates the heat measurements into an indication of calorific value and records it graphically (Note 3).

NOTE 2.—The specific model used by the National Bureau of Standards in its investigation work was the Cutler-Hammer Model Type AB. Since that time, a new model has been introduced with major changes in recorder. Both models are applicable. Figures 1, 2, and 3 are of the new model. However, for pertinent details of techniques and maintenance, the manufacturer's manuals should be consulted.

NOTE 3.—Refer to specific manufacturer's manual for pictures of the recorder.

Installation of Apparatus

5. (*a*) In order to secure the precise results that are possible with the recording calorimeter, it is important that the instrument be installed so that the surrounding conditions will not introduce errors. In general, more precise results will be secured when a narrow range is maintained on the various conditions of the calorimeter environment.

(*b*) *Calorimeter Room.*—A typical installation of a single recording calorimeter is shown in Fig. 4. The detailed requirements for the calorimeter room are given in Table I.

NOTE 4.—A detailed discussion of these requirements is included in the latest edition of the manufacturer's instruction book covering the recording calorimeter. The information can be applied to all models of the instrument.

NOTE 5.—The dimensions shown in Fig. 4 are for the latest model calorimeter.

(*c*) *Gas Connection.*—The sample line that brings the gas to be tested to the calorimeter tank unit should be located so that the heating value is actually representative of the conditions existing in the main gas line. The sample line time lag should be kept as small as possible by (*1*) locating the calorimeter tank unit close to the sample point, (*2*) running the sample line of small size pipe

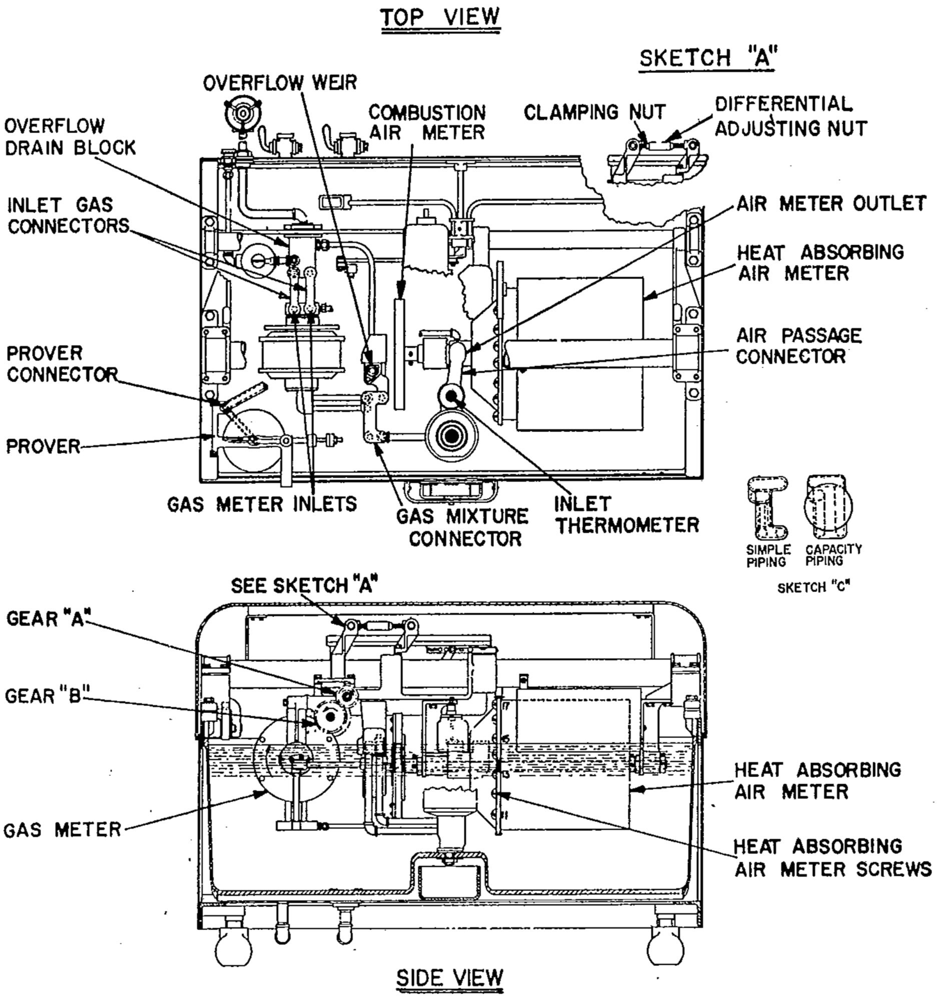


FIG. 2.—Calorimeter—Layout Diagram.

(Note 6), and (*3*) operating the sample line at low pressure. An additional purge burner or a bleed to a low pressure point shall also be provided.

NOTE 6.—Time lag may be calculated on the basis that the calorimeter uses about 1.2 cu ft per hr.

(*d*) *Electrical Wiring.*—The four leads for the resistance thermometers between the recorder and the tank unit shall be of No. 12 gage, insulated, solid copper wire without joints. They shall be run in separate rigid metal conduit which is grounded and contains no other leads (Note 7). Power circuit wiring should be No. 14 gage, insulated, solid or stranded, copper wire. The supply line should be provided with a suitably fused disconnect switch. For the model using an electronic recorder, it is essential that a suitable ground connection be made at both the recorder and the tank unit. Details are given in the manufacturer's instructions.

NOTE 7.—Where outdoor or underground wiring must be used, special care should be exercised to protect the terminals of the cables from moisture in order to prevent grounds in the measuring circuit.

(*e*) *Initial Installation.*—When the calorimeter is first installed, fill the tank unit with water (Note 8) and adjust it to a temperature that is 2 to 5 F below the normal room temperature. Allow the unit to operate at least 24 hr before performing the detailed calibration tests.

NOTE 8.—The water may be ordinary tap water supplied by most municipalities. If, however, it is found that excessive quantities of deposits and sludge are formed in short duration which interfere with satisfactory performance, it will be necessary to use distilled or demineralized water.

NOTE 9.—For actual test instructions and other information, see the appropriate instruction book provided by the manufacturer.

(*f*) *Recorder Installation.*—The recorder should be installed so that the instrument is reasonably free from mechanical vibration. This is particularly important for those models in which a suspension-type galvanometer is employed.

Condition of Gas Sample

6. (*a*) *Physical Contamination.*—The gas sample should be free of dust, water and other entrained solids. If experience indicates that the foreign materials can enter the sample line, a suitable sample line filter should be installed. To avoid any problems in the line from water accumulation, the line should be pitched to a low point and a drip leg provided.

(*b*) *Chemical Contamination.*— The sample line should be practically free from hydrogen sulfide. A small, low-capacity purifier can be constructed using iron oxide on wood shavings as the purifying material. The time lag in the purifier adds to the sample line time lag so that the purifier should be of small capacity. A design that will purify about 3 cu ft of gas per hr will be satisfactory

Preliminary Standardization of Calorimeter by Hydrogen

7. The use of preliminary standardization by hydrogen test gas before the use of standard methane at the time of the initial installation or after any complete major overhaul of the tank unit and recorder is required, because of the following factors:

(*a*) Because of the low density of hydrogen, the presence of any leaks in the system from the gas meter to the burner will result in a definite low reading. This situation should certainly be considered on the initial installation and whenever the gas meter assembly has been dismantled for inspection or cleaning.

(*b*) The hydrogen test gives another cross check of the slide wire and thermometer calibration at a different point on the scale of the instrument. A satis-

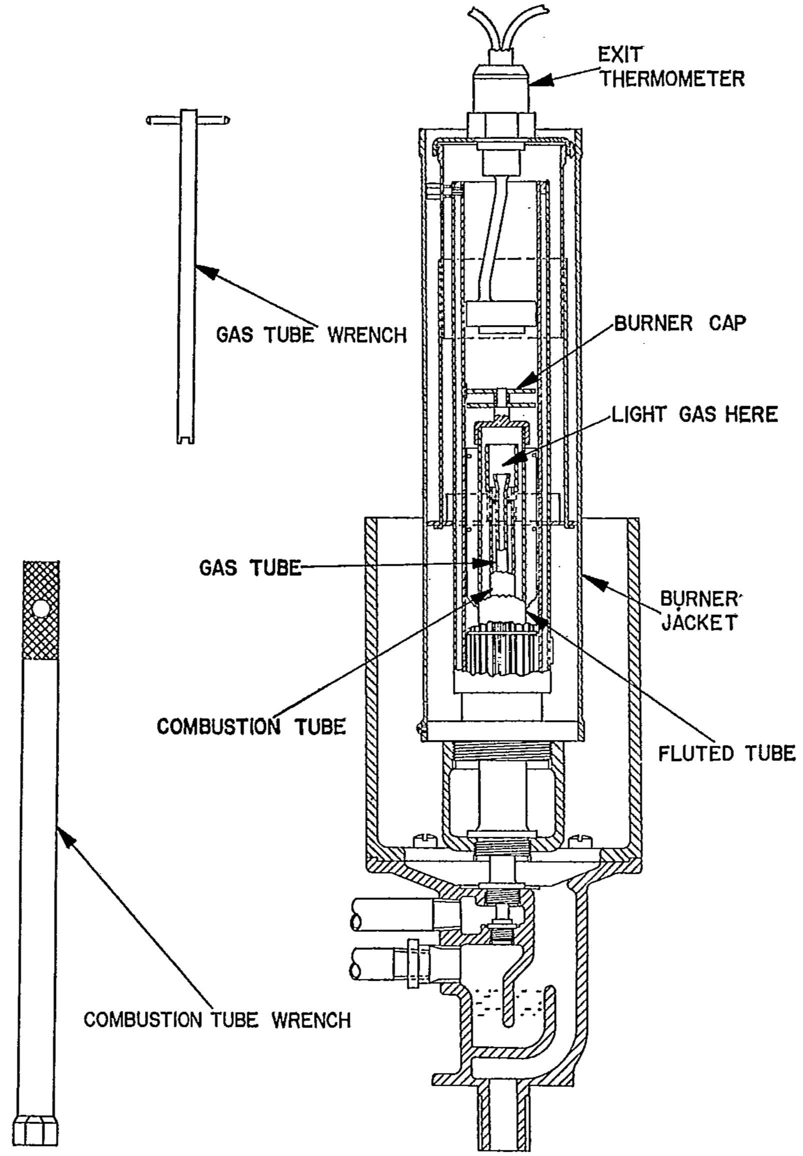


FIG. 3.—Calorimeter Combustion Chamber.

factory hydrogen test would give additional assurance that no error existed in this part of the instrument.

(*c*) There is practically no possibility of incomplete combustion on the hydrogen test. Therefore, a satisfactory hydrogen result gives assurance that, with the proper heat input, the correct scale reading will be secured. If a satisfactory hydrogen test has been secured and a low reading has been obtained on the standard gas, the possibility of incomplete combustion could be suspected. Without the hydrogen test, there might be some tendency to make adjustments to compensate in another way for the low reading. This is obviously undesirable.

NOTE 10.—The manufacturer's instruction manual shall be used for the hydrogen test. This test is considered satisfactory if the reading agrees with the theoretical value within 0.3 per cent.

Operation and Checking of Apparatus

8. The recording calorimeter is designed for continuous operation and, as a precision instrument, it should receive regular inspection. Recording the results of tests, the replacement of any parts, and the establishment of a regular inspection will ensure that the high degree of precision attainable will be maintained. The manufacturer's appropriate instruction book gives details of the procedure for operating the instrument. The following points should be checked periodically:

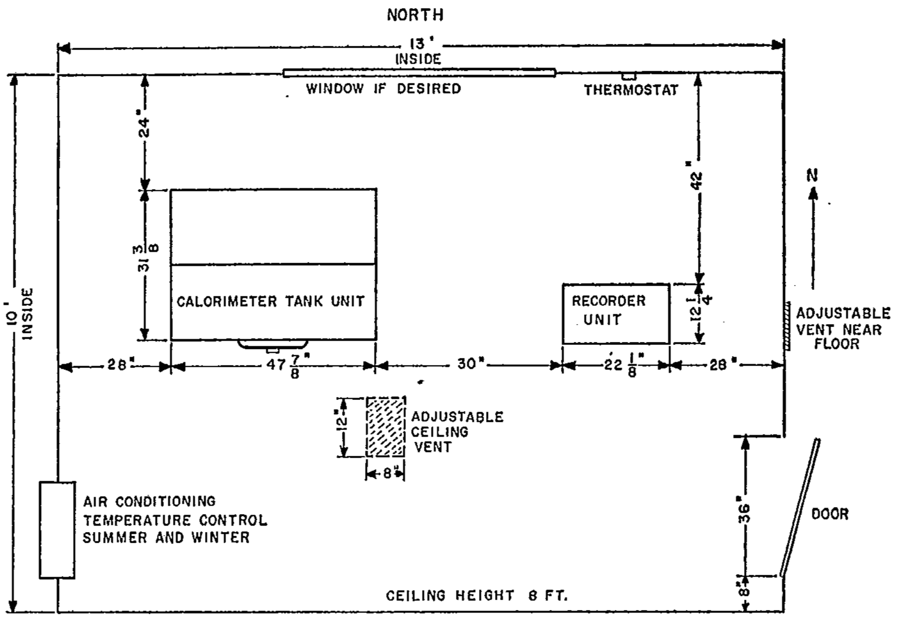
(*a*) *Recorder.*—Check the operation of the recorder at regular intervals to be sure that the chart is set at the proper time and that the pen is making a satisfactory line. Examinations of the chart record will aid in avoiding certain operating problems since the record will show if undesirable conditions develop. For example, an irregular chart may be the result of deposits in the burner parts or on orifice caps. Gradual changes in the record from normal values may indicate a failure to replenish the water in the reserve tank or may show the existence of obstructions on the overflow weir.

(*b*) *Tank Unit.*—To avoid contamination of the air in the room with combustible gas, take care to ensure that the bleeder burner remains lighted at all times. For unattended locations, it is possible to provide for the sample line a thermostatically-operated shut-off valve which closes upon failure of the bleeder flame. Regular inspection will indicate the necessity of replenishing the water in the reserve tank and thus ensure maintenance of the proper level in the main tank. The presence of any foreign material either in or on the water can be avoided by regular examination. This will prevent incorrect overflow weir operation. Periodic examination of the thermometers and the burner parts will avoid errors in reading which could be caused by deterioration of any of these parts.

Procedure for Cold Balance Test

9. (*a*) The object of the cold balance test is to check the complete temperature-measuring circuit. It is equivalent to the calorimeter measuring a gas with zero heating value. For this test, the same precautions and care should be observed that are required for the calorimeter in normal use. The over-all time of test shall not be less than 1 hr.

(*b*) If the cold balance is consistent within the range of the balancing rheostat (only small variations occurring



NOTE.—For each additional calorimeter at least 50 per cent additional space is required; for example, for two calorimeters the room should be 12 by 18 ft inside; for three calorimeters 15 by 18 ft.

FIG. 4.—Calorimeter Room.

TABLE I.—CALORIMETER ROOM REQUIREMENTS.

Detail	Requirements
Space	1000 cu ft, min.
Ceiling height	8 ft, min.
Side wall widths	10 ft and 13 ft, min.
Windows	One, on side normally away from sun (in northern hemisphere, the northern side).
Doors	One, with 3-ft opening, not in window wall. A door check is desirable.
Ventilation	Natural. In ceiling and base of door. No sudden drafts.
Tank unit location	Position to avoid, as much as possible, direct circulation from the door and from room temperature conditioning equipment.
Heating and cooling	Controlled in the range 72 to 77 F with a variation of not more than 2.5 F from the set point.
Foundation floor	3000-lb load should produce no deflection. Tank unit feet shall be on concrete floor.
Lighting	No direct sunlight permitted on calorimeter tank unit.
Condition of air	Essentially free from dust and absolutely free from any combustible gas.
Vibration	No vibrations or shocks shall be transmitted to the tank unit.
Water	Pure, clean water shall be available for filling the tank and replenishing the reserve tank.
Power supply	115 v, 1 phase, 60 cycles, 1000 w for small motors. Lighting in addition.
Gas supply	Sample pipe shall be capable of handling 2 to 4 cu ft per hr. Actual installation shall be the minimum capacity to reduce time lag. Pressure in line entering calorimeter room shall be not more than 1 psig.
Water supply and drain	Desirable but not essential.
Radiation	Tank unit shall be shielded from any hot radiation surfaces.

from one test to another), the thermometer leads and resistance elements in the circuit are in satisfactory condition.

(*c*) The rheostat provides a small amount of adjustment to compensate for any differences in the resistance of the thermometer leads. Thus, variations in the setting could be evidence of unsatisfactory electrical connections, or deterioration of the thermometers or connecting leads.

(*d*) When performing the test, it is very important that the room temperature be stable in order to avoid a false balance condition. In effect, a falling room temperature tends to result in a low-balance setting and a rising room temperature in a high-balance setting. The room temperature variation shall not exceed ±2.5 F during this test.

Procedure for Air - Gas Ratio Test

10. (*a*) The object of the air - gas ratio test is to ensure the fixed predetermined volume relation between the output of the gas meter and that of the heat-absorbing air meter. This volume ratio is a basic factor in the accuracy of the calorimeter.

(*b*) The room temperature shall be reasonably constant at the normal controlled value during the test.

(*c*) The tank unit shall be in proper mechanical operating condition; particularly, there should be no excessive gear or bearing wear existing.

(*d*) The air - gas ratio prover shall be accurately balanced. (See new model setup, Fig. 5.)

(*e*) There shall be no leaks in the gas meter, heat-absorbing air meter, or the prover and its connections.

(*f*) The tank unit level shall be checked before the air - gas ratio test is started.

(*g*) Recording of a typical air - gas ratio test is shown in Table II with the allowable tolerances.

Standardization of Calorimeter

11. (*a*) The over-all accuracy of the recording calorimeter may be checked by burning a gas of known heating value and comparing the results with this value. The total time of test shall be not less that 1.5 hr. For natural gases having heating values in the range 900 to 1200 Btu per cu ft, standard methane of known accuracy between 0.5 and 0.9 Btu per cu ft should be used (Note 11). The use of methane involves no change in the operation of the calorimeter, but merely a shift from the test gas to the standard gas. Thus, this eliminates the necessity of changing gears to compensate for chart reading and results in no water-level changes.

(*b*) For accepted performance, cali-

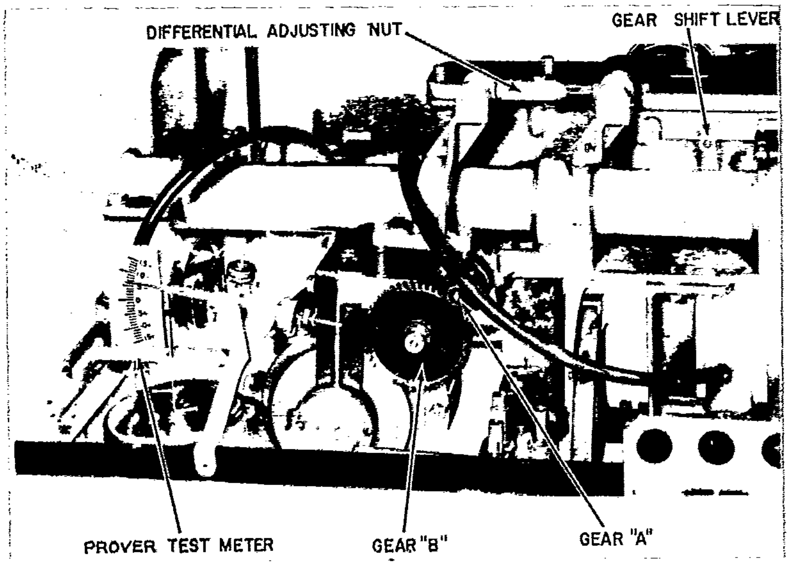


FIG. 5. Air-Gas Ratio Prover.

brations should be made weekly as set up in Fig. 6. However, before this is performed, it is essential that the calorimeter and recorder be in proper operating condition and calibration be performed as close as possible to the water temperature of the tank as expected during normal operation. The inlet pressure of the calibration gas shall be the same as for subsequent operation.

NOTE 11.—A standard gas, essentially methane, is supplied in high-pressure cylinders with certification of the heating value by the Institute of Gas Technology, 3424 S. State St., Chicago, Ill. 60616.

Compensation of Complicating Factors

12. (*a*) Because the calorimeter chart reading is to be a direct indication of the heating value of the gas, compensation in the instrument must be made either by standardization or by mechanical devices for all correction terms and other complicating factors.

(*b*) With a given initial temperature of gas and air, the temperature rise of the heat-absorbing air is directly proportional to the heat of combustion of the gas, but the resistance of the thermometers is a quadratic function of temperature. Hence, if the reading of the calorimeter is a linear function of thermometer resistance, it will not be a linear function of temperature, and therefore it will not be a linear function of heat of combustion. This effect can be compensated for by using a nonlinear scale of calorimeter reading versus resistance. In some Cutler-Hammer calorimeters the scale of heating values extends from zero to a maximum reading, and the effect on calorimeter reading of the nonlinearity of the resistance - temperature relation is considerably reduced by using two linear resistance-reading scales, each extending over about half of the total range of the instrument. In some instruments, however, a more open ("expanded") scale of heat of combustion is used, which covers only a limited range below the maximum, for example, the range from 900 to 1200 Btu per standard cubic foot. In more recent instruments, the scale is divided into a larger number of linear sections.

(*c*) When the temperature of the tank and therefore of the entering gas and air changes, the quantities of gas and air delivered by the meters change as a result of the thermal expansion of the gas and air, and also as a result of a change in partial pressure of the gas with change in the vapor pressure of water. The change in the quantity of gas delivered by the meter results in a change in the quantity of heat produced by combustion of gas per revolution of the gas meter, while the heat capacity of the air per unit volume is only slightly affected. Hence, if there were no compensating effect, a change in tank temperature would result in a change in reading of the calorimeter for a gas of a given heat of combustion. This effect is partially compensated for by the nonlinearity of the resistance - temperature relation of the thermometers. The compensation is not perfect, however, although it is very nearly so over the temperature range from 60 to 75 F. Outside this range, the reading on a gas of fixed heat of combustion changes rather rapidly with tank temperature.[3] Therefore, ideal con-

TABLE II.—TYPICAL RECORD OF AIR - GAS RATIO TEST.

Prover Readings for Beginnings and Endings of Air Meter Revolutions					Change in Prover Reading from Initial Reading			Average of One Revolution
Starting Time:					Prover Readings of 1st, 2nd, 3rd Complete Revolutions Minus Initial Readings			Column VII Value Divided by 3
Screw Number	Initial Reading	1st Complete Revolution	2nd Complete Revolution	3rd Complete Revolution				
...	0	1	2	3	1 - 0	2 - 0	3 - 0	...
15	−0.01	−0.08	−0.15	−0.21	−0.07	−0.14	−0.20	−0.07
16	−0.02	−0.07	−0.13	−0.19	−0.05	−0.11	−0.07	−0.06
17	−0.03	−0.09	−0.16	−0.21	−0.06	−0.13	−0.18	−0.06
Final Average of Column VIII..								−0.06
Column No.....	I	II	III	IV	V	VI	VII[a]	VIII[b]

[a] If any reading in Column VII exceeds ±0.30 per cent, adjust the air-gas ratio and repeat the test for the three complete revolutions.

[b] The averages in Column VIII should be less than ±0.10 per cent.

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[3] This change is shown graphically in National Bureau of Standards Investigational Report, p. 19.

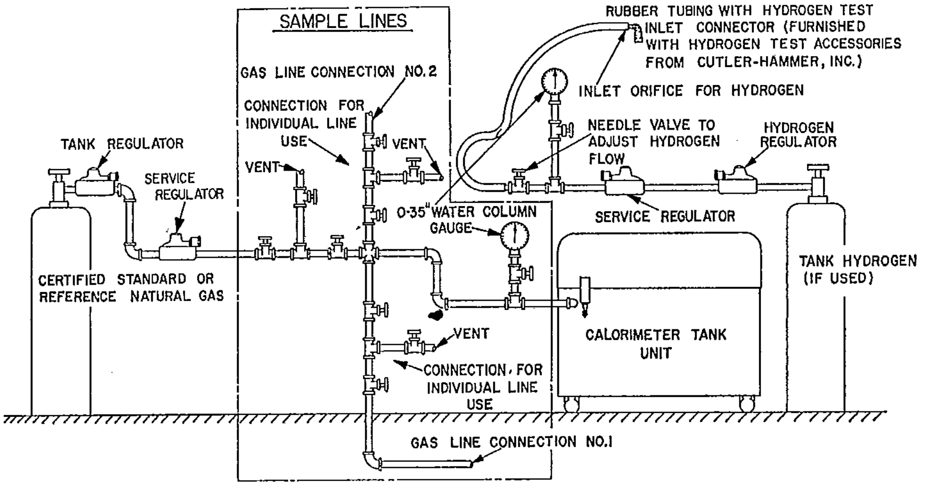

FIG. 6.—Calorimeter Set Up for Calibration.

ditions would be the maintenance of the temperature of the room by thermostatic control.

(*d*) The gas and combustion air enter the calorimeter burner saturated with water vapor at the temperature of the tank, and the exit flue gases (product of combustion plus excess air) are also saturated with water vapor at the temperature to which they are cooled by the heat-absorbing air. Because of the contraction in volume which takes place when most gases are burned under conditions in which the water formed is condensed to the liquid state, the total volume of the flue gases will usually be less than that of the entering gas plus combustion air. Hence, if the flue gases were cooled to the temperature of the entering gas, more water vapor would be condensed than was formed in the combustion reaction and, consequently, the quantity of heat imparted to the heat-absorbing air would be greater than that corresponding to the total heating value of the gas, that is, corresponding to the condensation of only the water formed in combustion. This effect is partially eliminated by the fact that the burner and burner housing are so designed that the exit gases leave the calorimeter at a temperature somewhat higher than that of the entering gas and air, and therefore carry off more water vapor than they would if cooled to the initial temperature of gas and air.

(*e*) *Barometric Pressure Variation.*—A change in the reading for 1-in. of mercury in barometric pressure is less than 0.01 per cent for any tank temperature between 60 and 90 F. However, calorimeters are adjusted as nearly as possible to the prevailing barometric pressure of the locality in which they are used.

(*f*) *Relative Atmospheric Humidity.*—This effect is eliminated because all the gases and air passing through the calorimeter are saturated with water vapor in the meters at the operating temperature.

(*g*) *Bleeder Burner - Chimney Effect.*—The bleeder burner of the calorimeter is located above the water level in the tank. Consequently, the gas pressure in the inlet chamber of the gas meter will vary, dependent upon its height above the tank water. This difference in pressure is too small to affect the density of the gas appreciably, but it is large enough to have a significant effect on the water level in the meter, and therefore the quantity of gas delivered by it per revolution. The effective height of the bleeder burner above the water tank has been set at 8½ in. (Note 12) Because the test gas and standard methane are of approximately the same density, the chimney effect is about the same for both gases and hence does not introduce any appreciable error into the reading of the test gas. It is important that the bleeder burner should not be piped to some other location, and the use of draft hoods or the like over the bleeder burner should be avoided.

NOTE 12.—In the new model calorimeter, the bleeder burner opening is at the level of the tank water.

Basis of Measurement

13. (*a*) The recording unit of the calorimeter is normally calibrated to give total heating value of the test gas directly in Btu per cubic foot at 30 in. of mercury (at 32 F), 60 F, saturated. The basis of measurement corresponds to the definition of a standard cubic foot of gas as contained in Section 3 (*f*). However, variations have been introduced in an effort to make the basis of measurement correspond to average conditions existing in a specific system. The recording calorimeter can be calibrated to give results at any of these special bases of measurement by design of the recorder slide wire.

(ASTM Section 13(b) and Table III not included.)

Precision

14. (*a*) The reproducibility of three calorimeters was followed over a 4-yr period.[4] The calorimeters were standardized with methane weekly. A rigid control was maintained over the room temperature so that no errors were caused by a change in the tank water temperature. An analysis of the data indicated that 1 week after standardization about 95 per cent of the errors were less than 0.3 per cent with a few errors as high as 0.5 per cent. It is expected that errors greater than these may be found if the period between checking against the standard methane is greater than 1 week.

(*b*) In general, therefore, when the apparatus is operated in accordance with the instruction manual under controlled conditions of temperature, and continues to operate at very close to the same temperature at which it was calibrated, the precision will probably be within 0.3 per cent. This is also based on industry-wide performance over the past few years.

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[4] National Bureau of Standards Investigaon, Table 6, p. 22.

APPENDIX I

MAINTENANCE

General Care:

A1. (*a*) *Tank Unit:*

(*1*) When lubricating tank unit parts, care should be exercised not to allow any grease or oil to drop into the water. Lubrication should be applied sparingly.

(*2*) Periodically check places where oil might accumulate and drip onto the water.

(*3*) The inside of the tank unit requires no paint. If any problem of organic growth is encountered, distilled water should be used.

(*4*) When the tank unit is overhauled, all the underwater parts should be thoroughly cleaned using a brush and cloth. Flush the meters with water to remove any sediment.

(*5*) If the tank unit is refilled with water, adjust the temperature so that it is from 2 to 5 F below the room temperature.

(*b*) *Recorder:*

(*1*) Lubrication of mechanical parts of the recorder should be done sparingly.

(*2*) Examine the slide wires occasionally for any evidence of wear or corrosion.

(*3*) The application of a small amount of petroleum jelly to the slide wires with a lint-free cloth is recommended to prevent wear and corrosion.

(*c*) *Maintenance Record:*

(*1*) Detailed maintenance instructions are included in the appropriate manual provided by the manufacturer.

(*2*) Be sure to record the results of all tests performed, indicating, where possible, the readings before and after any adjustments were made. Also record the replacement of any parts or the necessity for any unusual maintenance.

Weekly Care:

A2. (*a*) Check and record the room and tank temperatures.

(*b*) Fill the auxiliary storage tank to the proper level with water of approximately room temperature.

(*c*) Check the lubrication of the tank unit and recorder.

(*d*) Check the main burner water seal.

(*e*) Empty the condensate drip pan. If no condensate is found in the pan, it will be evidence that the main burner water seal requires attention and addition of water.

(*f*) Remove and clean with a wooden toothpick the primary and secondary air orifice caps.

(*g*) Check the orifice cap on the combustion air meter outlet for any obstruction of the orifice.

(*h*) Remove and clean the inlet thermometer and passage in the burner jacket using an appropriate brush.

(*i*) Remove and clean the burner cap, fluted tube, combustion tube, and inlet gas tube, using an appropriate brush. Take care in handling the fluted tube and burner cap so as not to bend any of the parts. Do not scrape the burner parts with sharp instruments to remove any deposits. Before reassembling the burner parts, examine each of them for defects and, if found, replace with new parts. A light coating of petroleum jelly should be added to the threaded ends to facilitate future removal. When the inlet gas tube, combustion tube, and fluted tube have been reinstalled, check to be sure that each tube is centered in the tube in which it is located.

(*j*) When lighting the burner, note the appearance of the flame for proper combustion.

(*k*) Check the operation of the water pump to be sure that water is being delivered to the main tank.

(*l*) Check the condition of the overflow weir surface.

(*m*) Perform weekly gas standardization check of the calorimeter, if this procedure has been established.

Monthly Care:

A3. (*a*) Check the inlet thermometer and remove any accumulation of dust and dirt.

(*b*) Check the condition of the tank water.

(*c*) Make a cold balance test.

(*d*) Lubricate the recorder in accordance with the manufacturer's instructions.

(*e*) Check the chart record for operation of the pen.

(*f*) Change the recorder chart roll.

(*g*) Check the mechanical operation of the recorder. Where required, check the mechanical balance of the galvanometer and recorder mechanism.

Four-Month Care:

A4. (*a*) Follow all instructions for weekly and monthly care, exercising special precautions in the inspection to detect irregularities in adjustment and the mechanical condition of the parts of both the tank unit and the recorder.

(*b*) If the tank water contains suspended solids or examination shows an accumulation of algae, the water should be replaced. If more frequent replacement seems to be necessary, the use of distilled water is recommended.

(*c*) Perform the lubrication suggested by the manufacturer at this period.

(*d*) Perform the air-gas ratio test.

(*e*) Perform the over-all accuracy check of the calorimeter, using the appropriate standardizing gas.

APPENDIX II

OPERATING PRECAUTIONS

Tank Unit:

B1. (*a*) Calibrate the instrument weekly.

(*b*) The inlet pressure used should be the same for both calibration and subsequent operation.

(*c*) Following the weekly care, Section A2, will eliminate the following adverse conditions:

(*1*) Chemical reactions in some of the burner parts cause gradual accumulation of insulating compounds which affect absorption of heat.

(*2*) Dust from the air and gas tends to accumulate in the gas and air orifices and in the fins of the fluted tube.

(*3*) Physical particles of slime tend to accumulate in the several meters.

(*4*) Appreciable wear of meter bearings.

(*5*) The surface tension characteristics of the water at the weir can change, causing some deleterious effect upon the efficiency of the instrument.

Recorder Unit:

B2. (*a*) Sensitivity or response to small heating value changes can vary because of such things as excessive tolerances of moving parts, the fineness of adjustment of the resetting levers, the degree of tension in the suspension strips, the presence of oil film or dust on the fiber pointer, imperfect contact with the slide wire, or the change in efficiency of the rectifier.

(*b*) Also, variations in the humidity of the room as well as improper tolerances on the adjustment of the rolls can cause differences in agreement between the scale and chart, amounting to as much as 2 Btu.

(*c*) For any specific summation of all such effects upon the recorded heating value, the cold balance rheostat or the baffle in the burner jacket can be changed in a direction that will cause the pen on the properly aligned chart to indicate a heating value in agreement with the heating value of the calibrating gas. However, no change greater than 0.15 per cent shall be attempted. But even when the calibration is in progress or during any subsequent time interval, slight changes in some of the mentioned factors can bring about a somewhat different summation of effects.

PHYSICAL PROPERTIES OF GAS – SPECIFIC GRAVITY

The specific gravity of a gas is related to dry air as unity and may be defined as the ratio of the weight of a given volume of gas to that of an equal volume of pure dry air when both the air and gas are measured at the same pressure and temperature. Specific gravity values are useful in gas engineering practice and are essential when gas is measured by orifice meters.

An extensive investigation of contemporary types of apparatus used for specific gravity determinations of gaseous fuels was conducted by the National Bureau of Standards in 1941 for ASTM. The results of this study were published as Miscellaneous Publication M-177 by the National Bureau of Standards.

M-177 gives greater detail than is given herein or in ASTM D 1070-63 on the apparatus described and also describes a number of other makes of apparatus of the same and of different types.

The recording displacement balance described in D 1070-63 as Method C has been omitted because the manufacturer has discontinued this particular instrument. No extensive investigation has been made of the instruments currently available for measuring a continuous gas sample such as was made by the National Bureau of Standards in 1941. For this reason no particular instrument for this application is described in detail. Instead some of the instruments now offered for this application are listed giving the method of operation.

Methods of Test for
SPECIFIC GRAVITY OF GASEOUS FUELS

Adapted from ASTM Designation: D 1070–63

(Detailed description of a displacement type balance has been omitted along with details on the care of a pressure type balance.)

Scope

1. (*a*) These methods are for determining the specific gravity of gaseous fuels, including liquefied petroleum gases, in the gaseous state at normal temperatures and pressures. The apparatus specified is sufficiently varied in nature so that one or more of the methods described may be employed for laboratory, control, reference, or in fact for any purpose where it is desired to know the relative density of a gas or gases as compared to the density of dry air at the same temperature and pressure.

(*b*) These methods are based on the assumption that fuel gases tested for specific gravity do not deviate from the fundamental laws governing the temperature and pressure relationships of ideal gases. This assumption can be made safely because, within the range of temperatures and pressures used in the measurement of the specific gravity of fuel gases, any such deviation is negligible in its effect on specific gravity.

(ASTM Section 1(c) not included.)

Application of Methods

(ASTM Section 2 replaced by the following.)

2. (*a*) The direct weighing method is intended for reference and check test purposes and for calibrations.

(*b*) The direct weighing method shall be employed (1) for determinations requiring exceptional accuracy, and (2) for determination of the specific gravity of gases to be used for the calibration of specific gravity instruments. As this procedure is not practical for field determinations, an acceptable field method has been included employing a pressure balance, the Ac-Me Gravity Balance (four-spring type). The method of operation is explained in sufficient detail to permit the observer to make measurements readily and accurately, providing the instructions given in these methods are properly followed. *It is not intended to imply that there are not other equally accurate and satisfactory instruments commercially available, or that others will not be developed in the future.*

Terminology

3. The most important terms used in the determination of the specific gravity of gaseous fuels are as follows:

(*a*) *Density.*—Mass per unit of volume of the fuel gas or air being considered.

(*b*) *Gaseous Fuel.*—Material to be tested, as sampled, without change of composition by drying or otherwise.

(*c*) *Relative Humidity.*—Ratio of actual pressure of existing water vapor to maximum possible pressure of water vapor in the atmosphere at the same temperature, expressed as a percentage.

(*d*) *Specific Gravity.*—Ratio of the density of the gaseous fuel, under the observed conditions of temperature and pressure, to the density of dried air, of normal carbon dioxide content, at the same temperature and pressure.

Accuracy

(ASTM Section 4 replaced by the following.)

4. The apparatus described in these methods for the determination of the specific gravities of individual samples of gaseous fuel may be expected to give

results which are accurate within plus or minus two per cent. The degree of accuracy can be proved by comparison with results obtained by applying the direct weighing method to the same sample or samples of fuel gas. An error of two per cent in the determination of specific gravity affects by about one per cent the measurement of fuel gas flow by a meter employing an orifice, a pitot, or venturi tube.

Types of Test

(*ASTM Section 5 replaced by the following.*)

5. These methods cover two procedures for determining the specific gravity of individual samples of gaseous fuels, using different types of apparatus, as follows:

(*a*) *Direct Weighing Method*—This method involves the differential weighing on an accurate balance of two suitable containers of as nearly as possible equal weight and volume, each filled successively with gas and air under similar conditions of temperature and pressure. (The pressure is always approximately atmospheric pressure.) The samples are reversed and reweighed, thus doubling the difference in weight and canceling errors from several sources. Provided this method is properly applied, it is possible to make specific gravity determinations with an accuracy of at least one order of magnitude greater than can be achieved by any of the instruments now commercially available. The apparatus required, recommended procedure, and calculations required for this method are given in detail in Sections 7 to 9.

(*b*) *Pressure Balances*—In this type of apparatus a beam carrying a bulb and counterweight is brought to balance, successively in air and in gas, by adjusting the pressure within the balance case; the absolute pressures are determined by means of a barometer and a mercury-filled manometer; and the specific gravity is computed from the ratio of the absolute pressures. Instruments of this type vary in size, method of supporting the balance beam, sealing the balance case, and other minor details of construction. They are all subject, however, to corrections and errors of the same kind, although not necessarily of the same magnitude. The Ac-Me Balance (four-spring type), which is described herein in Sections 10 to 16, is a typical example of a pressure balance. A partial list of pressure balances being marketed for measuring the specific gravity of gaseous fuels is given in the table at end of section on Principles of Other Methods for Determining Specific Gravity.

(*ASTM Section 6 not included.*)

METHOD A. DIRECT WEIGHING

Apparatus

7. The apparatus shall consist of the following:

(*a*) *Balance.*—An analytical balance with a capacity of at least 250 g, a sensitivity under that load of 0.1 mg, and room for the suspension of a 1-liter, or at least 0.5-liter, round flask from each balance-arm.

(*b*) *Flasks.*—Two glass flasks with well-ground stopcocks and connecting tubes with standard-taper male ends. The flasks must be closely matched in such a way as to identify one from the other.

(*c*) *Bath.*—A thermostat capable of maintaining a temperature constant to 0.1°C (0.2°F) in a bath with room for the two flasks mentioned above and facilities for supporting and connecting them and manipulating their stopcocks.

(*d*) *Manifold.*—Facilities and connections in a permanent manifold for evacuating the flasks, for supplying them with the sample to be weighed and with purified outdoor air, and for connecting them to the outer air without danger of contamination by diffusion.

(*e*) *Barometer.*—An accurate mercurial barometer.

Procedure

8. (*a*) Adjust the thermostat to a temperature a few degrees, not more than 5 C (9 F) above room temperature. Place the two flasks in the bath and connect them to the manifold by the tapered ground joints. The joints shall be lubricated with care to prevent getting any lubricant inside the tube where it would be difficult to remove. Evacuate and fill each flask three times. Fill one flask with the gas to be tested, and fill the other with purified outdoor air. Leave a slight excess of pressure (a centimeter or two of water column is sufficient) in each flask after the last filling. Close the valves and allow the flasks to remain 30 min. to reach the temperature of the bath; then arrange the manifold valves to permit purging gas and air to the outer atmosphere through the small tubes provided to prevent back-diffusion. After these tubes have been purged with the sample gas and with purified air, respectively, open the valves of the flasks for about 5 sec. to permit equalization of pressure. The gases in the flasks will be slightly chilled by expansion, possibly unequally. Again leave the flasks closed for about 5 min., during which time record the barometric reading. Again open the flasks to the air for 1 sec. and close the valves.

Remove the flasks from the bath and carefully clean them; then hang them in place on the balance and leave for 30 min. to attain the temperature of the balance case. In very dry weather, static charges may give trouble. If they do, the flasks should be exposed momentarily to steam from boiling distilled water before hanging in the balance. After the flasks have been in the case for a half-hour, bring the balance to equilibrium by adding weights to one side or the other.

(*b*) Repeat the procedure exactly as before except that the flask that formerly contained purified air now shall be filled with gas, and *vice versa.* Weigh the same flask on the same balance pan regardless of its contents.

(*c*) The accuracy of controls and manipulation can and should be checked to the satisfaction of the observer by conducting a determination of the specific gravity of air in the place of the gas. Deviation of the value obtained from unity will give a good idea of the overall accuracy of any determination made by the direct weighing method.

Calculations

9. Calculate the specific gravity of the gaseous fuel by means of Eq. 3 below, which is derived as follows:

B_1 = weight of flask 1,
B_2 = weight of flask 2,
V_1 = volume of gas in flask 1 at 760 mm. of mercury and the temperature of the bath,
V_2 = volume of gas in flask 2 at 760 mm. of mercury and at the temperature of the bath,
D_a = density of air at 760 mm. of mercury and at the temperature of the bath,
D_g = density of the gas at 760 mm. of mercury and at the temperature of the bath,
$(W_r)_1$ and $(W_l)_1$ = weights added to right pan and left pan, respectively, to produce balance during the first weighing, and
$(W_r)_2$ and $(W_l)_2$ = weights added to right pan and left pan, respectively, to produce balance after interchanging gas and air in the flasks.

At the prevailing barometric pressure, P, and the constant temperature of the bath, the quantity of gas in flask 1 (reduced to units of volume at 760 mm.) was $(P/760)V_1$, and the quantity in flask 2 was $(P/760)V_2$. Assume flask 1 to contain gas and flask 2 to contain air, both at a pressure of P_1 millimeters of mercury. The weight of gas in flask 1 is $(P_1/760)V_1D_g$. Likewise, the weight of the air in flask 2 is $(P_1/760)V_2D_a$. Assume also that flask 1 is placed on the left balance pan and flask 2 is placed on the right. When a weight equilibrium has been established, the following is true:

$$B_1 + \frac{P_1}{760} \times V_1 D_g + (W_l)_1 = B_2 + \frac{P_1}{760} \times V_2 D_a + (W_r)_1 \quad \ldots (1)$$

The gas and air are interchanged in the flasks, the temperature of the bath remaining constant, while the atmospheric pressure may have changed so that both flasks are now at a pressure P_2. As before, with flask 1 on the left pan and flask 2 on the right pan, an equilibrium is established.

$$B_1 + \frac{P_2}{760} \times V_1 D_a + (W_l)_2 = B_2 + \frac{P_2}{760} \times V_2 D_g + (W_r)_2 \quad \ldots (2)$$

Subtracting Eq. 2 from Eq. 1 and solving for D_g/D_a,

$$\text{Specific gravity} = \frac{D_g}{D_a} = \frac{P_2 V_1 + P_1 V_2}{P_1 V_1 + P_2 V_2} + \frac{(W_r - W_l)_1 + (W_l - W_r)_2}{P_1 V_1 + P_2 V_2} \times \frac{760}{D_a} \quad \ldots (3)$$

Two assumptions are involved in this derivation: (*1*) that the temperature remains constant, and (*2*) it is permissible to make a linear extrapolation from prevailing barometric pressure to 760 mm. of mercury with both air and gas.

METHOD B. AC-ME GRAVITY BALANCE (FOUR-SPRING TYPE)

Apparatus

10. The apparatus (Appendix II), is cylindrical in shape, approximately 6 in. in outside diameter, and roughly 20 in. in length (see Fig. 1 in Section 14 and Figs. 4 and 5 in Appendix II). It is mounted on a cast aluminum base provided with leveling screws and may be supported either on a table or a tripod. Its table height is about 11 in. When mounted on the accompanying tripod stand, with accessories, tripod, manometer, air dryer, pump, and hose connections, its height is roughly 64 in. The complete apparatus weighs about 76 lb. The essential features of the apparatus are described in the following Paragraphs (*a*) to (*d*).

(*a*) The balance beam is suspended from a frame attached to the face plate. This frame in turn slides into a cylinder, to the open end of which the face plate is attached by cap screws. Rubber gaskets are employed to ensure gas-tightness of the complete assembly. A plastic window in the face plate permits observation of a scale attached to the beam as well as a thermometer which is supported from the frame. Both scale and thermometer are located within the cylinder case.

(*b*) A hand pump of the reciprocating plunger type, supplied by the manufacturer of the balance, aids in the collection of samples. This accessory is equipped with check valves and may be employed to obtain either a vacuum or a pressure. An accompanying mercury manometer has tubes of 5.0- to 6.0-mm. bore mounted in a channel 2 in. wide made of a cast aluminum alloy, with a removable sliding cover and metal plugs to prevent spillage of mercury during transit. A millimeter scale with the zero at the center is stamped on an adjustable strip of thin metal mounted between the glass tubes of the manometer. The latest type of air dryer supplied with this instrument is made of transparent plastic tubing which permits ready observation of the drying agent ("indicating" silica gel). This material changes color when excessive quantities of moisture are absorbed. This accessory is mounted on the aluminum base and is connected to the valve on the container by a short length of Tygon tubing.

(*c*) Connections from the balance case to the hand pump are made through needle valves and heavy rubber tubing equipped with metal union fittings. The connection to the mercury manometer is also through a needle valve. A fourth needle valve permits controlled discharge of any excess pressure without disconnecting the balance from either the pump or gas supply.

(*d*) As indicated by Fig. 4, the Ac-Me balance beam is a metal rod with a large bulb at one end and large and small adjustable counter weights provided with lock nuts at the other. A cross-arm at the center of gravity of the beam is provided with screw clamps for attaching metal suspension strips and a short threaded vertical rod carrying a weight which regulates the sensitivity of the apparatus. Four thin metal suspension strips, two at either end of the cross-arm, are supplied in this type of balance. Viewed from the side they form a narrow topped X, a true Cardan suspension (see Fig. 5) although of rather extreme form. The suspension springs are phosphor bronze and are roughly 0.001 in. thick and about $\frac{1}{8}$ in. wide. This assembly is so arranged and fitted that it prevents lateral motion. Moreover, the construction of this particular model permits the balance beam to be raised and locked securely in place by means of a cam on a shaft, the shaft extending through a packed joint to the outside of the balance case.

Assembly of Apparatus

11. (*a*) *Setting Up Tripod.*—Set up the tripod in the shade and out of the wind, if possible. If on sloping ground, loosen the wing nuts on the legs and adjust so that the base is approximately level, tighten the wing nuts and tighten the thumb screw on the spider. If the tripod is set on loose, sandy ground, boards should be placed under the tripod legs.

(*b*) *Mounting Balance on Tripod.*—Lift the balance by the case and screw it onto the tripod. Unhook and remove the case, using it as a stool during the test. Level the balance with the leveling nuts, *K*, Fig. 4, and lock with wing nuts, *U*, underneath the base board.

(*c*) *Attaching Manometer.*—Attach the manometer by the bracket to the base board. Attach the hose (2½-ft. length) connecting the manometer to the third valve on the balance and open the valve. Be sure that the bonnet on this valve is pulled down sufficiently to prevent leaks. Fill the manometer with mercury to zero.

Procedure

12. In determining the specific gravity of a gas the following four readings should be made and recorded as described in Sections 13 to 17: average barometer reading, air reading, gas reading, and air check reading. These readings should all be made without any change in the adjustment or position of the balance. The temperature in the balance should be recorded for each of the air, gas, and air check readings and the level should be checked before and after each reading, particularly when the balance is on a tripod in the field. The precautions described in Appendices I and II should be observed.

Average Barometer Reading

13. Read the barometer at the beginning and at the end of each test and record on the report sheet the average of these two readings.

Air Reading

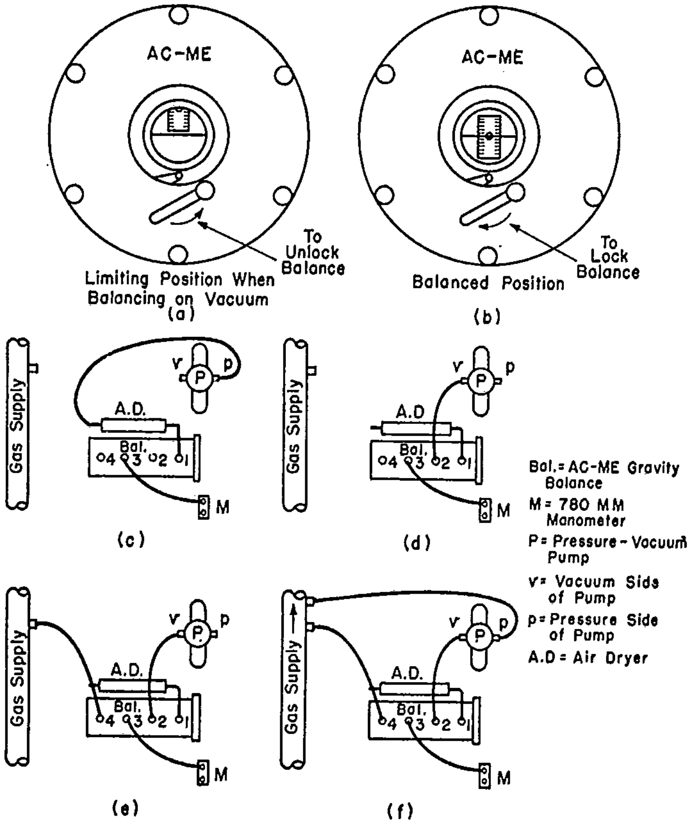


FIG. 1.—Connection Diagram for Ac-Me Gravity Balance (Four-Spring Type).

14. (*a*) *Connect Air Dryer.*—Connect the outlet of the pump (pressure side) through the air dryer to valve 1 of the balance (see Fig. 1, (*c*)), open valve 1, and compress the air within the balance until the manometer, connected through valve 3, shows a pressure of about 650 mm. above atmospheric; then close valve 1. Tap the manometer alternately on both sides several times until a steady reading is obtained. Read the temperature within the balance case. At the end of 5 min. again tap the manometer and read the temperature. If any decrease of pressure has occurred that is not fully accounted for by a cooling of the balance, or if the temperature has increased without a corresponding increase of pressure, leakage is indicated. The leak can usually be found with the aid of soapsuds and must be repaired before an accurate determination of specific gravity can be made.

(*b*) *Connect Vacuum Pump.*—When the balance has been found tight under positive pressure, disconnect the hose from the pump to the dryer and attach between the inlet (vacuum side) of the pump and valve 2 of the balance. Connect valve 4 to the supply of gas but do not open it. The connection is made at this time to avoid a possible disturbance of the balance after the air reading is taken. Connections will now be as shown in Fig. 1 (*e*). Open valve 2, reduce the pressure in the balance to about 650 mm. below atmospheric, close valve 2, and observe the manometer during 5 min. to determine leakage as before. (There may be leakage in one direction but not in the other.)

(*c*) *Admit Air to the Balance.*—When the tightness of the system is assured, admit air slowly through the dryer and valve 1 until atmospheric pressure is reached. Repeat the exhaustion and refilling of the balance to assure adequate purging and again exhaust. Check the level of the balance carefully. Unlock the balance beam by turning the locking lever counter-clockwise; the beam will then be in an unbalanced position with the zero above the hairline indicator. Admit air through valve 1 and air dryer until the beam has reached the balanced position as indicated in Fig. 1 (*b*).

(*d*) *Avoid Parallax.* — Errors from parallax may be very large in this apparatus unless special precautions are taken. It is very difficult to obtain an accurate reading from the relative positions of the index line and the scale. However, parallax can be avoided almost completely by arranging a light to cast a shadow of the index line on the scale and reading the position of the shadow. The light must, of course, have a fixed position in relation to the balance and come from a sharp source, such as the miniature bulb of a flashlight.

(*e*) *Oscillation of Beam.*—The characteristics of the suspension or its relation to the center of the scale are such that a different pressure is required to produce a large oscillation equally divided on both sides of the zero than to produce a small oscillation. The position of balance can be judged less accurately when the oscillation is large than when it is small; hence, the oscillation should be reduced to a small value of not more than three scale divisions on each side of the zero before balance is considered to have been achieved, and this amplitude as well as the position of the midpoint must be duplicated with accuracy at each setting. In bringing the balance to equilibrium, air may be admitted rapidly at first, but as the balanced position is approached air should be admitted in smaller and smaller increments until balance is obtained. After some practice the amplitude of the oscillations of the beam can be controlled by timing the small changes of pressure as the balance point is approached.

(*f*) *Lock the Balance and Read Manometer.*—Lock the balance; tap the manometer with alternate series of light taps on each side; read the position of the meniscus on each side of the manometer to the nearest half millimeter; and record the sum of the readings (distances from the center of the scale), which is the air reading. Verify the level of the instrument, and record the temperature within the balance.

(*g*) *Air Reading Above Atmospheric Pressure.*—If the air reading is to be had under a pressure above atmospheric, the pump should be connected through the air dryer and enough air introduced to produce an unbalanced position of the beam with the zero below the index line. Air should then be released from the balance through valve 2 and the beam brought to a balanced position in a manner similar to that outlined above. Keep the balance beam locked except when it is being balanced.

Gas Reading for Gas Under Pressure

15. (*a*) *Operation of Valves.*—Close valve 1 on the air dryer; then open valve 2, and exhaust the balance to a pressure about 650 mm. below atmospheric and close valve 2.

(*b*) *Admit Gas to the Balance.* — Through valve 4 (Fig. 1 (*e*)), admit gas into the balance until the manometer reads 650 mm. above atmospheric pressure.

(*c*) *Repeat Paragraphs* (*a*) *and* (*b*).—Repeat the operations described in Paragraphs (*a*) and (*b*) at least two more times, while keeping the connection between the gas supply and the balance under pressure at all times. The first operation leaves about 8 per cent of air in the balance. The second leaves about 8 per cent of the 8 per cent mixture, or 0.64 per cent of air. The third leaves about 8 per cent of the 0.64 per cent mixture or 0.05 per cent of air. Presence of this very small amount of air would result in negligible error in the determination of specific gravity. If the balance is purged by blowing gas through it, the purging should be continued until two successive readings (Paragraph (*d*)) will check.

(*d*) *Balance the Beam.*—Unlock the balance and release gas pressure through valve 2 until the balanced position of the beam is reached, using the same procedure as in balancing with air. Lock the balance. Tap the manometer and read and record the gas pressure shown. Verify the level of the balance and record its temperature.

Gas Reading for Gas Under Partial Vacuum

16. (*a*) *Avoid Condensation of Hydrocarbons.*—When making a reading on gas that is under a partial vacuum and has a high content of natural gasoline, it is important in avoiding condensation to have the pressure within the balance as nearly as possible equal to that in the line and never at a higher absolute pressure than that in the line.

(*b*) *Adjust Balance and Attach Hose.*—Adjust the apparatus to balance on gas at a pressure about 20 mm. less than that in the line (see Appendix I). Attach the hose (7½-ft. length) connecting valve 4 to the gas supply; then attach the hose (5½-ft. length) connecting valve 2 with the pump vacuum and the hose (5½-ft. length) connecting the pump pressure to the gas supply (Fig. 1 (*f*)). In cases of nearly complete vacuum it will be necessary to use a rotary pump instead of the Ac-Me hand pump.

(*c*) *Purge Balance.*—Open valve 4 and valve 2; then, by means of the pump, pull gas through the balance purging it until two successive readings (Paragraph (*d*)) will check.

(*d*) *Admit Gas and Balance the Beam.*—Close valve 4 and pull as high a vacuum as possible on the balance. Close valve 2. Unlock the balance and admit gas into it through valve 4 until the beam has reached the balanced position.

(*e*) *Lock Balance and Read Manometer.*—Lock the balance; tap the manometer with alternate series of light taps on each side; read the position of the meniscus on each side of the manometer to the nearest half millimeter; and record the sum of the readings (distances from the center of the scale), which is the gas reading. Verify the level of the balance, and record the temperature within it.

Air Check Reading

17. (*a*) *Disconnect Hose from Gas Supply.*—Disconnect hose from the gas supply to pressure connection on vacuum pump, but to avoid disturbing the balance more than is necessary, do not disconnect the one from valve 4 of the balance. Open valve 2 and evacuate the balance to a pressure about 650 mm. below atmospheric.

(*b*) *Admit Air.*—Admit air through the air dryer and valve 1 until atmospheric pressure is reached. Close valve 1.

(*c*) *Repeat Paragraphs* (*a*) *and* (*b*).—

Repeat the operations described in the last sentence of Paragraph (*a*) and in Paragraph (*b*) at least two more times, or until successive readings (Paragraph (*d*)) will check.

(*d*) *Evacuate Balance.*—Again evacuate the balance, close valve 2, unlock the beam, and admit air through the dryer to bring the beam to the balanced position, as when taking the first air reading (Section 14). Lock the balance, read and record the pressure shown by the manometer, verify the level of the balance, and record the temperature. This is a very important check on the accuracy of the test and requires little extra time if more determinations are to be made, because the balance must be purged of gas and filled with dry air for the next test anyway. If the next test is to be made immediately, the air-check test of one determination serves as the first air reading of the next determination if the balance is not moved.

(*e*) *Close All Valves When Test is Completed.*—When the test has been completed close all valves on the balance; also close the cock on the air dryer to prevent moistening of the drying material. *Be sure that the balance beam is locked.*

Calculations

18. (*a*) When an aneroid barometer is used it should be checked periodically with a mercury barometer, the reading of which has been reduced to 0 C. (32 F.). Aneroid barometers especially designed for use with specific gravity balances compensate for normal temperature changes. The effect of temperature on the mercury barometer must be determined and corrections applied whenever the difference in readings between the two types of barometers is significant. The aneroid barometer should be handled very carefully and be well packed for transportation. If the barometer reading is in inches, multiply it by 25.4 to convert to millimeters.

(*b*) Add the barometric pressure in millimeters, corrected for temperature, to both air and gas pressure readings (Note 1). Divide the absolute pressure for air by the absolute pressure for gas to obtain the specific gravity of the gas (Note 2).

Note 1.—If a mercury barometer is used and it is at the same temperature as the manometer, and if this temperature does not change between the air and gas readings, no correction of either barometer or manometer will be needed since it will cancel out when ratios are taken; otherwise all readings of both barometer and manometer should be corrected at all times. Reference should be made to Appendix III for a discussion of the corrections to be applied.

Note 2: *Example.*—A sample calculation is as follows:

	Manometer Reading mm.	Barometer Reading mm.	Absolute Pressure mm.
Barometer reading = 746 mm.			
Air reading............	−105	+ 746	= 641
Gas reading............	75	+ 746	= 821
Air check reading.......	−105		

$$\text{Specific gravity} = \frac{\text{absolute air pressure}}{\text{absolute gas pressure}} = \frac{641}{821} = 0.781$$

When there is a difference between the mean of the two temperatures for the "air readings" and the temperature for the "gas reading," the pressures should be multiplied by the inverse ratio of absolute temperatures to give the true specific gravity, as follows:

	Manometer Reading	Absolute Pressure, P	Temperature, deg. Fahr.	Absolute Temperature,
Barometer reading = 740 mm.				
Air reading..........	−190	550	103	563
Gas reading.........	−386	354	92	552
Air check reading	−196.5	543.5	97	557
Average of air check readings...........	−193.2	546.8	100	560

$$\text{Specific gravity} = \frac{P_a}{P_g} \times \frac{T_g}{T_a} = \frac{546.8 \times 552}{354 \times 560} = 1\ 522$$

Excessive changes of both temperature and balancing pressure were assumed for this example. Where such large differences occur, the result should usually be discarded and another set of observations made.

APPENDIX I

OPERATING PRECAUTIONS FOR THE AC-ME GRAVITY BALANCE (FOUR-SPRING TYPE)

"Wet Gas":

A1. When the specific gravity of a "wet" fuel gas is being determined, it is imperative that the pressure in the balance be maintained somewhat lower than the pressure at the source of the sample. This procedure should ensure against condensation in the balance. If condensate does appear, the test should be eliminated, the balance purged by evacuating several times, and the tests repeated at lower balance pressure.

Propane and Gasoline Vapors:

A2. A source of error, which becomes appreciable with propane and may be very large when the gas contains much gasoline vapor or even butane, is absorption in the great lengths of rubber tubing used, and possibly also in the rubber gasket material. The exposed surface of the latter should be kept at a minimum and whenever practicable the rubber tubing should be replaced by metal. If rubber tubing must be used, it should be presaturated with the gas to be tested by permitting a slow flow of gas through it, overnight if practicable. The tube used for gas should never be used for air. If gases of approximately the same composition are to be tested in succession, it will be desirable to keep air out of the gas tubing by stoppering the ends when not in use.

Testing for Leakage:

A3. The balance should be tested for leakage after every assembly or any change that might result in leakage, and at frequent intervals even when it remains undisturbed. Sometimes leakage will occur in one direction but not in the other; hence the tests should be made with pressures both above and below atmospheric. The connected manometer makes testing simple. When practicable, the sample line and valve should be kept under slight pressure at all times to assure against the leakage of air through connections and valve packings.

Tapping Manometer:

A4. The manometer must be tapped carefully before reading. The manometers supplied with this apparatus are rather difficult to read with accuracy. Lines of the scale must be mentally extrapolated to the highest point of each meniscus; at the same time all possible care should be taken to avoid parallax.

Clean Mercury:

A5. A principal source of irregular error in one direction is the sticking of the mercury meniscus in the narrow glass tubes of the manometers. Unless and until more adequate manometers are supplied, about all that can be done is to clean the tubes frequently and thoroughly, replace the mercury with clean and preferably recently redistilled mercury, and tap both tubes of the manometer several times alternately before every reading. The open end of the manometer should also be protected from dirt by a filter.

Verification of Balance Level:

A6. A careful verification of the level of the balance should be made before and after each operation with a balance mounted on a tripod, particularly in field work. The levels on these balances will not serve their purpose unless they are checked regularly as a matter of routine.

Temperature of Balance:

A7. Special care must also be taken to avoid everything (including personal contact) that would affect the temperature of the balance.

APPENDIX II

CORRECTIONS TO SPECIFIC GRAVITIES MEASURED WITH THE AC-ME GRAVITY BALANCE

Effect of Deviation of Gas from Boyle's Law:

A13. A source of error with this apparatus is the deviation of the gas from Boyle's law. This is common to all pressure balances and, in the case of gases containing much gasoline vapor or even propane and butane, it may be of considerable importance. Specific gravity at one atmosphere is usually desired. When testing a gas of unknown compressibility, and one that is known to be constant long enough to permit the measurements to be made, tests may be conducted at different pressures, preferably above and below the pressure of special interest, by adjusting the load on the end of the balance beam with a rider or counterweight. The specific gravities found under the two conditions are plotted with respect to the pressure of the gas, and an interpolation made by drawing a straight line through the two points and reading from it the specific gravity at the pressure of interest. This method should not be used for extrapolation.

Corrections of Barometer and Manometer for Temperature:

A14. All observations, whether with barometer or manometer, should be corrected to 0 C.(32 F.) unless a mercurial barometer and manometer are used at the same temperature, in which case the heights of the mercury columns can be used without correction. When the observed temperature is other than 0 C. (32 F.) corrections should be calculated as follows:

$$M = mPt \ldots\ldots\ldots\ldots (5)$$

where:

M = correction in millimeters of mercury to be subtracted if the temperature of observation is higher than 0. C. (32 F.) or added if the observed temperature is less than 0 C. (32 F.),

m = 0.00018 mm. per deg. Cent. or 0.00010 mm. per deg. Fahr.,

P = pressure to be corrected in millimeters of mercury, and

t = difference between the temperature of observation and the standard temperature, 0 C.(32 F.)

Corrections for Carbon Dioxide:

A15. In these standards the specific gravity of gaseous fuels has been designated as the ratio of the density of the gas to that of dry air of normal CO_2 content, (0.03 per cent) at the same temperature and pressure. The composition of outdoor air, unmodified by products of combustion from nearby equipment, is so constant with respect to all constituents except water vapor that its density when dried does not vary sufficiently to affect the limits of accuracy prescribed in this method. It is possible, however, in a laboratory or compressor station to encounter CO_2 concentrations far in excess of normal. Under such circumstances a correction for excessive carbon dioxide becomes necessary if the maximum attainable accuracy is desired. This is most easily accomplished by placing "Ascarite" or soda lime in a portion of the drying tube. When CO_2 is entirely removed its effects on observed specific gravity results are negligible. In the event carbon dioxide is not removed, however, corrections for carbon dioxide applicable to results obtained by use of the Ac-Me balance may be calculated as follows:

$$S_c = R(0.9998 + 0.529\, C_c) \ \ldots\ (6)$$

where:

S_c = specific gravity with respect to dry air with normal CO_2 content,

R = observed value uncorrected for carbon dioxide in the reference air,

0.9998 = specific gravity of dry air minus normal CO_2 content,

C_c = concentration of CO_2 in reference air expressed as a fraction of the total, and

0.529 = difference between the specific gravity of CO_2 and that of air.

Corrections for Humidity:

A16. (*a*) As the Ac-Me balance compares the sample of fuel gas directly with dry air, there is normally no correction to be made for humidity when the air dryer is in use and filled with a suitable reagent. There are special cases, however, for example in the manufactured gas industry, where it is sometimes desired to express specific gravity results under some other humidity condition of gas or air than that prevailing at the time of the observation. In this particular case standards for measurement designate a cubic foot of fuel gas as the quantity that will fill a space of 1 cu. ft. at a pressure of 30 in. of mercury and a temperature of 60 F. and in equilibrium with liquid water. It is inconvenient with the Ac-Me balance or any other apparatus incorporating the same principle to change the humidity of either gas or air. Consequently, the specific gravity determined by direct observation on a fuel gas may be the ratio of a gas of one humidity to air of another, in neither of which the observer is directly interested.

(*b*) Miscellaneous Publication M-177 of the National Bureau of Standards provides several formulas which permit ready calculation of the relative densities of gas and air under any condition of humidity in terms of their densities when dry, the density of water vapor, and the partial pressure of each component of the mixtures. In other words, they permit the calculation of the relative densities of gas or air for any condition of either from observations made under any other conditions. Symbols employed in these formulas are as follows:

R = ratio of density of gas to density of air under any definite conditions of humidity in each.

R_s = the particular value of R when both gas and air are saturated.

S = the specific gravity of dry gas; that is, it is the particular value of R when both gas and air are free from water vapor.

S_g = the specific gravity of gas containing a partial pressure, g, of water vapor; that is, it is the value of R when the air is dry and the gas is not.

a = the partial pressure of water vapor in the air.

g = the partial pressure of water vapor in the gas.

w = the pressure of water vapor at saturation. (When air is saturated, $a = w$; when the gas is saturated, $g = w$.)

b = the barometric pressure.

h = the average head of water during a determination, in millimeters of mercury.

P = the total pressure at which gas or air is saturated $(b + h)$.

0.622 = the specific gravity of water vapor; that is, it is the ratio of the density of pure water vapor to the density of dry air at the same temperature and pressure.

The specific gravity, S, of a dry gas in terms of the ratio, R, of the density of gas containing a partial pressure, g, of water vapor to the density of air containing a partial pressure, a, of water vapor is:

$$S = R\left(\frac{P - a}{P - g}\right) + \frac{0.622\,(R_a - g)}{P - g} \ldots (7)$$

The specific gravity, S, of a dry gas in terms of the ratio, R_s, of the density of saturated gas to that of saturated air is:

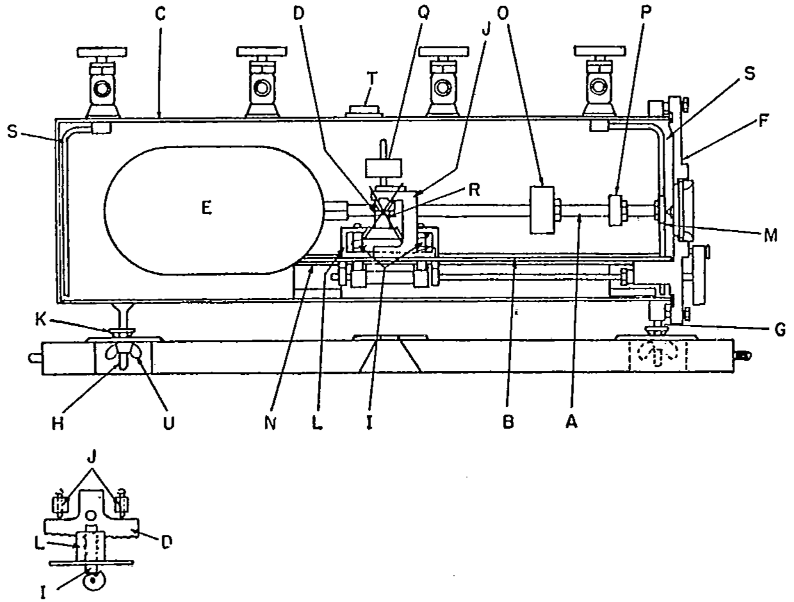
$$S = R_s + \frac{0.622w(R_s - 1)}{P - w} \ldots\ldots (8)$$

Another special case of Eq. 7 would be the specific gravity, S_g, of a gas containing a partial pressure of water vapor, g, expressed in terms of the specific gravity, S, of the dry gas, as follows:

$$S_g = S\left(\frac{P - g}{P}\right) + \frac{0.622\, g}{P} \ldots\ldots (9)$$

Still another special case of Eq. 7 involves a method for expressing the specific gravity, S_g, under the conventional standard conditions employed for designating the heating value of fuel gas in the manufactured gas industry. Here P = 30 in. of mercury and g = the vapor pressure of water at 60 F. In this case,

$$S_g = 0.9826S + 0.0108 \ \ldots\ (10)$$



A—Balance beam
B—Base plate.
C—Container.
D—Cross arm.
E—Float.
F—Face.
G—Front legs.
H—Rear leg.
I—Lift pins.
J—Support.
K—Leveling nut.
L—Pin guide.
M—Scale.
N—Aluminum rail.
O—Large balance weight.
P—Small balance weight.
Q—Sensitivity weight.
R—Suspension springs.
S—Purging ring
T—Spirit level.
U—Wing nut.

FIG. 4.—Ac-Me Gravity Balance (Four-Spring Type).

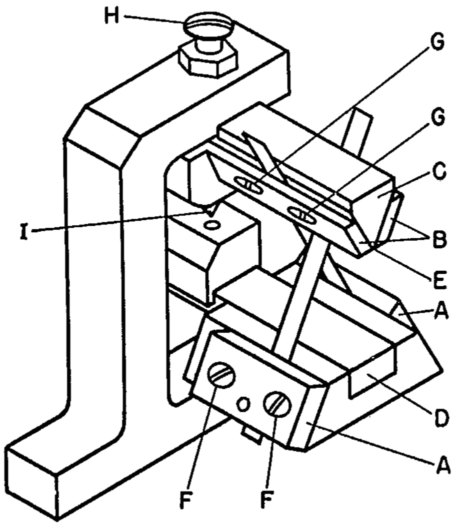


FIG. 5.—Ac-Me Gravity Balance Beam Cross-Arm.

PRINCIPLES OF OTHER METHODS FOR DETERMINING SPECIFIC GRAVITY

These cover five types of systems for determining the specific gravity of continuous samples of gaseous fuels, using different types of apparatus as follows:

(a) *Displacement Balance—Mechanical*—This classification covers instruments that depend on the principle of balancing the weight of a given volume of gas by displacement of the center of gravity of a mechanical balance beam. The amount of this displacement, or "deflection," subject to correction, measures the specific gravity. These instruments may operate at atmospheric pressure or at any controlled pressure with appropriate compensation for the pressure utilized. Instruments of this class may be of either the indicating or recording type. Apparatus of this general classification varies even more widely in construction than pressure balances (refer to Par. 5b, page 89).

(b) *Displacement Balance—Electronic*—With this principle of operation the sensing element or balance is a tiny glass dumbbell supported on a quartz fiber enclosed in a chamber through which a continuous gas sample flows under controlled pressure and temperature conditions. One end of the dumbbell contains a reference gas and the other end is pierced to permit the gas sample to enter. An electrostatic field is created around one end of the dumbbell which is coated with rhodium to make it conductive. The dumbbell is maintained in balance by varying the electric potential to this field. A mirror affixed to the dumbbell's axis reflects a beam of light on a dividing mirror which splits the beam equally between two photocells when the dumbbell is in balance. When the dumbbell is unbalanced, the light reflected to the two photocells is unequal. This difference signal is amplified and becomes the balancing potential applied to the electrostatic field to maintain balance of the dumbbell. The potential required to maintain the dumbbell in balance is a linear indication of the torque created by the difference in buoyancies between the two ends of the dumbbell, which is proportional to changes in specific gravity of the sample when the reference gas is air. The circuitry delivers a signal which may be fed to a suitable indicating meter or a standard potentiometer recorder calibrated to read specific gravity.

(c) *Differential Torque Type*—This type of instrument has two hollow cylindrical chambers. Each chamber contains an impeller and a companion impulse wheel of identical construction. The impellers of the two chambers are driven in opposite directions at equal constant speed. The impeller of one chamber draws in a continuous sample of gas which is directed against the vanes of the companion impulse wheel after which it is discharged to atmosphere. The kinetic energy transmitted to the impulse wheel creates a torque which is a measure of the gas density. Air is simultaneously passed through the other chamber which creates a torque on that impulse wheel which is proportional to the air density. The difference between the opposing torques of the impulse wheels is a measure of the specific gravity of the gas. This differential torque is transmitted through a lever and linkage arrangement to continuously indicate or record the specific gravity.

(d) *Orifice Pressure Differential Method*—With this method a constant volume of a continuous gas sample is passed through a calibrated orifice. The density is measured as a function of the difference in pressure across the orifice. This measurement may be considered as accurate if the pressure and temperature are maintained constant or if appropriate compensation is applied. By transmitting the orifice differential to a suitable differential pressure meter, variations in specific gravity may be indicated or recorded.

(e) *Centrifugal Fan Differential Pressure*—This method determines the specific gravity of gas by measuring the differential pressure due to centrifugal force between the inlet and outlet of a fan rotated at constant speed with a continuous gas sample passing through the fan. This differential pressure is transmitted to a bell-type float recording differential pressure gauge calibrated to show specific gravity.

PARTIAL LIST OF INSTRUMENTS AVAILABLE FOR MEASURING THE SPECIFIC GRAVITY OF GASEOUS FUELS

Pressure Balance	Ac-Me Specific Gravity Balance (1) Ac-Me Junior Specific Gravity Balance (1) Arcco—Anubis Portable Gas Balance (2) Gas Density Balance, Edwards (3)
Displacement Balance—Mechanical	Ac-Me Recording Gas Gravitometer (1) Arcco—Anubis Gas Gravitometer (2) UGC Instruments Gravitometer (4)
Displacement Balance—Electronic	Beckman Continuous Gas Density Balance (5)
Differential Torque	Ranarex Gas Gravitometer (6)
Orifice Differential Pressure System	Hagan Gas Density Measuring System (7)
Centrifugal Fan Differential Pressure	Metric Gravitometer (8)

NOTES TO TABLE ABOVE

(1) Chandler Instrument Company, Tulsa, Oklahoma
(2) Arcco Instrument Company, Inc., Los Angeles, California
(3) Arthur H. Thomas Company, Philadelphia, Pennsylvania
(4) UGC, Instruments Division, United Gas Corporation, Shreveport, Louisiana
(5) Beckman Instruments, Inc., Fullerton, California
(6) Ranarex Instrument Division, The Permutit Company, New York
(7) Hagan Corporation, Pittsburgh, Pennsylvania
(8) American Meter Company, New York, New York

COMPRESSIBILITY

For fuel gases, correction for compressibility is of major importance in relation to measurement of volume and flow at high pressure such as those encountered in underground storage and in transmission piping. It may also become significant when appreciable percentages of the heavier hydrocarbons are involved, because of their lower critical pressures. For the usual fuel gases, under conditions normally maintained in burner piping (below 100 psig) and in analysis procedures, the effects of compressibility, however real, are of small magnitude, and for purposes within the scope of this Code may be disregarded without serious consequence (error probably less than 0.5 per cent).

Matter in the gaseous phase completely fills any space in which it is confined. It is therefore necessary to specify conditions of pressure, temperature, and volume to define the state of a particular quantity of substance under consideration. The ideal gas, by definition, conforms to the relationship

$$\frac{PV}{T} = \frac{P_1 V_1}{T_1} = R$$

R being a constant of proportionability having the dimensions of work energy per degree per mole of material when expressed in consistent terms.

Real gases depart appreciably from this behavior, although all approach it when rarefied at low pressures. Causes of the deviation are attributed to the volume actually occupied by the molecules, which vary in size and structure for different substances, and to forces acting between them, which also vary with composition, and with the proximity and energy of the molecules manifested by pressure and temperature. While separate equations of state could be written to describe the behavior of individual gases, it is convenient to account for the deviation by use of experimentally determined "Compressibility" factors applied in the general equation

$$pV = ZRT \text{ or } Z = pV/RT$$

where Z = Compressibility factor
R = Molal gas constant
p = Absolute pressure
V = Molal specific volume
T = Absolute temperature

For the ideal gas, the value of Z is unity under all conditions. For real gases, Z may be equal to, less than, or greater than unity, as referred to a standard state; but this value is a function of composition, pressure, and temperature. For mixtures of gases, such values of Z are unique to the composition because of interaction effects between unlike molecules.

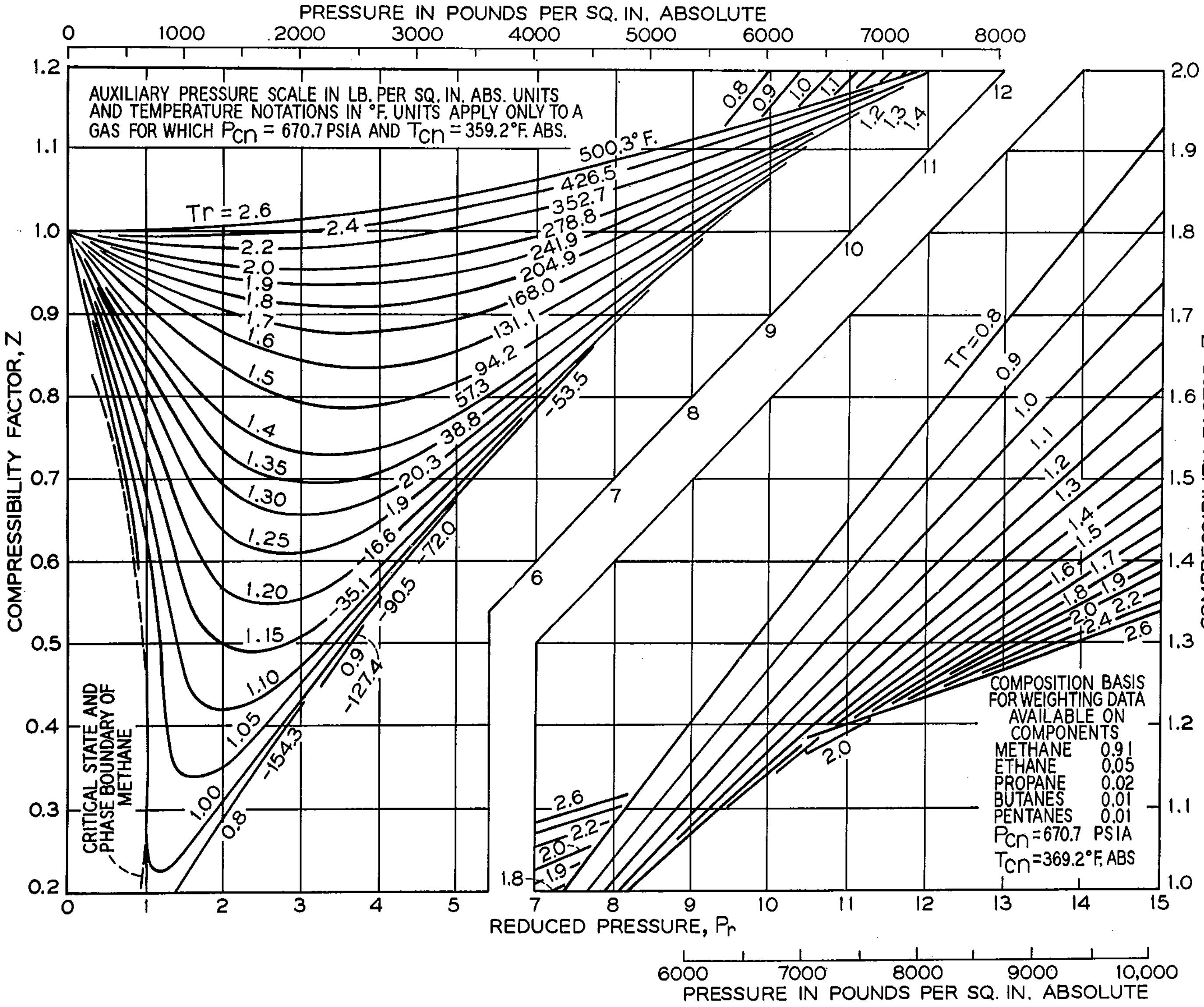
Accounting for compressibility is significant because the measured cubic foot of gas, at a specified pressure and temperature may contain more (or less) moles of substance than would have been indicated by calculations based upon the ideal gas equation. In consequence, a corresponding difference would exist in the calculated values of mass (or of fuel energy) delivered to the point of use. The deviation becomes more extreme as conditions approach dewpoint, where change of phase occurs, and therefore holds greater significance for calculations dealing with vapors than for the so-called permanent gases such as oxygen and nitrogen, which are normally remote from their critical states.

Correlations of compressibility data for different gases have been made (Bib. 10), based on the phenomenon of corresponding states, for which the reduced-pressure (P_r) and reduced-temperature (T_r) are used as parameters as shown in the figure on page 98. P_r and T_r are defined as the ratios of the actual to the critical pressure and temperature, respectively, for any single-component gas under consideration. For a mixture of gases, P_r and T_r are ratios of actual to molal-average critical pressure and temperature, respectively, of the mixture. This graph is intended for use with natural gas and other paraffin hydrocarbon mixtures, however, it will provide approximate values of compressibility factors for gases containing nonhydrocarbon components. The auxiliary pressure scale (psia) and temperature scale (F) on the chart is an example only for gas of the composition shown in the insert or for a similar gas having an identical reduced-pressure and reduced-temperature. By use of the reduced pressure and temperature scales the chart may be applied to natural hydrocarbon gases varying widely in composition. Other correlation charts have been prepared (Bib. 10) for evaluation of the compressibility range of various natural gas compositions based on (a) measurement of specific gravity, and (b) laboratory determination of the minimum value of compressibility factor at 100°F.

Measurement of compressibility is not covered by a standard procedure, and is not included in this Code since it required specialized equipment and techniques likely to be available only in research laboratories. Data for the pure components of air and fuel gases are available from reference sources (Bib. 10, 11, 12) and procedures for calculating the values for mixtures have been described (Bib. 10, 13, 14). Correction factors applying to the measurement of flow are covered by other ASME publications (Bib. 2, 3, 5). Where circumstances justify greater refinement in the calculation of Stoichiometric data, the method of Mason and Eakin should be considered. (See Bib. 14.)

STOICHIOMETRIC CALCULATIONS

When the composition of a fuel gas is known in terms of its constituent gases, as determined by chemical or other analyses, the *heat value* Equation (a) and *specific* gravity Equation (b) of the mixture may be calculated from corresponding properties of the constituent gases given in the Table XXIII on Combustion Constants. In a similar manner, the



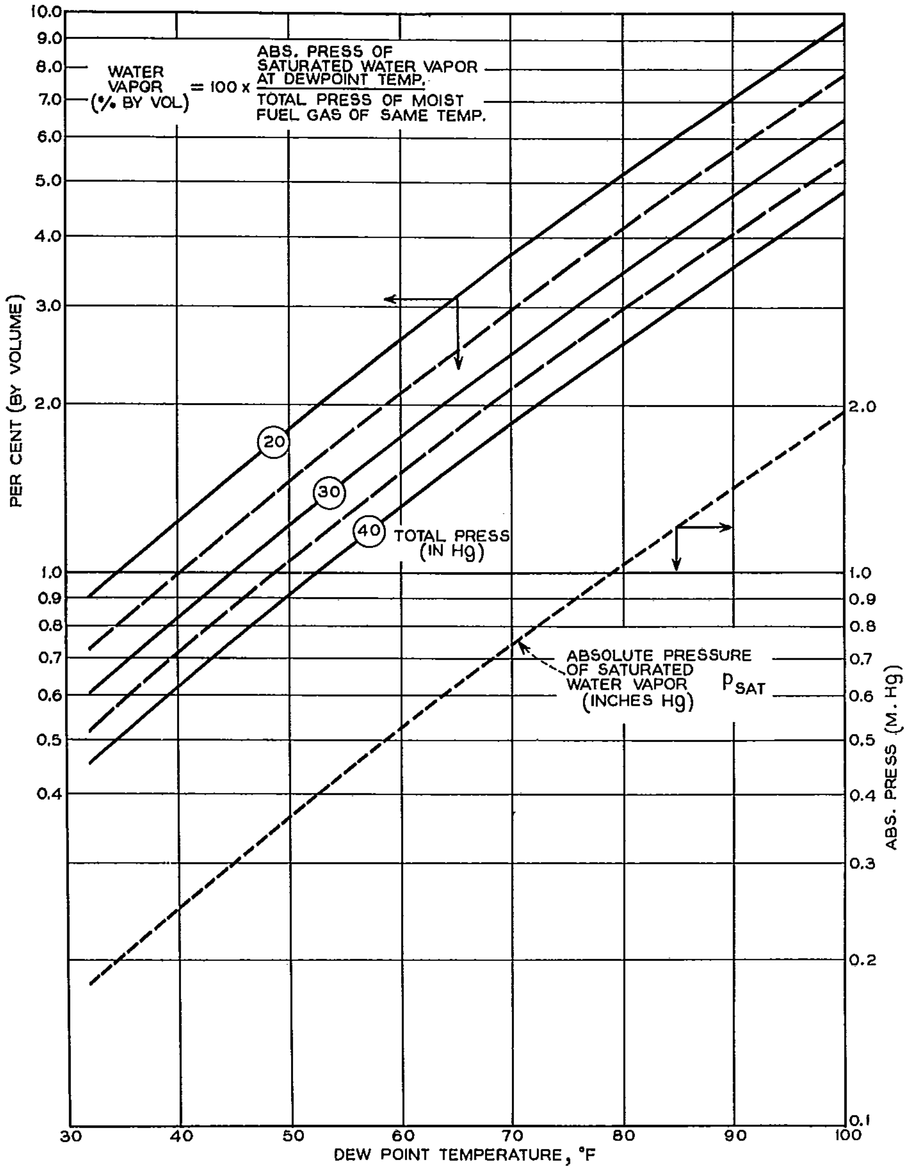
Compressibility Factors With Reduced Pressure and Temperature Coordinates for Paraffin Hydrocarbons and Natural Gas. *(Phase Relations of Gas Condensate Fluids,* C. Kenneth Eilerts et al.*)*

stoichiometric quantities of *air required* for combustion and the *gaseous products of combustion* may be calculated by use of multiplying factors given in the Table XIII on Combustion Constants. An example of these calculations is shown in the Table XXIV on Calculation from Fuel Gas Analysis.

Calculations may be made on the weight (lb), volume (cu ft) or molal (pound mole) basis. Consideration must be given to differences in temperature, pressure and water-vapor content between actual and standard or other reference conditions.

Since the fuel gas analysis is usually reported on a moisture-free basis, and water-vapor content is subject to variation, it is convenient to make separate calculation for the mixture of dry gases and to make subsequent corrections for moisture. Alternatively, the moisture may be included as an item of the analysis after adjusting the percentage values of other components to the moist-gas basis. Water-vapor content (per cent by volume) is measured by its partial pressure in the moist-gas mixture Equation (c), and may be evaluated at dewpoint temperature by means of data obtained from tables for saturated steam or read directly from the graph on Water Vapor Content of Moist Fuel Gas.

Change of volume attributable to differences in temperature, pressure, and water-vapor content between actual and



Water Vapor Content of Moist Fuel Gas.

standard conditions (or between various published standards) may be calculated by the general equation given as a NOTE in Table I on Standard Conditions Used for the Measurement of Gases. An example is shown in the table on Calculation from Fuel Gas Analysis for calculation of heat value, specific gravity, air required for combustion and products of combustion for a hypothetical fuel gas mixture. The initial volumetric analysis is given in Column 7. Successive steps in the calculation procedure are indicated in the headings of the other columns. The conversion from volumetric to weight percentages assumes behavior of all constituents according to the ideal gas law which is justified for engineering calculations. The analysis is not intended to represent a typical fuel gas; but has been chosen to include unsaturated hydrocarbons (illuminants), inerts, and "other gases" for the purpose of calling attention to the following considerations:

(a) *Unsaturated hydrocarbons* are here treated as a single component using averaged properties of C_2H_4 and C_3H_6. Significant error may accrue from this procedure if "illuminants" are present in appreciable percentage, because of wide differences in specific gravity and heat value per cu ft of individual members of this group. In such cases separate identification is required, beyond the usual analysis given by chemical absorption methods, which may be obtained from chromatograph or mass spectrometer analyses.

(b) *Inerts:* Carbon dioxide and nitrogen reduce the heat value of the mixture by dilution. However, they remain in mixture with the products of combustion.

(c) Other Gases: Hydrogen sulfide adds slightly to the heat value, and produces H_2O as well as SO_2 (which is treated as CO_2 in the products of combustion).

(d) Oxygen in the fuel gas is presumed to be utilized in combustion, thereby decreasing the requirement of air and its corresponding amount of nitrogen. The negative sign indicates substraction of these increments in the calculation procedure shown in Table XXIV.

Equations

(a) Heat value of fuel gas mixture $= \frac{1}{100} \times$ Summation of the numerical products obtained by multiplying the heat value of each constituent by the respective per cent* of that constituent in the mixture.

(b) Specific gravity of fuel gas mixture $= \frac{1}{100} \times$ Summation of the numerical products obtained by multiplying the specific gravity of each component by the respective per cent (*by volume*) of that constituent in the mixture.

(c) Water vapor per cent by volume

$$= \frac{1}{100} \times \frac{\text{Absolute pressure of saturated water vapor at dew point temperature (from steam tables or Pg. 99).}}{\text{Total pressure of moist fuel gas (barometer + gage) at same temperature.}}$$

* NOTE: Heat value may be expressed as (1) Btu per standard cu ft or (2) Btu per lb. The corresponding per cent values must be expressed as (1) by volume or (2) by weight.

TABLE XXIII—COMBUSTION CONSTANTS*

					Heat of Combustion(f)				Cu Ft/Cu Ft of Combustible(e)				Lb/Lb. of Combustible			
			Molecular	Spec. Gravity	Btu/Cu Ft		Btu/Lb(b)		Required for Combustion	Flue Products			Required for Combustion	Flue Products		
No.	Substance	Formula	Weight	(Air=1.000)	Gross	Net	Gross	Net	Air	CO_2	H_2O	N_2(a)	Air(a)	CO_2(a)	H_2O	N_2(a)
1	Carbon	C	12.01	—	—	—	14,093	14,093	—	—	—	—	11,484	3.664	—	8.820
2	Hydrogen	H_2	2.016	0.06959	325.02	274.58	61,095	51,623	2.382	—	1.0	1.882	34.209	—	8.937	26.272
3	Oxygen	O_2	32.000	1.1053	—	—	—	—	−4.76	—	—	−3.76	−4.31	—	—	−3.31
4	Nitrogen (Pure)	N_2	28.016	0.9672	—	—	—	—	—	—	—	1.00	—	—	—	1.00
5	Nitrogen (Atmos.)	N_2(d)	28.161(c)	0.9720	—	—	—	—	—	—	—	1.00	—	—	—	1.00
6	Carbon Monoxide	CO	28.01	0.9672	321.37	321.37	4,347	4,347	2.382	1.0	—	1.882	2.462	1.571	—	1.891
7	Carbon Dioxide	CO_2	44.01	1.5282	—	—	—	—	—	—	—	—	—	1.00	—	—
	Paraffin Series															
8	Methane	CH_4	16.042	0.5543	1012.32	911.45	23,875	21,495	9.528	1.0	2.0	7.528	17.196	2.743	2.246	13.206
9	Ethane	C_2H_6	30.068	1.0488	1773.42	1622.10	22,323	20,418	16.675	2.0	3.0	13.175	16.056	2.927	1.798	12.331
10	Propane	C_3H_8	44.094	1.5617	2523.82	2322.01	21,669	19,937	23.821	3.0	4.0	18.821	15.642	2.994	1.634	12.013
11	n-Butane	C_4H_{10}	58.120	2.0665	3270.69	3018.48	21,321	19,678	30.967	4.0	5.0	24.467	15.427	3.029	1.550	11.848
12	Iso-Butane	C_4H_{10}	58.120	2.0665	3261.17	3008.96	21,271	19,628	30.967	4.0	5.0	24.467	15.427	3.029	1.550	11.848
13	n-Pentane	C_5H_{12}	72.146	2.4872	4019.65	3717.15	21,095	19,507	38.114	5.0	6.0	30.114	15.293	3.050	1.498	11.745
14	Iso-Pentane	C_5H_{12}	72.146	2.4872	4010.71	3708.01	21,047	19,459	38.114	5.0	6.0	30.114	15.293	3.050	1.498	11.745
15	Neopentane	C_5H_{12}	72.146	2.4872	3994.00	3692.00	20,978	19,390	38.114	5.0	6.0	30.114	15.293	3.050	1.498	11.745
16	n-Hexane	C_6H_{14}	86.172	2.9704	4768.27	4415.23	20,966	19,415	45.260	6.0	7.0	35.760	15.207	3.064	1.464	11.679
	Olefin Series															
17	Ethylene	C_2H_4	28.052	0.9740	1603.75	1502.87	21,636	20,275	14.293	2.0	2.0	11.293	14.750	3.138	1.285	11.328
18	Propylene	C_3H_6	42.078	1.4504	2339.70	2188.40	21,048	19,687	21.439	3.0	3.0	16.939	14.750	3.138	1.285	11.328
19	Butylene	C_4H_8	56.104	1.9336	3084.00	2885.00	20,854	19,493	28.585	4.0	4.0	22.585	14.750	3.138	1.285	11.328
20	Iso-Butene	C_4H_8	56.104	1.9336	3069.00	2868.00	20,737	19,376	28.585	4.0	4.0	22.585	14.750	3.138	1.285	11.328
21	n-Pentene	C_5H_{10}	70.130	2.419	3837.00	3585.00	20,720	19,359	35.732	5.0	5.0	28.232	14.750	3.138	1.285	11.328
	Aromatic Series															
22	Benzene	C_6H_6	78.108	2.692	3751.68	3600.52	18,184	17,451	35.732	6.0	3.0	28.232	13.246	3.381	0.692	10.173
23	Toluene	C_7H_8	92.134	3.1760	4486.44	4284.81	18,501	17,672	42.878	7.0	4.0	33.878	13.474	3.344	0.782	10.348
24	Xylene	C_8H_{10}	106.160	3.6618	5223.00	4971.00	18,633	17,734	50.024	8.0	5.0	39.524	13.642	3.317	0.849	10.477
	Miscellaneous Gases															
25	Acetylene	C_2H_2	26.036	0.9107	1476.55	1426.17	21,502	20,769	11.911	2.0	1.0	9.411	13.246	3.381	0.692	10.173
26	Napthalene	$C_{10}H_8$	128.164	4.4208	5854.00	5654.00	17,303	16,708	57.170	10.0	4.0	45.170	12.914	3.434	0.562	9.918
27	Methyl Alcohol	CH_3OH	32.042	1.1052	868.00	767.00	10,258	9,066	7.146	1.0	2.0	5.646	6.457	1.374	1.125	4.959
28	Ethyl Alcohol	C_2H_5OH	46.068	1.590	1600.00	1449.00	13,161	11,917	14.293	2.0	3.0	11.293	8.983	1.911	1.173	6.899
29	Ammonia	NH_3	17.032	0.5961	441.00	364.00	9,667	7,985	3.573	—	1.5	3.323	6.073	—	1.587	5.486
										SO_2				SO_2		
30	Sulfur	S	32.06	—	—	—	3,980	3,980	—	—	—	—	4.302	1.998	—	3.304
31	Hydrogen Sulfide	H_2S	34.076	1.1898	646.00	595.00	7,097	6,537	7.146	1.0	1.0	5.646	6.072	1.880	0.529	4.663
32	Sulfur Dioxide	SO_2	64.06	2.264	—	—	—	—	—	—	—	—	—	—	—	—
33	Water Vapor	H_2O	18.016	0.6215	—	—	—	—	—	—	—	—	—	—	—	—

* Data from: Schnidman, L., Ed., "Gaseous Fuels," 2nd Ed., A.G.A. 1954, as revised in "Gas Engineers Handbook," published by the Industrial Press, N.Y., 1965. All values corrected for 60°F and 30 in. Hg Dry. For gases saturated with water vapor at 60°F, deduct 1.74% of the Btu value. To convert volumes to 68°F and 29.921 in. Hg saturated multiply by 1.0418.

(a) Composition of Air, by volume: O_2—21.0%, N_2—79.0%; by weight: O_2—23.2%, N_2—76.8%.

(b) Per pound of vapor (except Carbon and Sulphur).

(c) Apparent molecular weight to account for rare gases.

(d) Plus rare gases.

(e) May also be expressed as Moles/Mole.

(f) Estimated uncertainty of values varies from less than .01% to 0.1%. See F. D. Rossini, Bureau of Standards Circular 461—1947.

TABLE XXIV—CALCULATION FROM FUEL GAS ANALYSIS

FUEL GAS												PRODUCTS OF COMBUSTION							
CONSTITUENT						GAS ANALYSIS	CALCULATIONS					VOLUME, CU FT/CU FT GAS				WEIGHT, LB/LB GAS			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
			Specific Gravity (Air= 1.0)	Btu						Btu			Products				Products		
Name	Formula	Molecular Weight		Cu Ft	Lb	Per cent By Vol.	Wt. of Mol. Fraction	Wt. Per cent	Specific Gravity	Cu Ft	Lb	Air Required	CO_2	H_2O	N_2	Air Required	CO_2	H_2O	N_2
							$\frac{(3)\times(7)}{100}$	$\frac{(8)\times 100}{\text{Sum }(8)}$	$\frac{(4)\times(7)}{100}$	$\frac{(5)\times(7)}{100}$	$\frac{(6)\times(9)}{100}$	$\frac{1}{100}\times(7)\times$ factor Table XXIII				$\frac{1}{100}\times(9)\times$ factor Table XXIII			
DRY GAS																			
Saturated Hydrocarbons																			
Methane	CH_4	16.042	0.5543	1012.3	23,875	60.0	9.625	41.01	0.3326	607.4	9,791	5.717	0.60	1.20	4.517	7.052	1.125	0.921	5.416
Ethane	C_2H_6	30.068	1.0488	1773.4	22,323	20.0	6.014	25.62	0.2098	354.7	5,719	3.335	0.40	0.60	2.635	4.113	0.750	0.461	3.159
Propane	C_3H_8	44.094	1.5617	2523.8	21,669	10.0	4.401	18.75	0.1562	252.4	4,063	2.382	0.30	0.40	1.882	2.932	0.561	0.306	2.252
Unsaturated Hydrocarbons (Illuminants)																			
Ethylene	C_2H_4	28.052	0.9740	1603.7	21,636	3.0													
Propylene	C_3H_6	42.078	1.4504	2339.7	21,048														
Average*		35.065	1.2122	1971.7	21,342		1.052	4.48	0.0364	59.2	956	0.540	0.075	0.075	0.423	0.661	0.141	0.058	0.507
Inerts																			
Carbon Dioxide	CO_2	44.010	1.5282	—	—	2.0	0.880	3.75	0.0306	—	—	—	0.020	—	—	—	0.038	—	—
Nitrogen	N_2	28.016	0.9672	—	—	3.0	0.840	3.58	0.0290	—	—	—	—	—	0.030	—	—	—	0.036
Other Gases																			
Hydrogen Sulfide	H_2S	34.076	1.1898	646.	7,097	1.0	0.341	1.45	0.0119	6.5	103	0.071	0.010	0.010	0.056	0.088	0.027	0.008	0.067
													(SO_2)				(SO_2)		
Oxygen	O_2	32.000	1.1053	—	—	1.0	0.320	1.36	0.0111	—	—	(−0.048)	—	—	(−0.038)	(−0.059)	—	—	(−0.045)
Sum						100.0	23.473	100.00	0.8176	1280.2	20,632	11.977	1.405	2.285	9.505	14.787	2.642	1.754	11.392
MOIST GAS																			
Dry Gas	Mixture	23.473	0.8176	1280.2	20,632	98.26	23.065	98.66	0.8034	1267.9	20,338	11.788	1.381	2.226	9.339	14.417	2.608	1.732	11.107
Water Vapor (60°F, 30″ Sat.)	H_2O	18.016	0.6215	—	—	1.74	0.314	1.34	0.0108	—	—	—	—	0.0174	—	—	—	0.0134	—
Sum						100.00	23.379	100.00	0.8142	1267.9	20,338	11,788	1.381	2.243	9.339	14.417	2.608	1.745	11.107

* Illuminants assumed to contain 50% C_2H_4 and 50% C_3H_6.

LIST OF ILLUSTRATIONS

LIST OF TABLES

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