DEPARTMENT OF COMMERCE

BUREAU OF STANDARDS

George K. Burgess, Director

GAS-MEASURING INSTRUMENTS

CIRCULAR OF THE BUREAU OF STANDARDS, No. 309

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GAS-MEASURING INSTRUMENTS[1]

ABSTRACT

A general knowledge of the various instruments for measuring gases and gas flows is of considerable aid in arriving at a satisfactory answer to many of the questions involving gas measurement which are continually arising both outside and within the fuel-gas industry. The following circular contains information on this subject. Definitions of the more important terms commonly used in gas measurement and a classification of the instruments and methods of measurement used are given. There follows a description of the construction and operation of the instruments and an outline of the methods. In many cases methods of testing and adjusting the apparatus are given in detail and the important points to be watched in such work are mentioned. In the case of velocity or inferential meters, such as the orifice meter or Venturi tube, the general equation of flow is stated and its derivation indicated.

Wherever practical there have been stated the situations in which a particular meter is most commonly used or in which it might properly be used. In other cases it was more convenient to enumerate some of the conditions which might interfere with the satisfactory operation of a meter in some particular service.

CONTENTS

[1] Prepared by H. S. Bean.

I. INTRODUCTION

The Bureau of Standards has been receiving an increasing number of requests for information on the various types of gas-measuring instruments, particularly as to their construction and operation and the methods of test. In order to supply this information in more complete form than would be possible by individual letter this circular has been prepared.

In preparing this circular very little original investigational work was performed by the bureau. For the most part the information herein given has been obtained from articles appearing in books, engineering journals, and trade periodicals. In many cases specific reference is made to the article from which the statement is taken. No attempt has been made to make this circular an exhaustive treatise on gas-measuring instruments; but, rather, emphasis has been placed upon important points concerning the design, operation, methods of test, and particular field of usefulness of the several different types of meters. When a more extensive discussion of any particular meter is desired reference should be made to some of the articles given in the bibliography.

The bibliography presents a list of references and also indicates, by means of a concise statement, the particular subject treated by the article. It is hoped this will assist those interested in locating articles on a particular subject.

Acknowledgment is here given for the assistance furnished by many manufacturers of gas meters in providing a large number of the illustrations contained in this circular.

II. CLASSIFICATION OF COMMERCIAL GAS-MEASURING INSTRUMENTS AND METHODS

In order to follow a logical order of discussion, the following classification of gas-measurement instruments and methods is used in this paper.

- I. Gas containers or gasometers.
  - 1. Fundamental standards.
    - (*a*) Immersion type of cubic-foot bottles.
    - (*b*) Cabinet types of cubic-foot bottles.
    - (*c*) Portable type of cubic-foot standards.
  - 2. Meter provers.
  - 3. Gas holders.
- II. Gas metering instruments.
  - 1. Positive displacement meters.
    - (*a*) Dry meters.
    - (*b*) Wet meters.
    - (*c*) Nutating bell gas meters.
    - (*d*) Rotary displacement meters.
  - 2. Velocity or inferential meters
    - (*a*) Pitot tubes
    - (*b*) Orifice plates or meters.
    - (*c*) Funnel meters
    - (*d*) Venturi tubes or meters.
    - (*e*) Rotary meters.
    - (*f*) Float meters.
  - 3. Electrical gas meters.
    - (*a*) Thomas electric meter.
  - 4. Proportional meters.
- III. Another method of measuring gas.
  - 1. Method of gas mixtures.

III. GENERAL DESCRIPTION OF COMMERCIAL GAS-MEASURING INSTRUMENTS AND THEIR MOST COMMON USES

The fundamental standard for all commercial gas-measurement work is the cubic-foot bottle. There are three general types of cubic-foot bottles in general use: (*a*) The cabinet type of bottle, in which a cubic foot of gas is displaced by or displaces an equal volume of water from a stationary bottle (the moving tank type, which is commonly used in the fractional cubic-foot sizes, is strictly a modification of the cabinet type); (*b*) the immersion type, in which the displacement is caused by raising or lowering the bottle in a tank of water or oil; (*c*) a portable type similar in design to a meter prover, in which a bell moves vertically in an annular tank containing a sealing fluid.

The most general use of cubic-foot standards is in the calibration of meter provers and other gas containers. They are also used in testing meters, particularly small wet laboratory meters, for which purpose the fractional cubic-foot bottle is especially useful.

Meter provers used in meter testing are of two types—the standard and the automatic. For general meter-inspection work the standard type of meter prover is used. There are many variations in the design and fittings of standard provers, but the essential features consist of a tank containing a sealing fluid, a sheet-metal bell arranged to move vertically in this tank, and a scale and pointer, one of which is attached to the bell and the other to the tank. The scale is usually divided into cubic feet and fractions thereof. Standard provers are commonly made in 2, 5, 10, and 20 cubic-foot sizes. The automatic meter prover is seldom used except in meter-adjusting work where a single revolution of the meter tangent is used for the test.

Gas holders are seldom used for gas-measuring work except for the determination of large volumes.

In gas-metering instruments of the positive displacement group the principle employed is to alternately fill and empty two or more chambers which have a fixed cubical displacement. The number of times the chambers are filled and emptied is recorded by a suitable mechanism with hands and dials arranged to read in cubic feet of gas passed. The construction and operation of the several types of positive displacement meters are discussed under appropriate headings.

In flow or velocity meters some means is employed to obtain an indication of the velocity of the gas as it passes through a channel of known area. With the velocity and cross-section area of the gas streams known, it is then possible to compute the volume passed during any given period of time.

Electrical gas meters employ the principle that the specific heat of a homogenous gas is practically constant at ordinary temperatures. So, if we can measure the energy required to change the temperature of the gas a known amount, and the specific heat of the gas is known, the weight and accordingly the volume may be determined.

Proportional meters operate on the principle that when two passages are provided through which a quantity of gas may flow, the stream will divide in inverse proportion to the resistance they present to the gas flow. Hence, if a small part of the total gas stream is diverted through a small passage and measured by a displacement meter, the indications of the displacement meter multiplied by 1 plus the proportioning factor will give the total volume passed.

In the method of mixtures a small quantity of a suitable gas is introduced at a known rate into the gas stream to be measured. At

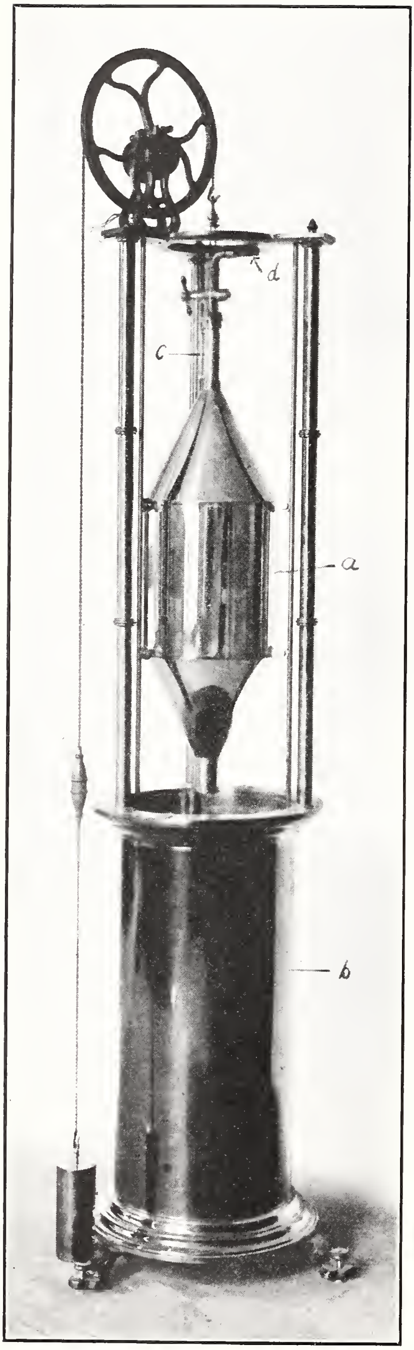

Fig. 1.—*Immersion type cubic-foot bottle*

The tank contains water or oil, and displacement is produced by raising or lowering the bottle.

a point farther downstream a sample of the mixture is obtained and analyzed. When the proportion of the two gases in the mixture is determined it is possible to compute the total volume of gas flowing per unit of time.

IV. GAS CONTAINERS OR GASOMETERS

1. FUNDAMENTAL STANDARDS

(*a*) IMMERSION TYPE OF CUBIC-FOOT BOTTLE

The cubic-foot bottle or standard now generally made and used in this country is the immersion type illustrated by Figure 1. As is indicated by the figure, the apparatus consists of the copper bottle *a*, which is open at the lower end and so supported that it may be easily lowered into or raised from the tank *b*. The tank contains water or some other liquid, and when the bottle is lowered into it the liquid will enter the bottle through the lower neck and displace exactly 1 cubic foot. The marks on the bottle defining the cubic foot are the bottom of the lower neck and the gauge mark *c*, which partly surrounds the gauge glass in the upper neck.

To prepare the apparatus for use, the bottle is lowered into the tank until it rests upon the bottom of the tank. The tank is then filled with water or oil until the surface of the liquid in the gauge glass of the upper bottle neck is in the plane of the top of the gauge mark. A rubber tube is then attached at *d* for connecting the standard to the apparatus under test.

If water is used as the liquid in the tank, this type has a serious disadvantage when it is used in such a way as to draw air from the apparatus under test into the bottle. In this case the bottle rises from the water with the outside wet, and the change in temperature, due to the evaporation from this wet surface, may cause either serious errors or inconveniently slow operation. There are two ways in which this trouble may be overcome. One is to insure that the air in the room as well as that in the bottle is saturated with water vapor. The other method, which is recommended as the more preferable one, is to use an oil, such as kerosene or a light machine oil, in the tank.

For some tests the immersion bottle has the advantage that a very low constant pressure may be maintained within the system when transferring the air from the bottle to the apparatus under test and vice versa. Under such conditions the operation of this standard is simple and easy. In other cases, however, it may be necessary to make the test when the pressure in the apparatus is slightly in excess of the atmospheric pressure. In these cases it will always be necessary to make the test in such a manner that the air (or gas) is drawn from the apparatus under test into the bottle. When making a test in this manner considerable skill will be required in the manipulation of the bottle, due to the fact that when the bottle is filled with air the bottom of the lower neck will still be under the surface of the liquid by an amount sufficient to balance the excess pressure. Therefore, it will be necessary to raise the bottle very slowly when it is nearly filled with air and to stop the motion the instant the first small bubble breaks out from the bottom of the bottle. If done carefully not more than one or two small bubbles of air will escape and the error thus introduced will be negligible in most cases.

(b) CABINET TYPE OF CUBIC-FOOT BOTTLE[2]

A cabinet type of cubic-foot bottle is illustrated in Figure 2. It consists of a copper vessel of oval cross section *m*, which is the cubic-foot bottle, supported by two shelves located immediately above and below it. The tubes leading from the copper vessel, both above and below, are of glass for about 6 inches, and around these glass sections are placed the upper and lower limit marks of the cubic foot. Above the upper glass tube is a 3-way cock *o*, one outlet of which leads through the valve *b*, and tube *c*, to the threaded connection *d*. It is to this threaded connection *d* that the apparatus under test is connected. A second outlet leads to the bottle through the gauge tube *l*. On the third outlet of the 3-way cock *o*, is the

[2] The cabinet type of cubic-foot bottle is no longer made, therefore a detailed description of its operation has been omitted.

air vent *p*. The lower glass tube is likewise connected to one branch of the 3-way cock *g*, another branch from which leads to the lower tank *j*, and the third branch leads through the cock *f*, and tube *e*, to the upper tank *a*. The other parts of the apparatus include the funnel *h*, by which water may be added to the system, and the two cocks *i*, by which it may be drained off; *k* indicates a pump by which water may be pumped from the lower to the upper tank through the tube *n*.

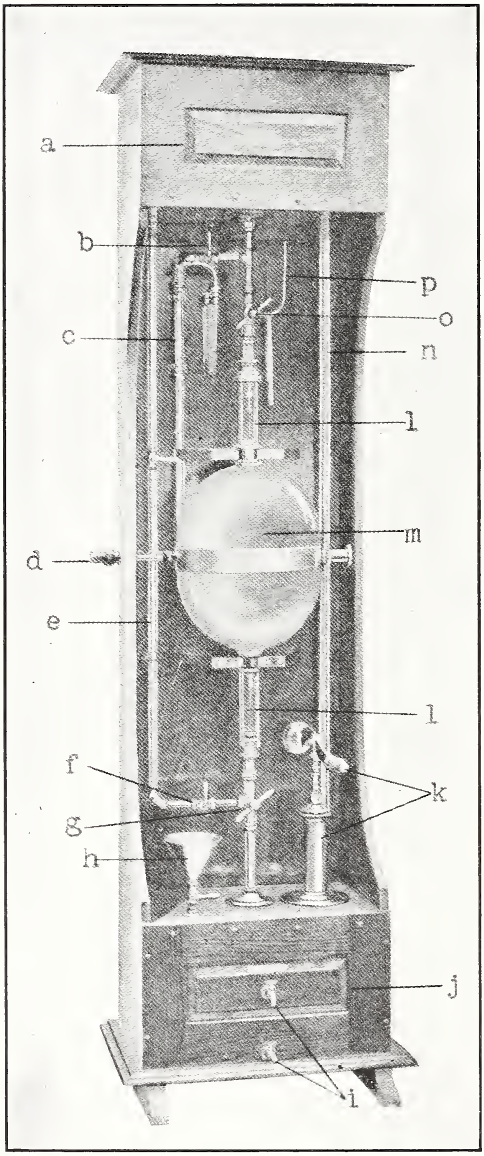

FIG. 2.—*Cabinet type cubic-foot bottle*

When using this type of cubic-foot bottle, water may first be pumped into the upper tank and then allowed to flow into the bottle by way of tube *e*, *f*, *g*, *l*, and thus displace the air in the bottle. As an alternative the bottle may first be filled and then allowed to drain into the lower tank, thus drawing air from the apparatus under test into the bottle. In the first case the flow of the water should be started when the bottom of the water meniscus is in the plane of the top of the lower gauge mark and stopped when the bottom of the water meniscus is in the plane of the top of the upper gauge mark. In the second case the order of starting and stopping is reversed. This may be used for making tests at either atmospheric pressure or at slightly higher or lower than atmospheric.

Figure 3 illustrates a moving tank form of cubic-foot bottle which, as previously stated, is strictly a modified form of the cabinet type.

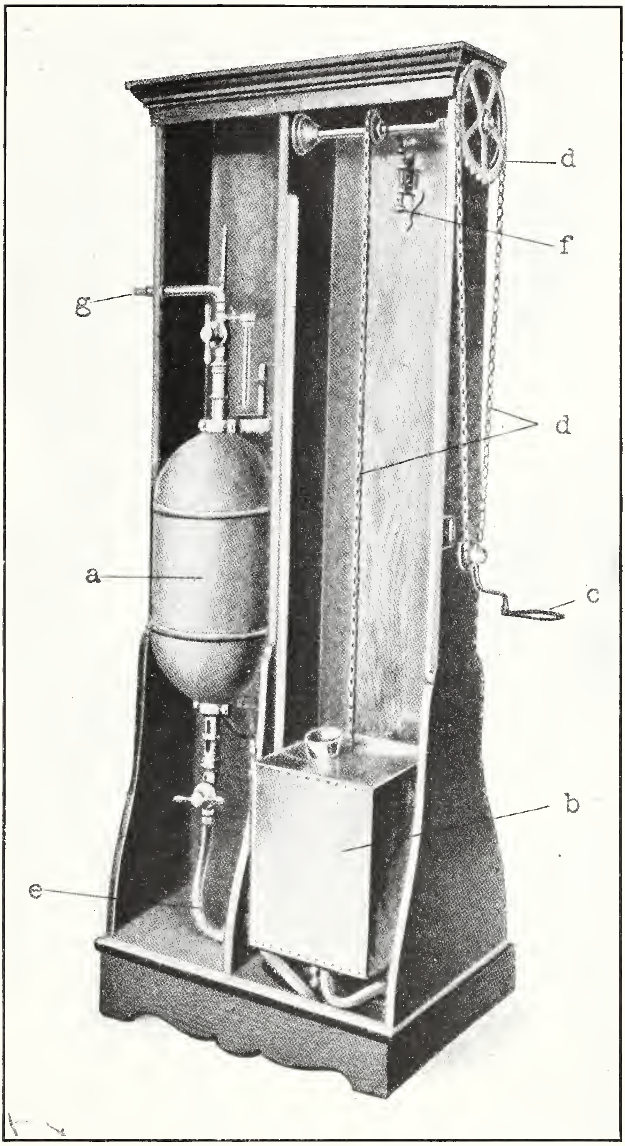

FIG. 3.—*Moving tank cabinet type cubic-foot bottle*

When the tank *b* is raised water flows from it into the bottle *a* displacing an equal volume of gas.

a is the cubic-foot bottle. In this apparatus, instead of an upper and lower tank being provided, the water is made to enter or leave the bottle by changing the position of the movable tank *b*. The tank is moved from the lower to the upper position by means of the crank *c*, operating the sprocket and chains *d*. To facilitate moving the tank a counterweight is fastened to the opposite end of the chain to which the tank is attached. Connection between the tank and the bottle is by means of the rubber tube *e*. The adjustable stops *f* (upper one only visible), are provided so that the upper and lower positions of the tank will always be the same during any test. When

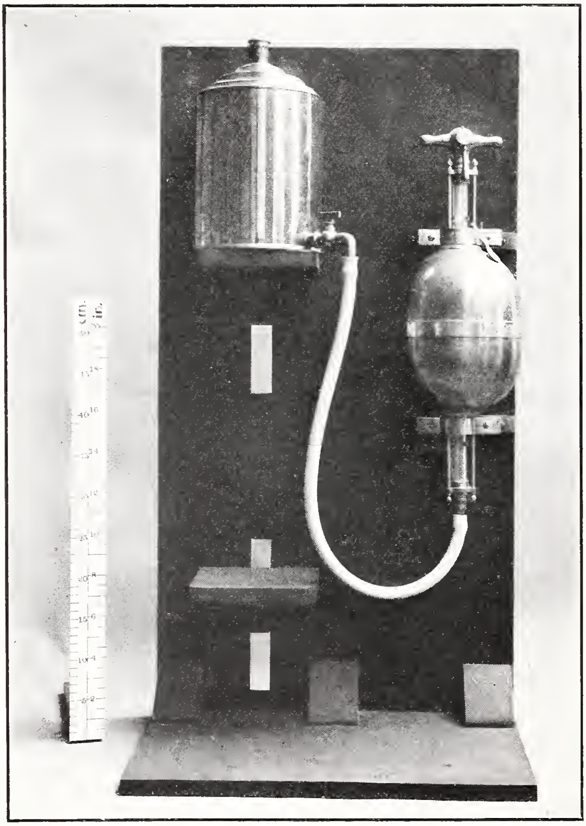

FIG. 4.—*A 1/10-cubic-foot bottle of the moving-tank type*

Ordinarily used for testing laboratory wet gas meters.

preparing the standard for use the positions of these stops and the quantity of water in the tank are mutually so adjusted that when the tank is against the upper or lower position the bottom of the water meniscus in the corresponding gauge glass will be exactly in the plane of the top of the index or gauge mark. This adjustment may be made either at an atmospheric pressure or with the bottle connected to the apparatus under test, and the whole system being at a pressure in excess of atmospheric. The bottle is connected to the apparatus under test by the tube *g*.

This type of standard is much more easily transported than the older cabinet type and at the same time it retains the advantages of a fixed bottle with a dry exterior. It can be operated easily and rapidly.

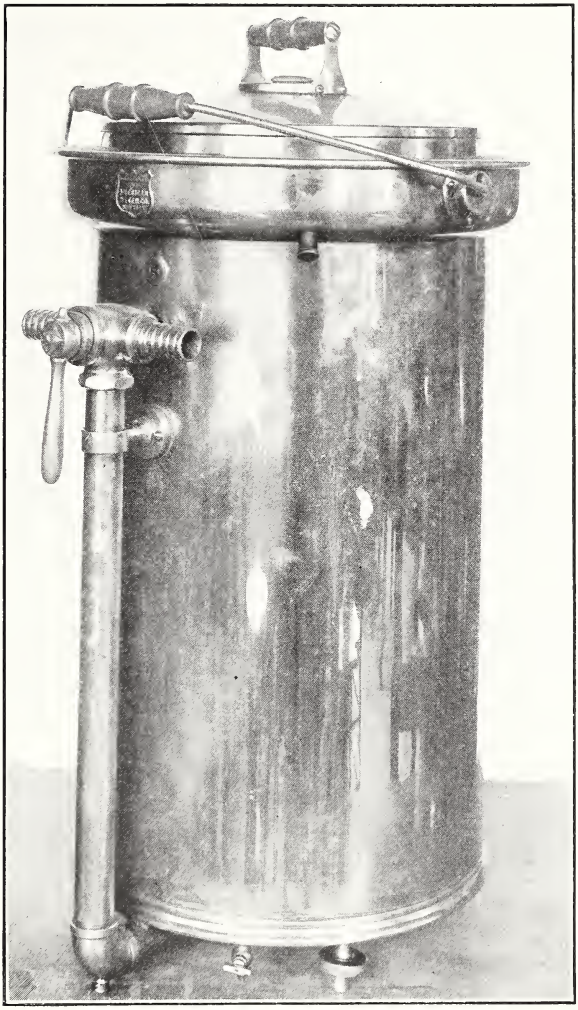

FIG. 5.—*A portable cubic-foot standard*

This standard is easy to operate and may be carried from place to place readily.

Figure 4 illustrates a one-tenth cubic-foot bottle of the moving-tank type.

(1) CALIBRATION OF CUBIC-FOOT BOTTLES.—The method of test and calibration of the cubic-foot standards thus far described is to weigh very carefully the quantity of distilled water that they will

hold between the two gauge marks. The weight of the water should be 62.279 pounds when at a temperature of 60° F. and under a pressure of 30 inches of mercury. If the quantity of water held by a bottle varies from this amount the positions of the gauge marks are changed to correct for the error.

(c) PORTABLE CUBIC-FOOT STANDARD

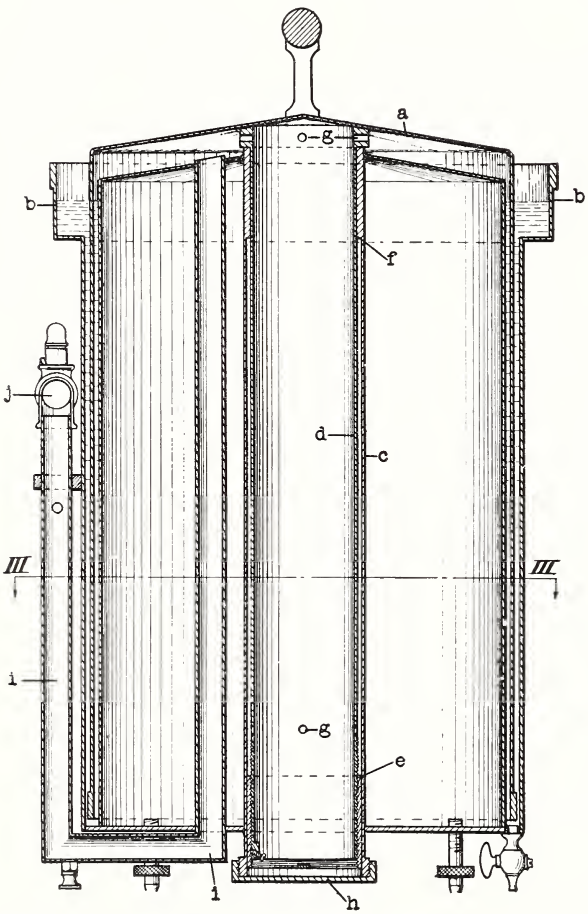

Fig. 6.—*Cross section of a portable cubic-foot standard*

A portable cubic-foot standard (also called a Stillman cubic-foot standard) is illustrated by Figures 5 and 6. The essential details of construction (shown by fig. 6) are as follows: The bell *a* fits into the annular tank *b*, guided by the telescoping tubes *c* and *d*, and the guide rings *e* and *f*. By changing the position of ring *e* on tube *d* the height to which the bell may be raised is changed. It is by this means that the displacement of the bell is adjusted to be exactly 1 cubic foot. Water or a light oil may be used as the sealing fluid in the annular tank *b*. The quantity of sealing fluid required is a little over 1 gallon.[3]

For adjusting a portable standard to receive or deliver 1 cubic foot of gas an accurately adjusted immersion type of cubic-foot bottle is connected to the standard. The stroke of the bell is then so adjusted that upon discharging 1 cubic foot of gas from the im-

[3] For a more detailed description of this standard, see B. S. Tech. Paper No. 114, A Portable Cubic-Foot Standard for Gas.

mersion bottle into the portable standard no change of pressure takes place within the system. Both the portable standard and the immersion bottle must, of course, be at the same temperature.

If water is used as the sealing fluid this standard will be subject to the same disadvantage as was mentioned in the discussion of the immersion type of cubic-foot bottle, which may be overcome by the same methods as then suggested. This standard may be operated at atmospheric pressure or at pressures slightly in excess of atmospheric. In either case it is essential to have the pressure within the standard and apparatus under test the same at the end of the bell stroke as at the start. Other points which should be observed when using this type of standard are as follows: The bell should be rotated slightly when raising or lowering it so as to keep the sealing fluid well stirred and at a uniform temperature; the bell should be turned so that it will always be in the same position relative to the tank when at the bottom and top of its stroke; the bell should rest tightly against the stops when at either the upper or lower position, but should not be allowed to strike either stop hard; the bell should be raised and lowered evenly and without undue force.

This portable standard has the important advantage of being very easily moved. If provided with a suitable case it may be shipped from place to place without danger of injury and is therefore particularly well adapted to the needs of State testing agencies. The method of operation is very easy and rapid. When used to calibrate a meter prover the ordinary prover pressure may be used, a practice that is not always possible when using other types of cubic-foot bottles, particularly an immersion bottle. This bureau has found that it is possible to calibrate meter provers with this type of standard to practically the same degree of accuracy as is obtained when the older forms of cubic-foot bottles are employed.

When using a cubic-foot bottle or standard for calibrating another instrument it is important to make sure that the temperature of the bottle, the apparatus under test, and the room are sensibly the same. The differences should never be over 2° F., and less than this should be easily attainable. Also, care must be taken to see that the air or other gas used within the bottle and other apparatus is saturated with water vapor before the test is started. A further discussion of these points is given in the section on "calibration of meter provers."

2. GAS-METER PROVERS

(a) STANDARD GAS-METER PROVERS

Figures 7, 8, and 9 illustrate three designs of the standard type of gas-meter prover. The prover shown in Figure 7 is a common

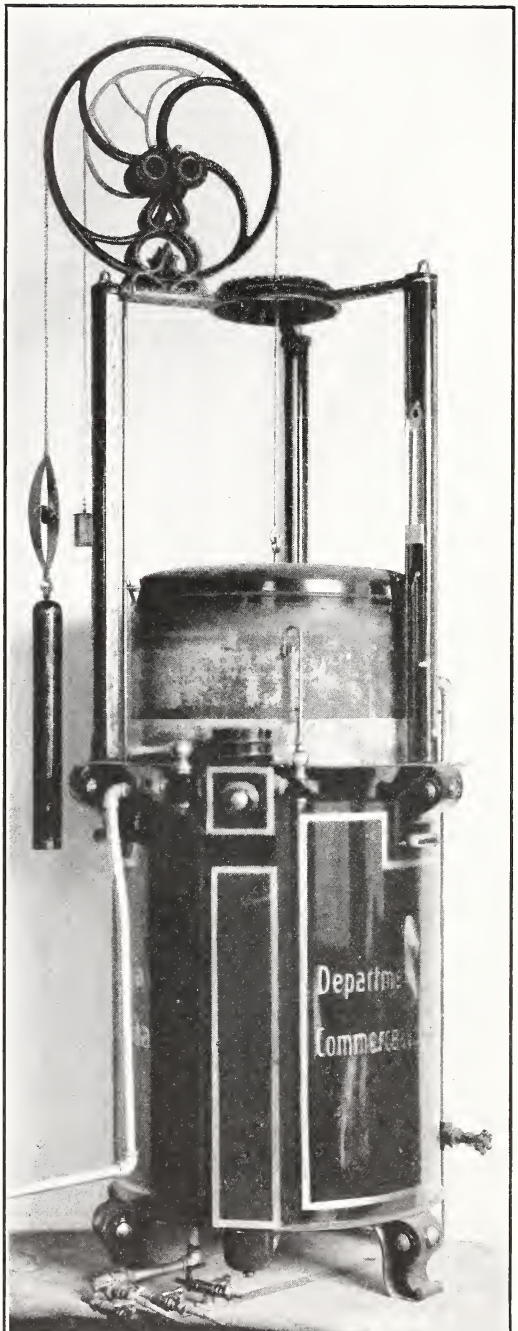

FIG. 7.—*A meter prover with uncovered bell*

Note that the scale is attached to the column and the pointer to the bell. This is not the best practice.

design of uncovered bell prover. The designs shown in Figures 8 and 9 have covered bells.

The prover tank is preferably made annular, so that a minimum amount of water or oil will be needed to fill it. This design also permits the prover to assume the room temperature more rapidly, allows more rapid filling and emptying, and makes the whole outfit lighter. On the other hand, the annular tank is more difficult to clean and repaint.

The bell is usually made of copper or galvanized iron; the copper bell, though initially more expensive, is considered by some to be more economical because of its greater resistance to corrosion. It is also claimed that a copper or brass bell has the advantage in that if kept well polished and slightly oiled practically no water will adhere to its surface and the temperature change due to evaporation from the surface of the bell is thus reduced.

Communication with the confined space under the bell is secured by a tube which extends from above the surface of the

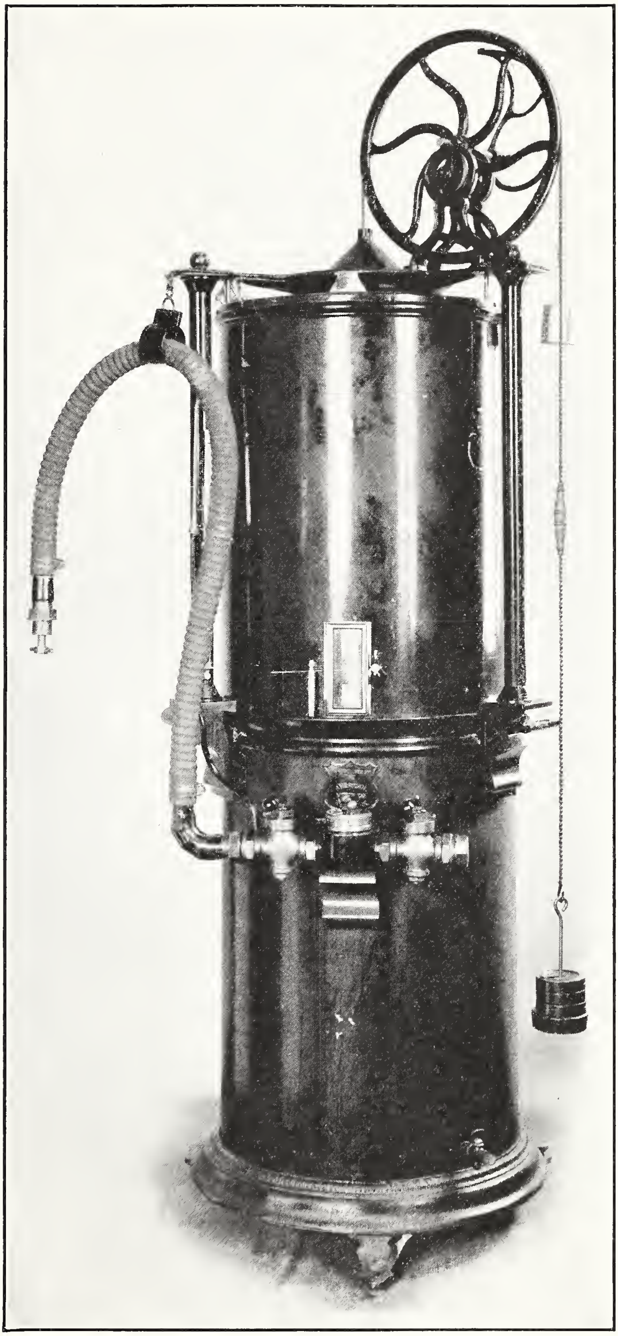

FIG. 8.—*A 5-cubic-foot covered bell meter prover*

Here the scale is attached to the bell and the pointer to the frame, which is good practice.

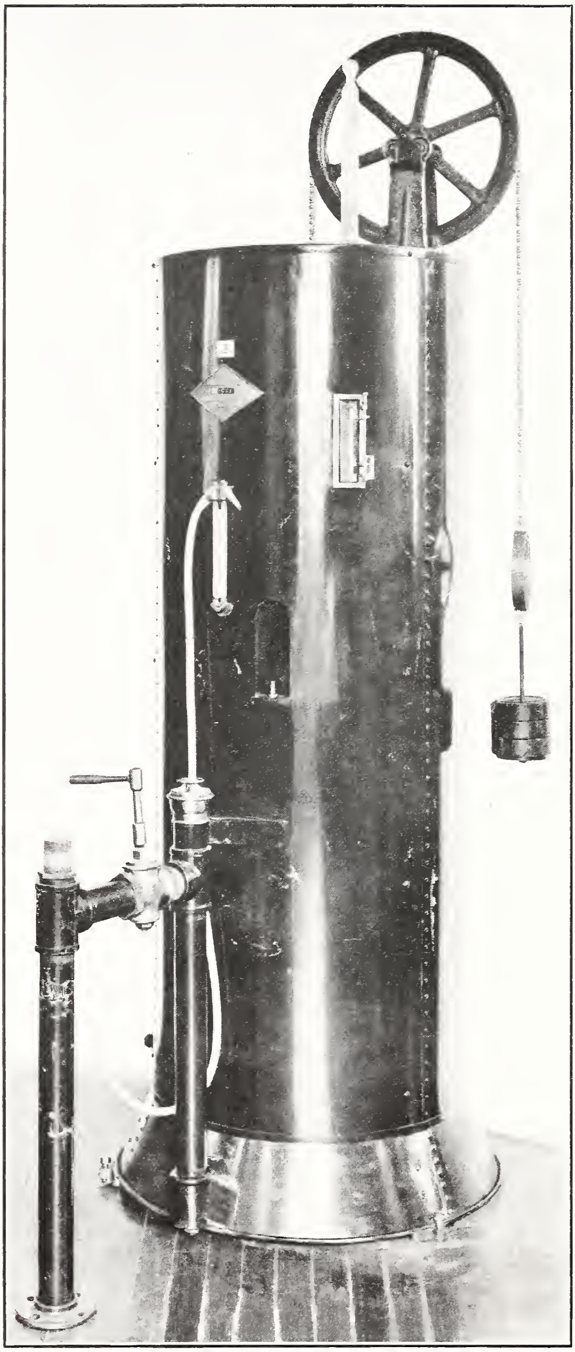

FIG. 9.—*A covered bell meter prover*

Here also the scale is attached to the bell.

sealing fluid, under the bell, down to the bottom of the tank, out and up along the outside of the tank to a convenient height, where it terminates in the valves which control the passage of air to or from the prover.

There are two methods which are used to decrease or prevent temperature changes in the bell due to evaporation from its surface when raised. One method is the use of the covered bell prover, as illustrated by Figures 8 and 9. These covers prevent air currents from striking the bell and make it possible to maintain nearly uniform temperatures in the bell. The other method is to use a light oil in the prover tank.

The prover should preferably be raised above the floor by legs with screw feet. This facilitates leveling of the apparatus, and it reduces the lag of the temperature of the prover behind that of the room by allowing free circulation of air under the prover. This construction also lengthens the life of the prover by preventing the corrosion which results from the accumulation of moisture on the underside of the tank.

The scale may be fastened to the bell and the pointer located on the tank, or the scale may be placed on one of the pillars which carry the bell support and the pointer attached to the top of the bell. A dial is sometimes used instead of the usual straight scale and pointer; the indicator being mounted by a friction joint on a drum which is rotated by a fine wire attached to the top of the bell. Having the scale attached to the bell is considered the best practice, since in this way the same scale divisions will apply to the same portions of the bell at all times.

The equipment of a prover should also include two thermometers and a pressure U gauge. One of the thermometers should be mounted about half way up one of the prover pillars and at such a distance from the operator's position that his presence will not influence it. This thermometer indicates the temperature of the air about the prover. The other thermometer is suspended in the sealing fluid between the bell and tank. The pressure U gauge should be connected to the prover outlet beyond the outlet cock. In this position it will indicate the pressure of the gas delivered by the prover to the instrument under test. A convenient location for the gauge would be on one of the pillars at about the level of the operator's eyes.

There are a few points that it is well to observe in the location and care of a prover. The special precaution as to its location is to select a well-lighted room in which the temperature changes will be small and the air comparatively still. Temperature changes greater than 5 to 10° F. should not occur during a period of 24 hours if they can be avoided, since it is essential that the prover and the meters to be tested be as near the same temperature as possible. A difference of 3° C. or 5° F. between the prover and the meters under test may cause an error of more than 1 per cent. For this reason the prover should not be near a radiator, steam pipe, or hot or cold air ducts. It must be protected from drafts and direct sunlight should never be allowed to fall on the prover or the meters under test. As the temperature of the prover usually lags behind that of the room it is desirable to provide convenient means for changing the temperature of the fluid in the prover tank. This is commonly done by adding hot or cold water or steam when water is used in the tank, and by steam pipe coils or inclosed electric heating coils when oil is used in the tank. In any case the fluid should be thoroughly stirred before taking its temperature.

There are two sets of weights counterbalancing the weight of the bell. The main counterweight hangs on a chain which passes over a large grooved wheel and is fastened to the center of the top of the bell. The second counterweight is suspended from a grooved spiral which is fastened to the same shaft as the grooved wheel. The function of the main weight is to provide a way to change the pressure of the gas within the bell. The function of the secondary weight is to counteract the increasing buoyant effect of the sealing fluid as the bell descends. As may be seen in Figures 7 and 8, the spiral is so attached that as the bell descends, the radii to the successive points at which the cord leaves the spiral, continually shorten; thus the turning moment or counterbalancing effort produced by the secondary weight, as applied to the bell through the grooved pulley and main weight chain, decreases. The amount of the secondary counterweight should be such that the gas in the bell is at a constant pressure irrespective of the position of the bell. If this is not the case the correct amount of the secondary weight may be determined in the following manner: The main counterweight is increased until, with the prover valve open, the bell will neither rise nor fall of itself. The bell is then moved to another position and if it does not remain stationary the spiral counterweight should be increased or decreased as the conditions may require, the main counterweight being simultaneously decreased or increased until the bell will remain stationary at any point with the valve open. The main counterweight may then be decreased until the pressure within the bell is the desired amount, usually equal to 1½ inches of water.

The chains or cords supporting the counterweights should be flexible and run freely over the wheel and spiral.

It is necessary to arrange at one side of the prover a bench or table on which meters may be placed during test, preferably with the test dial at about eye level. If one man uses two provers the bench may be placed between them and the two meters under test at any one time are thus within easy reach of the operator.

The hose for connecting meter and prover should be conveniently supported in such a way that when disconnected from a meter it will remain free from sharp bends. This is usually accomplished by having the hose rest in a saddle suspended from an overhead support. However, the saddle should not be wider than the hose, for if it is the hose may flatten over the saddle and crack. When a considerable number of meters must be tested a device for rapidly connecting the meters with the prover is very desirable.

The valves of the prover should be kept free from dust and be well greased at all times. Any grit in the valves will soon scratch the bearing surfaces and cause leaks. When not in use the circular slide valve should be covered to keep out the dust.

Although all provers are carefully tested by the manufacturer before shipment they must be again examined after being set up for use to insure that they have not been damaged in shipment.

The prover bell should first be raised and carefully examined to make sure that it is not dented. The counterweights should then be adjusted to produce a very small pressure, the air allowed to escape, and the fall of the bell noted to see that it is easy and regular and free from excessive friction in the guides and bell-lifting mechanism. The difference in pressure within the bell with the air escaping and with it confined should not exceed 0.1 inch of water pressure. The prover should be tested for leaks by leaving the bell filled with air under a pressure of 2 or 3 inches and observing whether there has been any escape of air after a period of an hour or more, making the necessary corrections for any change of temperature, pressure, and vapor pressure which may have taken place.

(b) CALIBRATION OF GAS-METER PROVERS

For the standardization of a prover it is essential to have the temperature of the room constant throughout the test, and with some operations it is a great advantage to have the air of the room saturated with moisture. To prevent temperature changes occurring, drafts must be excluded. In some laboratories the air of the room is kept nearly saturated by sprinkling the floor with water and hanging wet sheets in the room. It is not always necessary to saturate the air in the room if care is taken to saturate the air used in the test before it is measured and to prevent temperature changes due to the evaporation of water from the outside of the bell.

The calibration of the prover by the cubic-foot bottle can be made either by measuring the air into the prover 1 cubic foot at a time until the prover is filled, or by filling the prover and measuring the air out 1 cubic foot at a time. The latter method has several advantages, especially if a cabinet type of bottle is employed. It is often recommended that in every test of a prover comparisons be made by both methods. It is unquestionably best to make both forms of comparisons the first time that a prover is tested, but after a first test it is not usually necessary to calibrate again by more than one method. There is no inherent reason why the two methods should not agree, and if a discrepency is found it must be due to some experimental errors. Successive calibrations should agree with each other within 0.3 per cent.

The bottle and prover should be kept near together for a long enough period before the test, preferably overnight, so that they will be at the same temperature. During this time the prover bell should be raised as far as possible without unsealing it, if water is used as a sealing fluid, so that the air in the bell will be fully saturated with water vapor and the outside of the bell will be dry before the beginning of the test. The bottle, while empty, is connected with the prover and the connections tested for tightness by opening the valve between the bottle and prover until the pressure in the bottle is the same as that in the prover. The prover valve should then be closed and the set-up allowed to stand for 5 or 10 minutes to test it for leaks. If the temperature of the gas (or the air) and prover does not change the pressure within the bottle and connections, as indicated by the gauge on the prover connection, should remain the same during this interval. If it does not do so a leak in the bottle or the connections is indicated.

(1) Calibration of a Prover with an Immersion-Type Bottle—(*a*) *Bottling out of the prover.*—Bottling out of a prover with an immersion bottle may be done either at atmospheric pressure or at the usual prover pressure. Assuming first that the calibration is to be made at the usual prover pressure the procedure is as follows: After making sure that all connections are tight, as described above, and with the bell raised as high as possible without unsealing, the valve between prover and bottle is opened, thus making the pressure within the bottle the same as in the prover. The quantity of liquid in the bottle tank is then adjusted until the surface of the liquid within the upper gauge glass of the bottle is in the plane of the gauge mark. There may be some difficulty in making this adjustment due to the fact that the surface of the liquid in the tank will be above the gauge mark by an amount sufficient to balance the pressure of the prover. By manipulation of the prover slide valve the zero of the prover scale is now brought exactly to the zero of the pointer. Now raise the bottle steadily from the tank, thus drawing into it air from the prover. Since the test is being made at the usual prover pressure the opening of the lower neck will still be submerged by an amount sufficient to equal the pressure of the prover when the bottle is filled with air. Therefore it will be necessary to raise the bottle very slowly when it is nearly filled with air and to stop the instant the first small bubble breaks out from the bottom of the bottle. If the work is done carefully there is no need of losing more than one or two very small bubbles of air at the most.

Now that a cubic foot of air has been removed from the prover the valve between the prover and bottle is closed and the reading of the prover scale is noted. A small amount of air is then returned from the bottle to the prover so as to raise the 1-foot mark of the prover scale above the index mark and the remainder of the bottle full of air is discharged so as to again submerge the bottle. Now adjust the prover bell so the 1-foot scale mark coincides with the index mark and proceed to bottle out another cubic foot of air.

This procedure may be subject to a slight error if water is used in the tank of the bottle and the air in the room is not saturated with water vapor. Under these conditions the bottle raises from the tank wet and the evaporation from the wet sides may cool the air within sufficiently to cause an appreciable error. This possibility of error may be greatly reduced by having the air in the room saturated with water vapor and by keeping the surface of the bottle well polished or oiled, and may be practically eliminated by using a light clear oil in the bottle tank.

If the test is made at atmospheric pressure the procedure will be substantially the same as that just described. The special precautions occasioned by the prover pressure will now be unnecessary. However, it would be advisable when raising the bottle from the tank not to completely unseal the bottom of the lower neck until after closing the valve between the prover and the bottle in order to guard against accidental shifting of the prover bell.

(*b*) *Bottling into the prover.*—This method is the reverse of the preceding with the exception that it is practically necessary to use atmospheric pressure in the bottle and prover during the test. This merely requires that the counterweights of the prover be increased until the bell is just balanced.

The same care must be taken to prevent temperature changes and errors due to moisture on the sides of the bottle which was mentioned in the preceding section.

(2) Calibration of a Prover with a Cabinet-Type Bottle.—(*a*) *Bottling out of the prover.*—When the tightness of the connections is assured the bottle should be filled with water to the upper gauge mark. Enough air is allowed to escape from the prover to bring the bell exactly to the zero mark. The air from the prover is then allowed to pass into the bottle until the water level in the bottle just reaches the lower gauge mark, when the lower valve of the bottle is closed and the prover reading noted. After closing the proper valve and opening the bottle outlet to the air the bottle is again filled with water and a second foot of air measured out of the prover. This cycle of operations is repeated until all the cubic-foot graduations of the prover scale have been checked. It is to be noted that if the lower water valve of the bottle is closed before the prover valve is closed the pressure of the gas in the bottle will be the same as that in the prover, and corrections for pressure differences will then be unnecessary.

This method does not require the changing of the bell counterweights.

(*b*) *Bottling into the prover.*—This method is essentially the reverse of the method just described. In this method we start with the bell empty and introduce 1 cubic foot at a time from the bottle. Unless some means are used to saturate the air of the room with water vapor the air should be drawn through water when filling the bottle each time.

While some inspectors prefer to counterbalance the bell so that it is just balanced, it is not necessary, as it is a simple matter to have enough water in the upper tank to provide sufficient head to equal the pressure in the prover.

A possible source of error in this method is that since the bell rises from the tank wet the cooling effect of the evaporation from its sides may be appreciable. This, of course, may be overcome by using oil as the sealing fluid in the prover or by giving the bell a coat of oil or paraffin. The failure to thoroughly saturate the air with water vapor before drawing it into the bottle may also cause appreciable errors.

(3) Calibration of a Prover With a Moving-Tank Cabinet-Type Bottle.—In general, the calibration of a prover with this type of bottle is the same as that already described for the regular cabinet type, the only notable difference being in the different manner of operating the two types of bottles, the moving tank in this form taking the place of both the upper and lower tanks.

If the test is to be made with the usual prover pressure, it is important to have the bottle connected with the prover and the prover valve open when adjusting the quantity of water in the tank and the positions of the stops for bringing the water in the sight glasses into the planes of the gauge marks. The same precautions regarding temperature changes and having the air fully saturated with water vapor apply as in the previous method.

(4) Calibration of a Prover with a Portable Cubic-Foot Standard.—As in the former cases, this comparison may be made either by measuring the air out of or into the prover. A combination of these two methods may also be used to advantage; that is, a cubic foot of air is passed from the prover to the standard and back several times in succession for the same interval of the prover scale, thereby obtaining an immediate check upon each prover reading and the value of the interval being tested and also tending to maintain the temperature of the two instruments the same. It is best to have the connections in this case as short as possible and tested for leaks in the same manner as is described on a preceding page.

Nothing need be said about the manipulation of the standard, as it is self-evident from its construction. If the same care is used with this as with the other types of cubic-foot standards, results that are fully as satisfactory for all ordinary requirements can be obtained as with any of the other types. It is unnecessary to increase the counterweights of the prover bell, as there is no difficulty in using the usual prover pressure. If oil is used as the sealing fluid in both the prover and the standard, the errors due to evaporation and the resultant cooling of the surfaces of the standard or prover will be eliminated, so that if the temperatures of the prover and standard are the same there should be no corrections necessary. A calibration by this method may be much more rapidly carried out than by any of the other methods that have been described, and there is the added advantage that the standard can be very easily carried from place to place.

(5) Calibration of a Prover with a 1-Cubic-Foot Prover.—As its name implies, the 1-cubic-foot prover is a miniature meter prover, the bell of which is long in comparison to its diameter, thus making possible the use of an open scale which is easy to read. The gas passage of this prover is provided with a lever handle cock so that the flow of air or gas into or out of the bell may be quickly and easily controlled. Other suitable valves and pet cocks are provided to enable the operator to empty the bell rapidly and to adjust it to the zero scale mark without touching the lever handle cock. Also the counterweights of this prover are adjusted so that the pressure within the bell will be less than that of the large prover by 0.1 inch or less of water. This is so the air or gas will pass from the large prover into the 1-foot prover.

To make a test the 1-foot prover is connected to the large prover with a rubber hose and all connections checked for tightness. The large prover is filled and set to zero scale reading with pressure in the hose up to the lever handle cock of the 1-foot prover. The small prover is then set at zero scale reading, and the lever handle cock opened so the air or gas will pass into the small prover. When the 1-foot prover scale reading indicates that 1 cubic foot has passed into it, the cock is closed and the large prover scale reading noted. This is repeated for each foot of the large scale, thus enabling the scale of the large prover to be tested out in the manner in which the prover is used when testing meters.

(c) THE AUTOMATIC GAS-METER PROVER

The automatic gas-meter prover is a miniature meter prover similar in design to the standard provers just described but having a capacity which is sufficient to produce only one revolution of a gas-meter tangent.[4] In order that the flow from the prover to the meter may be stopped the instant the tangent has made one com-

[4] See the following section on gas meters for a description of this part of a meter.

plete revolution the connection between the prover and meter is provided with a valve which is closed automatically by a lever which is actuated by the meter tangent. Several different scales are ruled on the proved-scale bar, each scale corresponding to the capacity per tangent revolution of different meter sizes.

This type of prover is particularly adapted to meter adjustment work and is rarely, if ever, used for the final or official testing of gas meters.

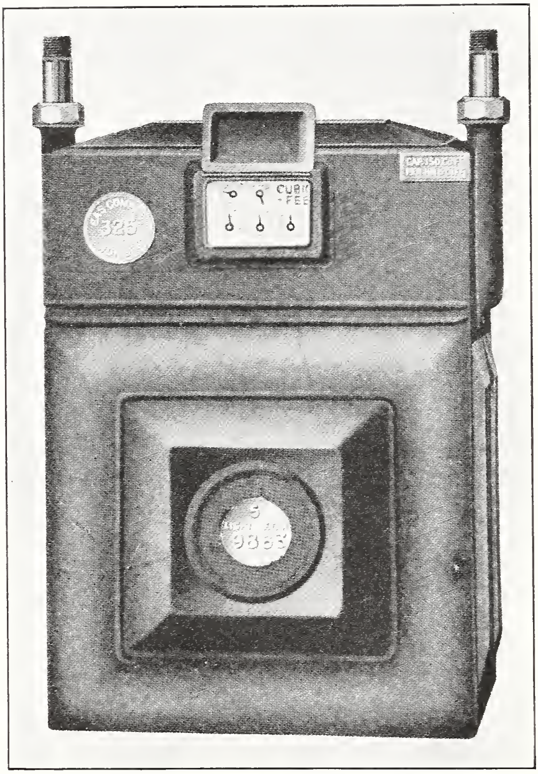

FIG. 10.—*A typical tin-case dry gas meter*

(d) OIL IN PLACE OF WATER AS A SEALING FLUID

A number of references have already been made to the use of oil in the place of water as a sealing and displacing fluid in the meter-prover tank and with the cubic-foot bottles. Some of the advantages gained by this substitution are:

1. The errors due to change of volume caused by the introduction of a vapor into the air to be measured are reduced to a degree which may be neglected.

2. Errors due to a change of volume caused by the cooling effect of evaporation on the outside surfaces of the bottle and prover bell are practically eliminated.

3. The low specific heat of the oil permits the prover and portable standard to follow changes of room temperature more closely.

4. The testing apparatus is not injured by the sealing liquid but rather preserved in good condition.

An oil which has been found to be satisfactory for this purpose when air is used has the following approximate specifications:

Flash point	150° F.
Fire point	195° F.
Viscosity	45 seconds, Saybolt viscosimeter.
Specific gravity	0.86 (or 32° B.).

When gas is used in the prover for meter testing certain constituents of the gas may be absorbed by some oils and thus cause a change of volume. However, a careful selection of the oil will probably reduce the error resulting from this cause to a point where it may be neglected.

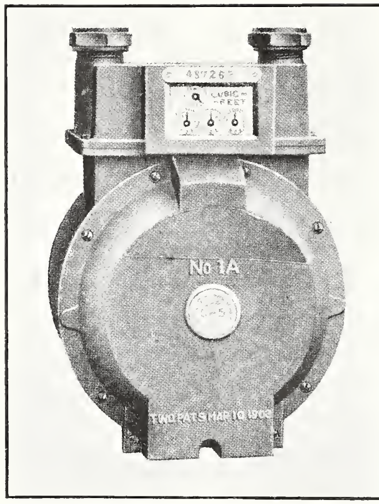

Fig. 11.—*An iron-case dry gas meter*

A layer of oil on top of the water in the prover tanks may produce much the same results as having the entire tank filled with oil. Several gas companies have stated that this practice gives satisfactory results.

V. GAS-METERING INSTRUMENTS

1. POSITIVE DISPLACEMENT METERS

(a) DRY GAS METERS

The positive displacement dry meter is the only type of gas meter used in this country for measuring gas to domestic consumers, and it is also generally used for measuring gas to industrial consumers using less than 17,000 cubic feet of gas per hour. In cases where the consumption is greater than this meters are often set in batteries; that is, two or more in parallel. Figures 10, 11, 12, and 13 illustrate some of the common types of dry meters, these being made in appropriate sizes for measuring volumes varying from about 50 cubic feet per hour up to about 17,000 cubic feet per hour. While the details of construction and the mechanical features of valve design and operation are different in the various makes they are all based upon the application of the same general principle, namely, that of alternately filling and emptying chambers which have movable walls, the movement of the wall being so regulated that the cubical displacement on successive cycles is the same.

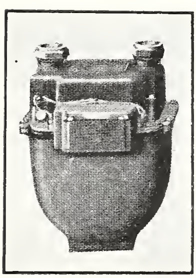

Fig. 12.—*An iron-case dry gas meter*

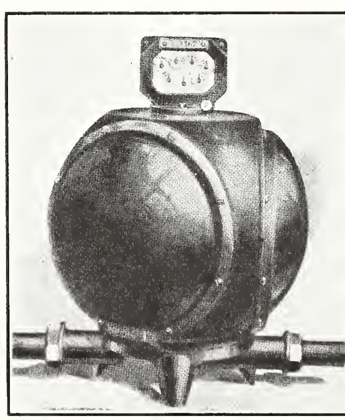

Fig. 13.—*An iron-case meter with three diaphragms known as a "Tobey" meter*

(1) Tin-Case Meters.—Figures 14 and 15 illustrate the construction of a typical tin-case meter. Four measuring chambers (*1*, *2*, *3*, and *4*, fig. 16) are formed by the bellows *a* and *b* with the central partition *c* and the meter case. Flags *d*, which are soldered rigidly to the flag wires *e*, are connected to the center of the bellows by hinge joints. This permits the back-and-forth motion of the bellows disks to be transmitted by the flag wires *e*, through the stuffing boxes *f*, to the long flag arms *g*, which in turn are linked to the tangent *i* by the

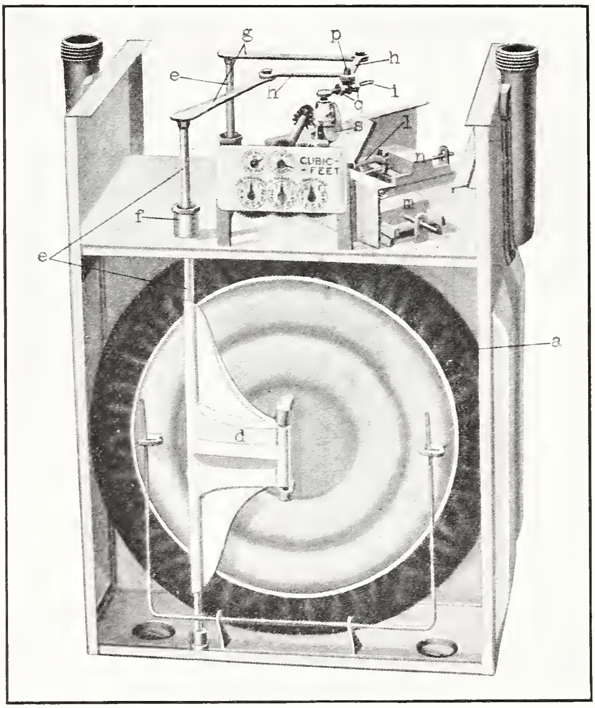

Fig. 14.—*The interior of a tin-case dry gas meter, front view*

short flag arms *h* and the tangent post or wrist *p*. The tangent is attached at right angles to the top of the crank *k*, which operates the valves *m* and *n* through the valve arms *l*. Valve *m* provides communication for chambers *1* and *2* (fig. 16) with the inlet and outlet, while valve *n* provides like communication for chambers *3* and *4* (fig. 16). The worm *j*, mounted on the crank near the upper end, drives the recording mechanism. The upper bearing for the crank is in one end of the cross arm of the crank stand or king post *r*, the other end of the cross arm carries a pawl or "click" *s*, the purpose of which is to prevent a backward motion of the tangent and thus to prevent a reverse flow of gas through the meter.

The cycle of operations is clearly illustrated by Figures 16, 17, 18, and 19 and needs no further explanation. The mechanism described in the preceding paragraph is adjusted so as to bring the valves into correct position for allowing the gas to enter or leave the chambers in the sequence illustrated.

Adjustment of the volume passed during a complete cycle is made by moving the tangent post *p* out or in along the tangent *i*. The tangent post is held in any desired position on the tangent by the nuts *q*. Moving the tangent post out along the tangent permits a greater movement of the flag arms *g*, and, therefore, of the bellows, thus increasing the volume of gas passed by the meter in a complete cycle, or for each revolution of the tangent, which is the usual way of expressing it. Similarly, moving the tangent post in toward the crank will decrease the volume of gas passed by the meter per revolution of the tangent.

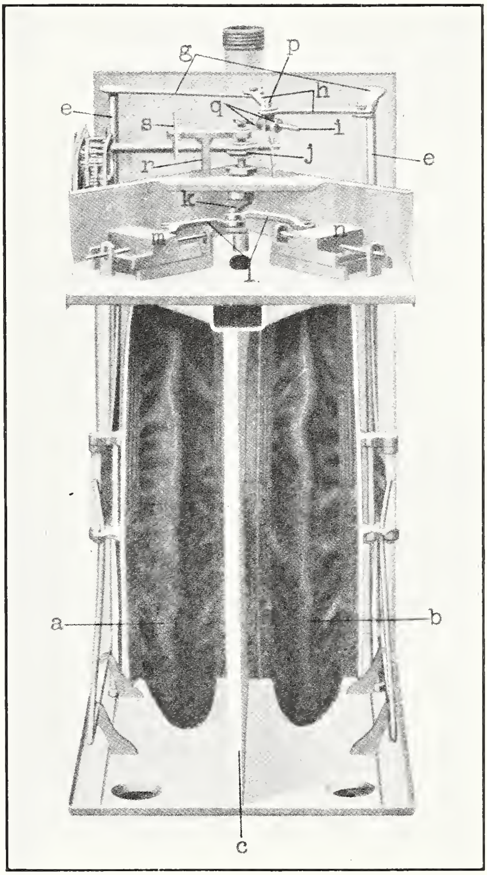

Fig. 15.—*The interior of a tin-case dry gas meter from the side*

The construction and operation of the tin-case meter is probably as simple as that of any dry meter. Except in the development of details no changes have been made in the essential features of the design of this type of meter since it was first brought out in 1843.[5] In the metering of gas to domestic and even to fairly large commercial customers the number of tin-case meters used in this country far exceeds that of all other types combined and is constantly in-

[5] See Appendix A of "The Romance of the Gas Industry," by O. E. Norman.

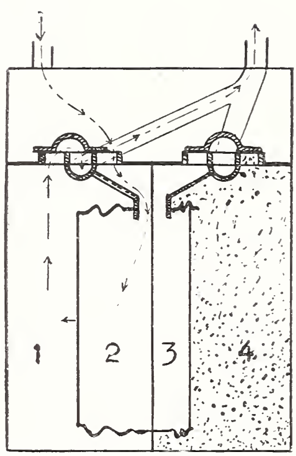

Fig. 16.—*Compartment 1 is emptying, 2 is filling, 3 is empty, and 4 has just filled*

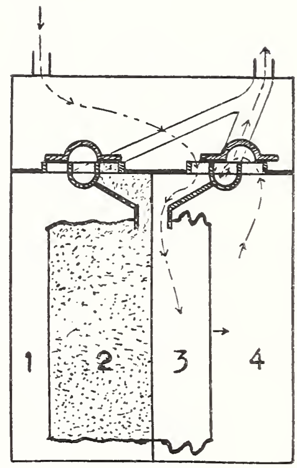

Fig. 17.—*1 is now empty, 2 is full, 3 is filling, and 4 is emptying*

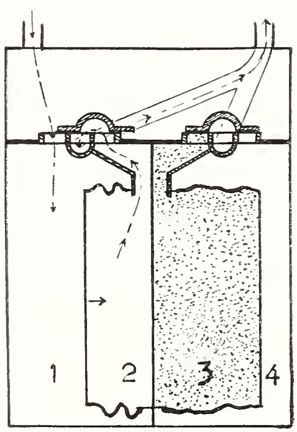

Fig. 18.—*Compartment 1 is filling, 2 emptying, 3 has filled, and 4 has emptied*

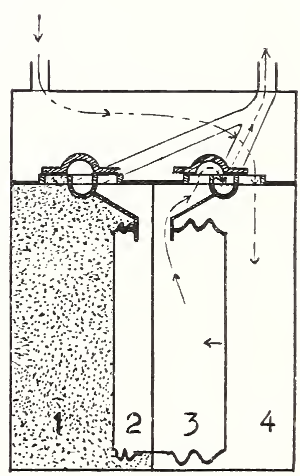

Fig. 19.—*Compartment 1 is now completely filled, 2 is empty, 3 is emptying, and 4 is filling*

Figures 16 to 19 show the four stages in a complete cycle of a tin-case dry gas meter.

creasing. To meet the great variety of needs there have been many different sizes developed. In recent years some attempts have been made to reduce the number of these sizes and to establish certain standards, but to date (1926) very little has been accomplished in this direction.

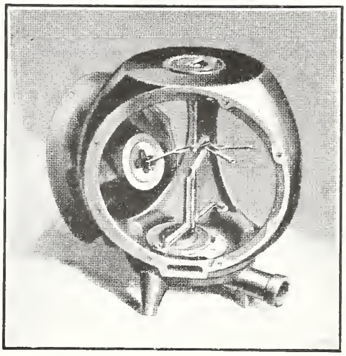

Fig. 20.—*Interior of a "Tobey" meter*

(2) Iron-Case Meters.—The construction of some typical iron-case meters is shown by Figures 11, 12, and 13. As indicated by the name, the case of these meters is made of cast iron. The interior mechanism of a meter like that of Figure 12 is very similar to that of a tin-case meter, as may be seen from Figure 21, which shows the interior of another iron-case meter which is similar in construction to that shown in Figure 12. The interior construction of two other iron-case meters is shown by Figures 20 and 22, and while these differ from that of the meters previously described it is hardly necessary to describe them in detail.

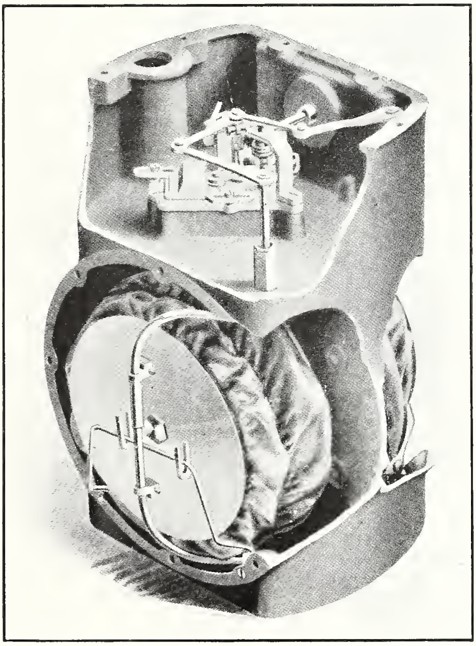

Fig. 21.—*Interior of an iron-case dry gas meter*

The use of iron-case meters came about very largely in conjunction with the development of natural gas. In most districts where natural gas was first supplied the service pressures were much higher than those common to manufactured gas and it was thought that the tin-case meters could not withstand these higher pressures. That this belief was well founded is questionable and the question of the pressure being too high for a tin-case meter is seldom raised now. However, it was found that in many districts using natural gas the construction of the houses was such as to make it necessary to place the meters outdoors and the iron-case

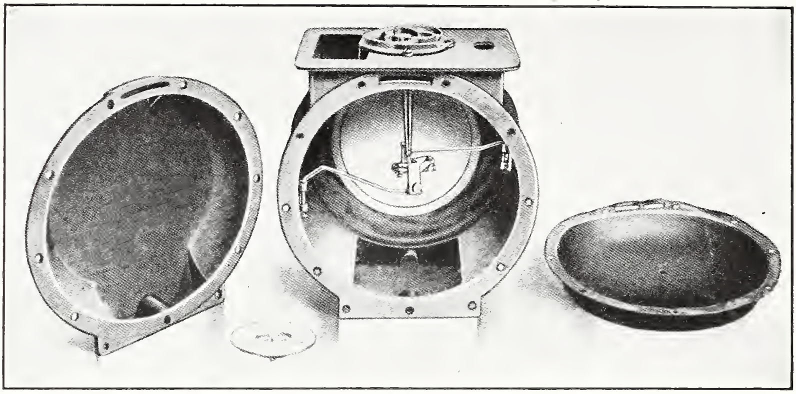

FIG. 22.—*Interior of an iron-case gas meter such as shown in Figure 11*

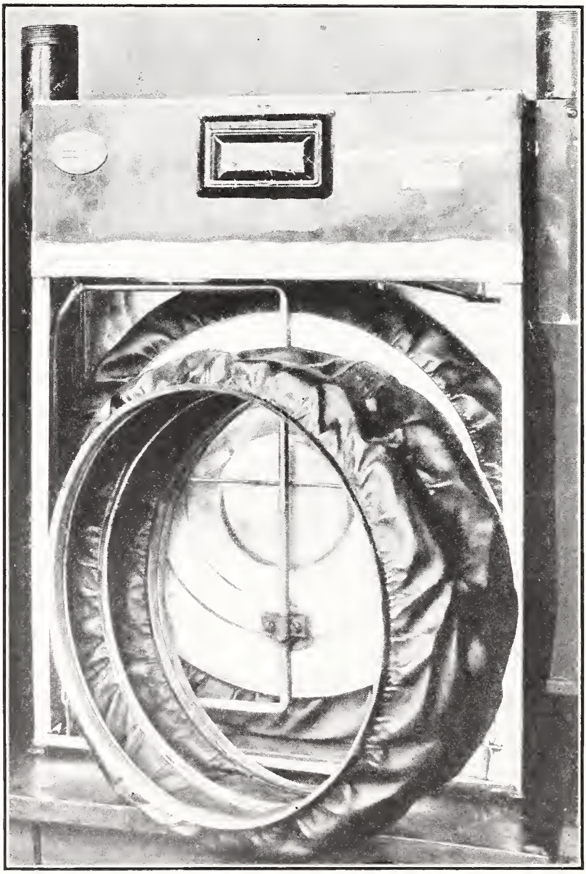

FIG. 23.—*A double diaphragm meter with the front removed*

A double diaphragm is shown in front of the meter.

meter seemed to withstand this exposure better than the tin-case meter. Moreover, it has been claimed that the iron-case meter is more easily and quickly repaired than the tin case. These two points are of considerable importance to companies distributing natural gas at a low rate of cost to consumers, a large portion of whom are in small towns and rural districts.

(3) Double Diaphragm Dry Meters.[6]—With the growth of industrial uses of gas it became desirable to have a meter of greater capacity than any of the older types and at the same time not excessively large. To meet this need the double-diaphragm meter was developed. The important feature of this meter, illustrated by Figures 23 and 24, is that of having two diaphragms placed in

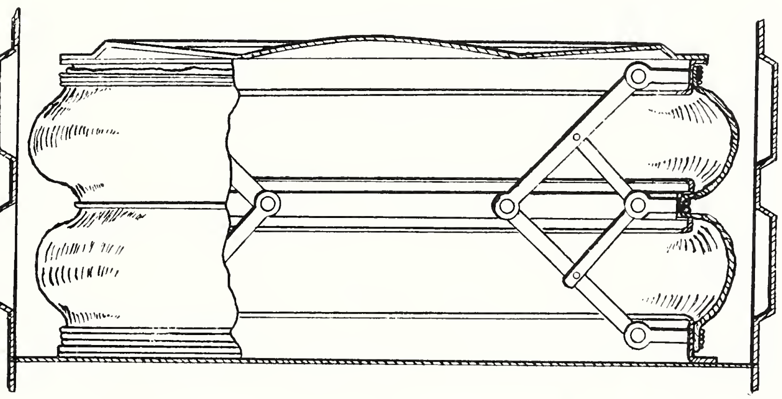

Fig. 24.—*Interior of a double diaphragm dry gas meter*

The toggle link connections to the diaphragm rings insures equal movement of each diaphragm leather.

tandem on each side of the central partition instead of one. As shown by Figure 24, the stationary and two movable diaphragm rings are so linked together that the two diaphragm or bellows sections will expand and contract equally, thereby preventing binding and uneven wear of the diaphragm leathers. The displacement for each filling or emptying of the bellows is nearly twice that of a meter with a single diaphragm of the same size. To accommodate this greater movement of the diaphragm disks it was necessary to increase the thickness of the meter case a small amount over that of the ordinary meter having a single diaphragm of the same size. Also some departures were necessary from the ordinary design of flags, flag wires, and flag-arm linkage.

[6] For further description see U. S. Patent Office Papers No. 1431122 and No. 1506313.

(4) Testing Small-Capacity Dry Meters.[7]—The procedure for testing a small-capacity dry meter is essentially as follows:

Connect the meter to the prover hose with a coupling of the proper size. With the prover valve leading to the meter closed fill the prover with air through the circular slide valve, then pass 1 or 2 cubic feet of air through the meter to insure that it is working properly. Test for tightness of the connections and the soundness of the meter by closing the meter outlet with the hand and opening the prover valve so that the full pressure of the prover is on the meter and connections. With the outlet still closed close the prover valve and watch the pressure gauge. If the pressure falls, there is a leak either in the connections or in meter itself that must be stopped before the test is made. If the leak is in the meter itself, the meter is rejected as unsound without a test for accuracy (unless it is a complaint meter).

Place the proper outlet cap on the meter to allow air to pass at 6 cubic feet per hour per rated light capacity or about one-fifth of its rated capacity.[8]

By manipulation of the prover outlet valve pass air through the meter until the hand of the test dial is brought exactly to one of the division lines of the dial. It is always well to bring the test hand to the same mark on all meters so that there will be no chance for confusion as to which mark was selected for any one test. The mark selected should be such that the test hand stands nearly in a horizontal position and preferably when on the up swing. Adjust the prover by raising it above the zero mark and allowing air to escape through the circular slide valve until it is exactly on zero. Open the connection to the meter and allow air to pass until exactly one revolution of the test hand has occurred. Usually this requires 2, 5, or 10 cubic feet of air, depending on the size of the meter.

Record the reading of the meter prover to the nearest one one-hundredth cubic foot, and from this calculate the correction [9] to the meter by the formula

$$\frac{(\text{prover reading}-\text{meter reading})}{\text{meter reading}}\times 100=\text{correction in per cent of meter reading.}$$

This formula gives the correction, in per cent of the meter's reading, which is to be added to or subtracted from the meter's reading in order to obtain the correct volume passed. The prover scale is so graduated that the percentage correction may be figured mentally from the prover readings without the use of tables.

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[7] A very extensive discussion of gas meter testing is given in the report of the 1920 Consumers' Meters Committee of the American Gas Association. See proceedings of second annual convention A. G. A., technical section.

[8] See Section IX for method adopted by the A. G. A. as standard for badging and capacity testing of meters.

[9] See Section IX, (*c*) for discussion on the computing of meter corrections and errors.

If the meter is not over 1 per cent fast or slow it may be passed on this one test. If it is in error by more than 1 per cent it is better to make a second test and to take the average of the two results as the correction for the meter. If the two results do not agree within 0.5 per cent a third test should be made and the average of the three results taken as the correction for the meter, or one result discarded if obviously in error.

If the meter is found to be within 2 per cent fast or slow[10] it is customary to consider it "correct" for commercial purposes. Many companies do not like to set meters that are more than 1 per cent fast or slow. Meters can readily be adjusted to be within 0.5 per cent to 1 per cent fast or slow; and whenever new, repaired, or adjusted meters are submitted to a check test, they should, in general, be correct within such limits or be made so before being put into service, even though a tolerance of 2 per cent may be allowed.

Gas meters are ordinarily tested at the open pipe and check rates. The open-pipe rate is self-evident from its name. The check rate is 6 cubic feet per hour per rared light capacity or per size number of the meter. When it is desired to test a meter at a rate other than these such special test may be made in a manner similar to that described for the regular test by using the necessary sized cap on the outlet to give the desired rate.

The practice of testing meters at other than the normal rate varies in different localities. In some cases methods are prescribed by municipal or State commissions, while in others the gas company adopts a procedure that seems reasonable to them. However, it is recommended that before a meter is placed in "O. K." stock for setting it should be tested at both the check and open pipe rates. If it is correct within the prescribed limits at both of these rates one is reasonably sure that the meter will register correctly at any rate.

For testing a meter to ascertain whether it will register small flows of gas it is customary to connect it to a burner consuming about one-half a cubic foot of gas or less per hour. By running it with such a burner for 15 to 20 minutes a meter that does not register at such a rate is easily detected by the failure of the test hand to move.

There are certain precautions and procedures that should be observed in all meter-testing work.

The meters should stand in the prover room a sufficient length of time before they are tested to insure that they have the same temperature as the prover. Ordinarily this will require about two hours, although some rules require that the meters be in the vicinity of the prover for at least five hours before being tested.

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[10] There is some variation in the tolerance allowed gas meters in different localities, but 2 per cent fast or slow is about an average. For a tabulation of regulations regarding gas-meter tolerances, see B. S. Cir., No. 32, "Standards for Gas Service."

The temperatures of the room and the water in the prover should not differ by more than 2° F. The thermometers used to check these temperatures should be occasionally compared, for example, by placing them both in a beaker of water to determine that they read the same when at the same temperature. Readings of the room and water temperature should be taken frequently during testing, not less often than once an hour.

When testing the meter for accuracy of registration both the open pipe and check rates should be used. As previously described the method of adjusting the volume passed per cycle by a meter to obtain correct registration is by shifting the position of the tangent post on the tangent. For a meter that tests "fast" the tangent post is moved outward along the tangent and inward for a "slow" meter. As finally adjusted the difference in the accuracy of the meter at the open and checked rates should not be more than 1 per cent. The adjustment to secure this is as follows: If at first the quantity passed by the meter as read on the prover scale is less for the open pipe than for the check rate shift the tangent on the crank in the direction in which it normally turns. This will make the time of cut-off by the valve later with respect to the position of the diaphragm. If the opposite condition is found shift the tangent on the crank in the opposite direction to that in which it normally turns, thus making the time of cut-off earlier. In addition to making this adjustment it will probably be necessary to readjust the position of the tangent post on the tangent to secure correct registration.[11]

It is customary to test under a prover pressure of 1.5 inches of water. As rate caps are made for use at this pressure there is considerable advantage in adhering to this pressure.

When a number of consecutive tests, in which air is used as the test medium, are made upon a meter that has been in service for some time it is often noticed that the later tests indicate that the meter is much faster than was indicated by the first tests. The difference between successive tests may be as much as 1 per cent. The cause for this is probably as follows: The gas that passed through the meter while it was in service saturated the diaphragms with light and volatile oils often spoken of as "meter condensates," and since the gas (that is, manufactured gas) is ordinarily more or less saturated with these oils, it had no tendency to reabsorb them. But if air is brought into contact with the diaphragms the evaporation of the oils immediately commences with the result that the diaphragms become hard and stiff and the measuring chambers formed by them

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[11] For a more detailed discussion of meter adjusting and a discussion of the cause of differences in the check and open pipe tests, see report of 1920 Consumers' Meters Committee of American Gas Association in report of technical section of second annual convention of A. G. A.

will not have the same capacity as before, but will usually be decreased in volume since the air can not by its small excess of pressure over atmospheric pressure smooth out the diaphragms as it did when they were soft and pliable. For this reason the first test of such a meter with air probably gives results applicable to the conditions of former use. For this reason the screws of all meters should be capped as soon as the meters are removed from service at the customers' premises.

A committee of the American Gas Institute made an investigation [12] to determine the relative values of different proving mediums, principally air, air saturated with meter condensate, gas, gas saturated with meter condensate, and gas saturated with benzol. The results of the investigation as shown by a comparison of successive tests on meters in which the same proving medium was used, indicate:

1. That the least variation between successive tests is obtained by using gas saturated with the meter condensates, followed in order by gas saturated with water vapor, air saturated with meter condensates, gas saturated with benzol vapor, gas direct from lines, air with saturated water vapor, and air direct fom the room.

2. That the error due to the vaporization of condensates from the meter and water from the prover is least when gas saturated with condensate vapor is used as the proving medium, and largest when air from the proving room is used.

3. By the use of gas or gas saturated with condensate vapor as the proving medium the injurious effects of air on the interior of meters that have been in service is avoided. It also prevents the occurrence of an explosive mixture of gas and air in the meter.

The use of gas in proving meters offers no particularly objectionable feature if proper ventilation is provided.

When air is used for proving new meters it is preferable that it be saturated with water vapor, or, better, with the vapors of meter condensates.

(*a*) *Special precautions to be observed in testing complaint meters.*—Whether tested by the gas company or by public officials, complaint meters should be tested in the conditions "as received" from the customer's premises, and as soon after being removed as possible, giving due attention to securing temperature uniformity. Whenever possible it would be desirable to make these tests with the same medium (that is, gas) that was passing through the meter when in service. Since subsequent tests may not agree with the first, for reasons pointed out in a preceding paragraph, it is recom-

[12] Proc. Amer. Gas Inst., 7, p. 657; 1912.

mended that the results of only the first test be used as a basis for the settlement of any claim for a refund or additional charges.[13]

(5) Testing Large-Capacity Dry Meters.—Large-capacity dry meters may be tested in a manner similar to that described for the small meters, though, of course, one should have a prover of sufficient capacity to produce at least one revolution of the test hand of the meter.

A method that is sometimes used, particularly in natural gas distribution systems, for testing dry meters of large capacity without removing them from their service position is by comparing the meter with a so-called "flow meter," or "funnel meter." In order thus to test a meter in the field it is necessary to have a by-pass around the meter so as not to interrupt the gas service while testing the meter. It is also necessary to have a T placed between the meter outlet and the outlet valve, the offset of the T being capped except when the meter is being tested. When testing the meter this offset cap is removed and the flow meter connected to the offset. With the outlet valve closed the inlet valve is opened slowly and to such positions as to allow gas to pass through the meter under test and the flow meter at the rates desired for testing. The theory and use of the flow meter is discussed under its appropriate heading on a later page.

(6) Accuracy and Testing Requirements.—While it is possible to adjust a dry meter so that it is correct within 0.5 per cent or less, it is hardly practicable in commercial practice to adjust all meters to this degree of accuracy before they are placed in service. It is, however, very easy to adjust all meters that are in good repair to within 1 per cent of correct, and this is usually done by the gas companies of to-day. In many localities there is a legal requirement to this effect. Of course, it is understood that the allowance of 1 per cent variation from correctness does not mean that all meters shall be set in error by this amount; this tolerance of 1 per cent is simply to allow for the unavoidable irregularities of adjusting meters on a commercial scale, and the average of the errors should be practically zero since substantially as many should be slightly slow as are slightly fast.

While a meter should be set to be correct within close limits before being installed, it can not be expected to retain this degree of accuracy indefinitely. In nearly all localities there are either State or municipal regulations specifying the error a gas meter may have before it shall be classed as "incorrect," and in some cases also there is specified the error a meter shall have before the consumer or com-

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[13] For a further discussion of these tests see "Tests on Request of Consumer" and "Adjustment of Bills for Meter Errors" in B. S. Cir., No. 32, Standards of Gas Service.

pany is entitled to an adjustment of charges. On the average these regulations permit the meter to be in error either way by 2 per cent and frequently an error of 3 per cent is required before an adjustment of charges can be obtained.

It is the practice of gas companies, and, in fact, most State or municipal regulations require gas companies to remove meters from service and test them at regular intervals. The experience of many companies and of State and city officials would seem to indicate that once in five years is approximately the right interval to specify for this periodic testing. If too frequent tests are required the expense is excessive; on the other hand, if too long an interval is allowed the number of meters in error by appreciable percentages becomes too great.[14]

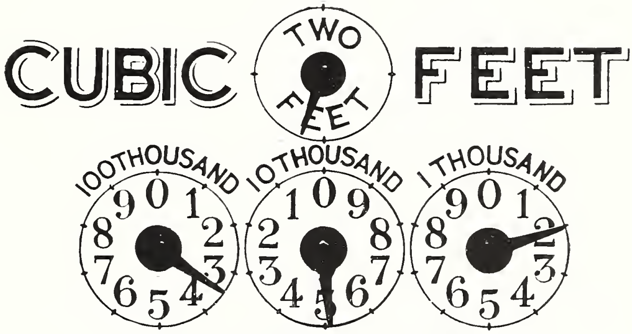

Fig. 25.—*The index of a gas meter*

Each dial is marked with the volume of gas passed per revolution. The smaller top dial, which is marked "Two Feet" inside of the circle, is generally called the "testing circle" or "proving head" and is used principally in testing the meter.

(7) Uses of Dry Meters.—Undoubtedly the largest and most familiar field of use for dry meters is in measuring gas to domestic and small industrial consumers. As the capacities of the dry meters now on the market range up to 17,000 cubic feet of gas per hour the variety and size of industrial users of gas who may be supplied through these meters is much larger than is popularly believed.

Some of the iron-case dry meters are made to withstand rather high pressures, perhaps, 300 to 500 lbs./in.^{2}, and are particularly intended for use in some natural gas fields where such pressures are encountered. In many fields the larger sizes of these meters are used as town border meters.

(8) Gas Meter Index and How to Read It.—Figure 25 illustrates the index of an ordinary gas meter, which is similar to that of an electric meter or a wattmeter. The smaller top dial, which is marked

[14] For a tabulation of the meter testing requirements of several States and cities, see B. S. Cir. No. 32, 4th ed., p. 109.

"Two feet" inside of the circle, is called the "testing circle" or "proving head," and is used principally in testing the meter. One revolution of the hand of the testing circle indicates that 2 cubic feet of gas have passed through the meter. In some meters one revolution of the hand of the testing circle represents more or less than 2 cubic feet of gas, and the testing circles are correspondingly marked. The indication of the hand of the testing circle is ignored in the ordinary reading of the meter.

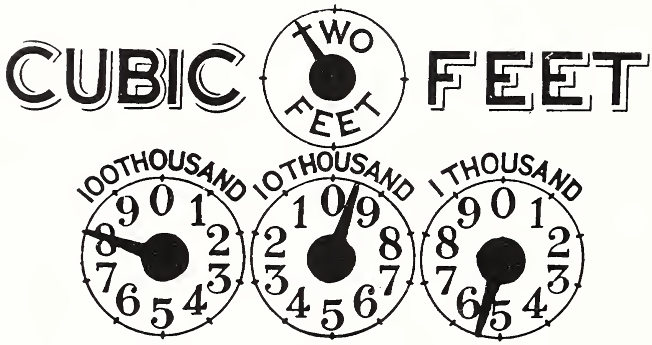

Fig. 26.—*Gas meter index reading 79,500 cubic feet*

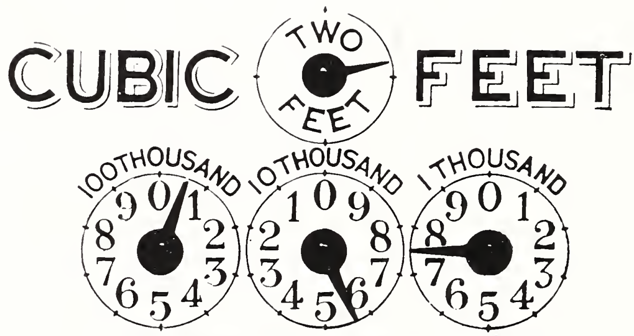

Fig. 27.—*Gas meter index reading 5,700 cubic feet*

Of the large dials, the first at the right is usually marked "1 thousand." This means that during one complete revolution of the hand 1,000 cubic feet of gas have passed through the meter. This dial is divided into 10 equal parts, so that the passage of the hand over each part indicates the passage of one-tenth of 1,000 cubic feet, or 100 cubic feet. For most meters it may be said of the other dials that the complete revolution of the hand indicates the passage of ten times as much gas as one revolution of the hand of the dial of next lower denomination (usually the one to the right). The figure representing the number of cubic feet discharged during one revolution of each hand is written over the respective dials.

Thus if the first dial is marked "1 thousand," the second dial will be marked "10 thousand," the third "100 thousand," and so on.

The reading of the index, as illustrated in Figure 25, is as follows:

	Cubic feet
Reading of "1 thousand" dial	200
Reading of "10 thousand" dial	5,000
Reading of "100 thousand" dial	30,000
Complete reading of meter	35,200

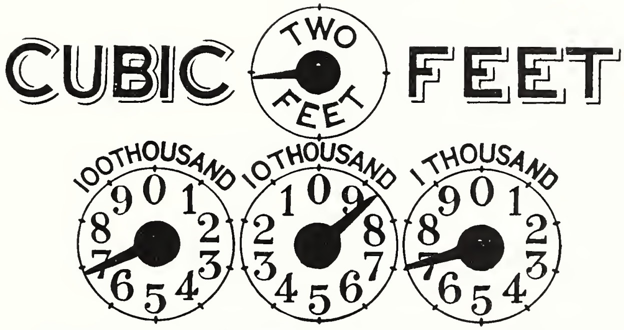

FIG. 28.—*Gas meter index reading 68,700 cubic feet*

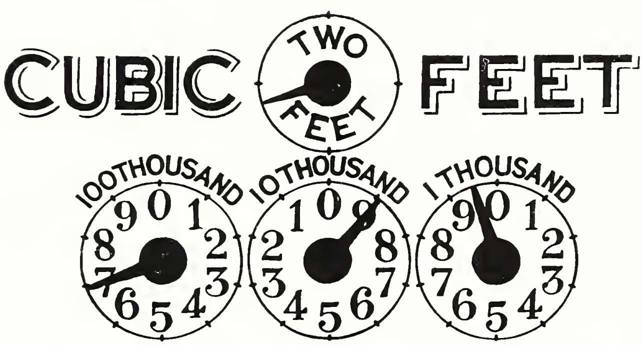

FIG. 29.—*Gas meter index reading 68,900 cubic feet*

It is not necessary to write down separately the reading of each dial, but it is much shorter to set down from right to left the figure last passed over by the hand of each dial, commencing with the dial of lowest denomination and then (if the dial of lowest denomination is marked "1 thousand") appending two zeros to the resulting figures. To illustrate further the method of reading meters illustrations of several settings of a meter index are given with the correct readings in Figures 25 to 29, inclusive.

If a hand is very nearly over one of the figures on a dial, it is impossible to tell without consulting the dial of next lower denomination whether the figure under the hand or that just previously passed by the hand should be read. For example, in Figure 26 the hand of the "100 thousand" dial is over 8, and considering that dial alone the reading might be taken as 8; but it is seen that the reading of the "100 thousand" dial can not be 8, since the hand of the dial to the right (the "10 thousand" dial) has not reached zero. The reading of the "100 thousand" dial is therefore 7, and the correct reading of the entire index is 79,500 cubic feet.

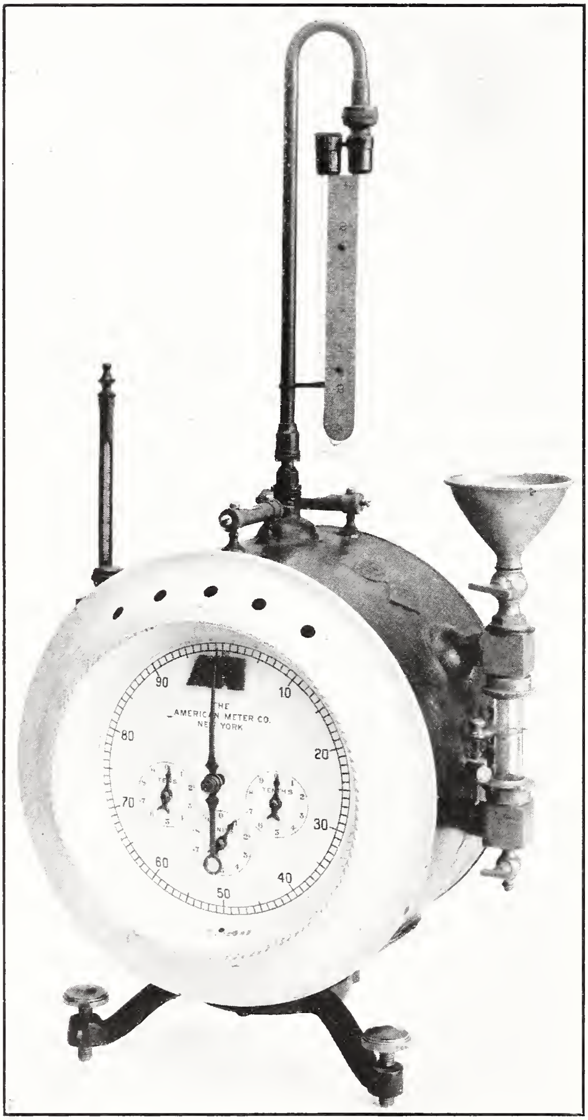

FIG. 30.—*A laboratory wet gas meter*

This meter will measure small flows of gas with a high degree of accuracy.

When reading a meter index it is important to notice that the hands do not all revolve in the same direction as is indicated by the direction in which the numbers on the dials read. In Figures 25 to 29 the numbers on the right hand or "1 thousand" dial read in a clockwise direction, the direction in which that hand rotates. On the middle or "10 thousand" dial the numbers read and the hand rotates in a counterclockwise direction. With the third or "100 thousand" dial the direction in which the numbers read and the hand rotates is again clockwise. If there were a fourth or "1 million" dial the direction would be counterclockwise, and so on.

It is of interest to note that in recent years attempts have been made to adapt a direct reading index similar to that of a revolution counter or the total mileage index of a speedometer to gas meters. These attempts have resulted in the development of direct reading indexes which are probably satisfactory from a mechanical standpoint, but as yet the cost of making such direct reading indexes is

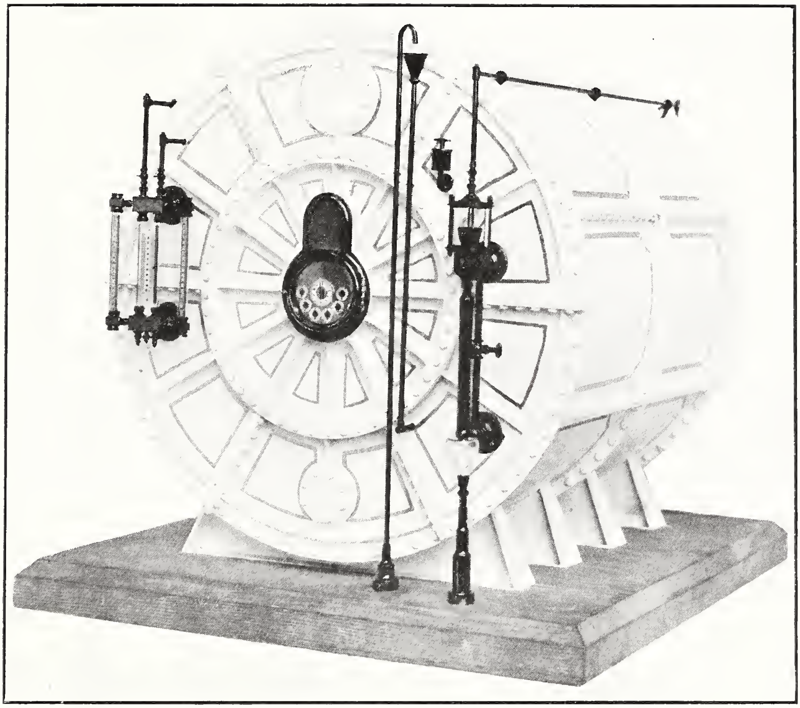

Fig. 31.—*A wet station meter*

more than that of the clock dial index. This difference in cost may be reduced in time so that the direct reading index may come into common use.

(b) WET GAS METERS

Figures 30 and 31 illustrate two sizes of wet meters. The principal features of construction, indicated by Figures 32 and 33, comprise an exterior casing and a rotating drum. The drum is usually divided into four compartments, of approximately helical form, by suitable partitions. A fifth compartment is formed at the rear end of the drum by a hood or convex partition attached to the circumference of the rear head and having a central opening larger than the shaft. This forms the inlet compartment or dry well. Each measuring compartment has an opening on both the front and the rear heads. These openings are nearly radial and are placed with an angle of about 160° between them. The surface of the water must be sufficiently high to seal the opening of the inlet chamber and also momentarily to seal off both openings of a measuring compartment when it is at its highest point. This usually requires that about two-thirds of the measuring drum be submerged.

The cycle of operations illustrated by the series of Figures 34, 35, and 36 is as follows: Start with one of the measuring compartments at its lowest position when it is full of water and both openings are under water. As the drum revolves the opening in the rear of the compartment emerges allowing the gas in the inlet chamber to enter the measuring compartment until it becomes filled with gas. Before the opening in the front of the compartment emerges from the water the one at the back is submerged, thus closing off momentarily a certain volume of gas. The opening at the front then emerges and the gas escapes into the outer casing as the drum continues to revolve and again submerges the compartment. The gas leaves the meter casing through the outlet connection. The rotation of the drum is produced by the greater pressure of the gas on the inlet side, over that on the outlet side, against the inclined partition walls of the compartments.

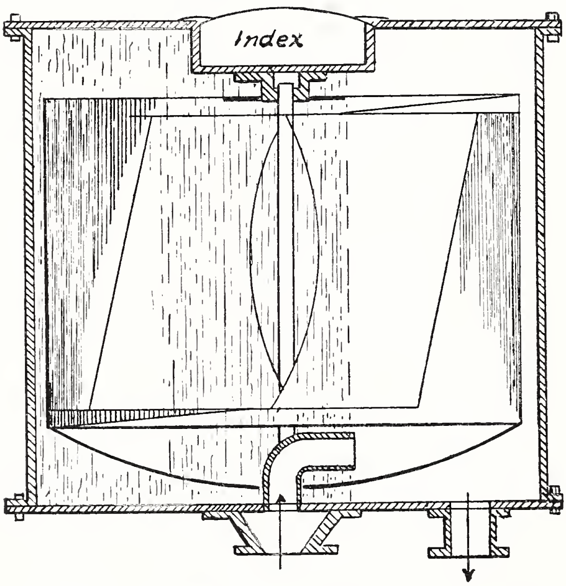

FIG. 32.—*Longitudinal cross section of a wet gas meter*

During each revolution each compartment delivers the amount of gas it contained at the instant it was sealed off, an amount which will evidently depend on the height of the water surface. It is thus evident that the accuracy of the meter is dependent upon the position of the water surface and that the adjustment of the water sur-

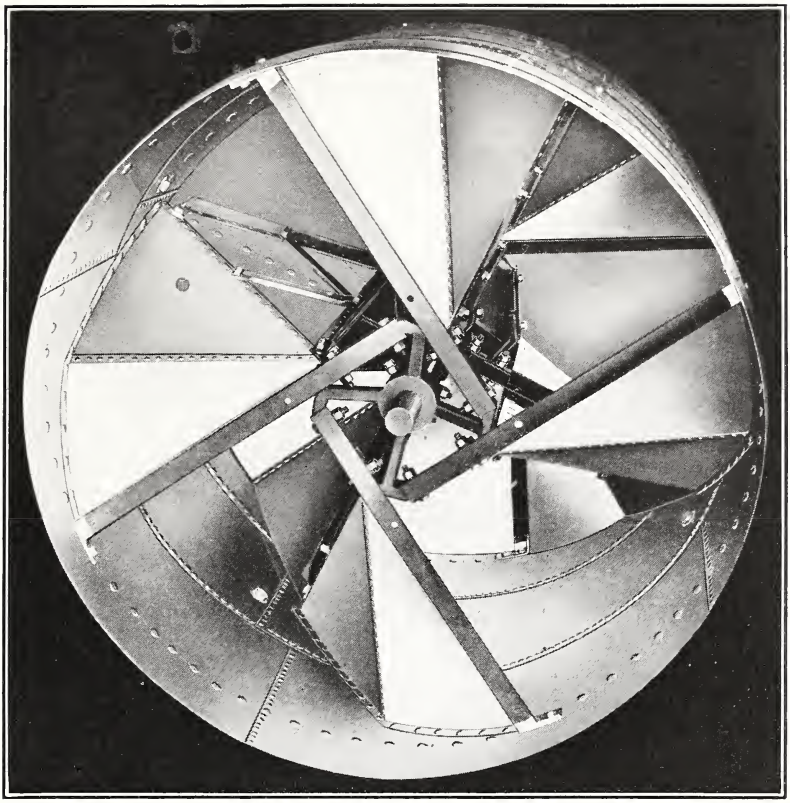

Fig. 33.—*Drum of a large wet station meter showing the method of fastening and bracing the partitions*

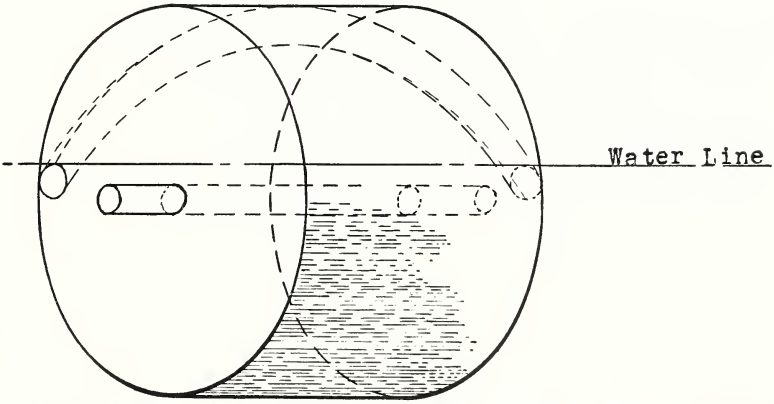

Fig. 34.—*Schematic representation of a measuring compartment of a wet gas meter*

The tube fastened in a spiral about the inner wall of the drum represents a measuring compartment, and with each revolution of the drum a tube full of gas is measured out. If we imagine three more such tubes fastened within the drum and then have these tubes expand until their walls meet, we have the essentials of a drum of a wet gas meter.

face should be carefully made. It should also be noted that because of practical difficulties in construction the capacity of the several compartments will not, in general, be equal, hence the use of fractional revolutions should be avoided, particularly in the use of small

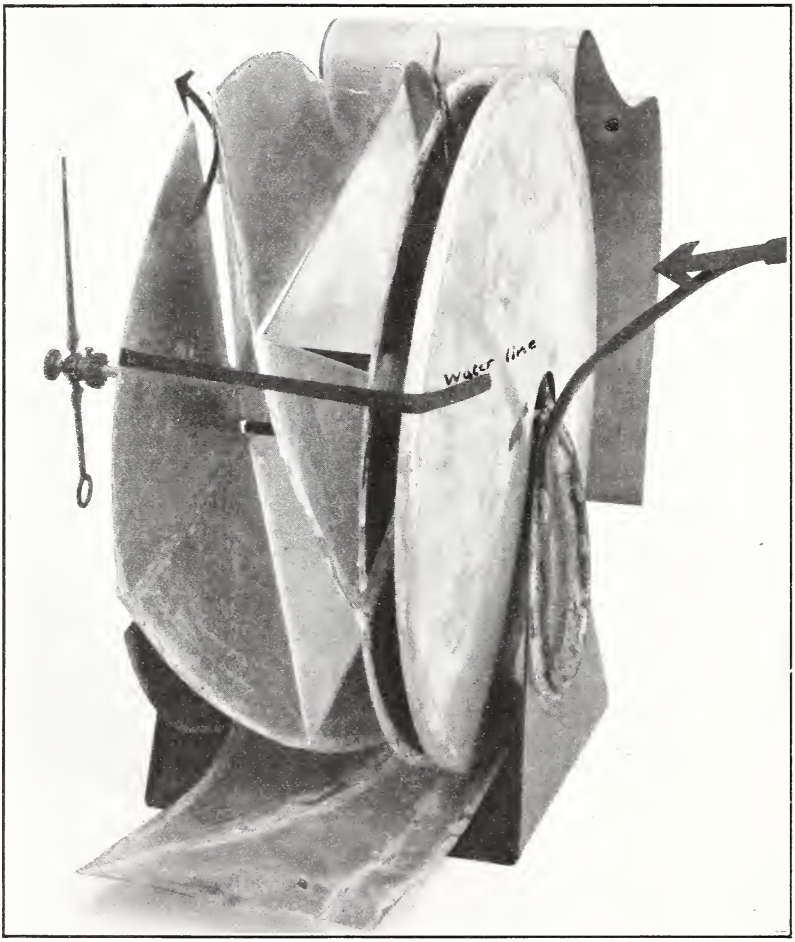

FIG. 35.—*Drum of a laboratory wet gas meter*

This view shows the front and back openings of the measuring compartments. The direction of rotation of the drum is counterclockwise as viewed from this position. The arrows indicate the direction of gas flow and the band above the center represents the water line.

test meters where considerable accuracy is desired. In the case of large station meters an overflow trap is usually built into the water level gauge and the top of this water gauge is connected to the inlet of the meter, thus providing that the pressure above the water in this gauge is the same (or very nearly so) as the pressure of the gas within the drum. By continually admitting a small quantity of water to the meter whenever it is in operation the water can be made to drip continually at the overflow, and in this way it is as-

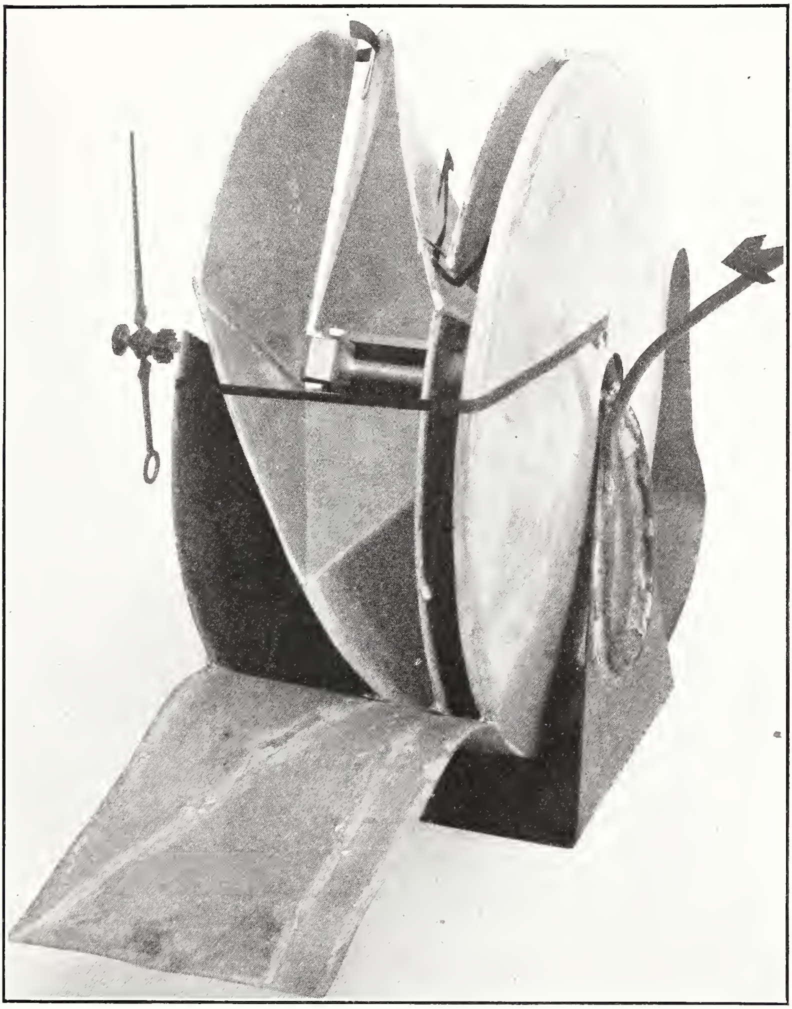

FIG. 36.—*Drum of a laboratory wet gas meter*

As here shown the drum has been rotated through an angle of about 45° from the position shown in Figure 35. Viewed from the side and rear of the drum.

sured that the height of the water surface within the drum remains practically constant, so that the drum will discharge equal quantities of gas for each revolution. It is particularly important in the use of both large and small wet meters to have the meter case level so that the axis of the drum will be parallel to the water surface.

(1) Testing Wet Meters, Small Size.—The testing of small wet meters is usually performed with a cubic-foot or fractional cubic-foot bottle. For a one-tenth cubic-foot meter a one-tenth cubic-foot bottle is used. The generally approved procedure for testing a laboratory wet gas meter with a fractional cubic-foot bottle of the moving-tank cabinet type is as follows: The meter inlet is connected to one of the outlet nipples of the 3-way cock on top of the bottle (see fig. 3) and all connections inspected for leaks. Starting with the reservoir on the lower shelf and normally full of water, lift it from the shelf and hold it 2 inches or so below the shelf so as to draw the water in the lower gauge glass of the bottle well down below the lower gauge mark. Close the reservoir outlet cock and replace the reservoir on the lower shelf. With the 3-way cock turned so as to connect the bottle with the meter, open the reservoir cock and see if the water will rise in the lower gauge glass, against the back pressure of the meter, until the bottom of the water meniscus is in the plane of the top of the gauge mark. If it does not, adjust the position of the lower shelf and repeat this process until this condition is obtained. Then place the reservoir on the top shelf and by a similar procedure adjust the position of this shelf so that, when flowing against the back pressure of the meter, the water will rise in the upper gauge glass until the bottom of the water meniscus is in the plane of the top of the gauge mark. Now turn the 3-way cock so as to open the bottle to the air, and placing the reservoir on the lower shelf draw the water from the bottle into the reservoir and thereby draw air into the bottle, preferably through water so as to insure that it is saturated with water vapor. To start the test hold the reservoir, as before, a little below the lower shelf so as to draw the water well below the lower gauge mark, close the reservoir cock, and replace the reservoir on the lower shelf. Turn the 3-way cock so as to connect the bottle with the meter and then open the reservoir cock. When the water in the lower gauge glass has come to rest (with the bottom of the meniscus in the plane of the top of the gauge mark) read the meter and then carefully place the reservoir on the upper shelf. When the water has filled the bottle to the upper gauge mark exactly one-tenth cubic-foot of air (or some other definite amount, depending upon the capacity of the bottle) will have been passed to the meter. The correction to the meter is equal to the capacity of the standard minus the indication of the meter.

If the purpose of the test is to determine the accuracy of the meter, one or more such trials may be sufficient. If, however, the object of the test is to determine the correct position of the water surface in the meter it may be necessary to repeat the test many times, changing the quantity of water in the meter until it registers correctly, or at least within 0.5 per cent.[15]

During such a test care should be taken to maintain a nearly constant temperature in the room and to have the temperature of the water in the meter and bottle as nearly room temperature as is practical. There should be no difficulty in getting the temperatures to agree to within less than 1° F. Also, in order to avoid changes in volume due to absorption of water vapor by the air after leaving the bottle provision should be made to insure that the air is thoroughly saturated with water vapor before it enters the system. This may be done by passing the air through water before it enters the bottle, or meter.

(2) Test of Large Wet Meters.—The test of a wet station meter should be made with a wet-test meter which has been carefully tested and proved to be correct at a given rate of speed. The meters should be so connected that the gas will pass first through the test meter and then the station meter. The main inlet and outlet valves of the station meter should be tightly closed, and if possible sealed with water. The supply of gas should be from a source having the least possible variation in pressure.

Pressure gauges should be fixed so as to show the inlet and outlet pressure on both the test meter and station meter, observation of which will indicate any undue resistance in either meter and will also furnish a basis for any necessary corrections in the test on account of the drop in pressure between the two meters. Thermometers should be placed so as to show the temperature of the gas at the inlet and outlet of each meter.

The station meter and testing connections should be tested for leaks before beginning the test of the station meter. This may be made by a shut-in test similar to that used when testing small meters with a prover and noting whether the pressure, as shown by the gauges, falls or not. As a general rule, a leak in the case will be indicated by the station meter drum revolving slightly as the pressure falls, while it will remain stationary for a leak in the testing connections. The soundness of the drum may be determined incidently by the test made for the establishment of the water line. The capacity of the drum is usually known either by calculation of its dimensions or by previous experience or both, and any decided increase in this amount would indicate a leak in the drum. A better method of determining the tightness of the drum will be to test

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[15] See Section VI, Measurement of Gas Volumes—Investigation of Laboratory Types of Gas Meters, in B. S. Tech. Paper No. 36, Industrial Gas Calorimetry, by Waidner and Mueller.

the meter at two different rates. If there is a leak in the drum, the percentage inaccuracy for the slower rate will be larger than for the faster rate since there will be a longer period of time for the leaks to affect the result. The approximate location of a leak in the drum may be determined by taking readings of both meters every 10 or 15 minutes throughout the test. The greatest differences between the indications of the two meters will occur during the interval when the leaky portion of the drum is above the water.

The test for accuracy consists of passing gas through the two meters in series. The volume to be passed through the meters during any test will depend upon the size of the meter under test and also upon the preference of the person conducting the test. However, it would seem desirable that sufficient gas should be passed through the meters to cause at least one complete revolution of the drum of the large meter.

If the test is being made to establish the correct position of the water line a long pointer should be secured to the secondary spindle of the station meter by means of which the revolutions of the drum may be accurately noted. Gas is then passed through the meters at the rate at which the test meter has been proved correct and the volume passed during one or two complete revolutions of the station meter drum noted on the test meter. It may be necessary to change the water line and repeat the test a number of times before the correct position is found. If the test is being made on a station meter already installed for the purpose of determining the correctness of its registration several hundred, or even one or two thousand, cubic feet of gas may be passed through the two meters and their registrations compared.

The ideal temperature condition is that existing when the temperatures of the room, the water in the two meters, and the gas are the same. Since this is seldom obtained in practice it usually becomes necessary to correct the tests as made for variations of temperature. These corrections are based on the observations of the temperature of the gas as it leaves the drums of the two meters and should be referred to some standard temperature. A further correction should be made for the drop in pressure which occurs between the two meters, due to friction in the meters and the connections. This drop is usually small, but should be corrected for, the correction being based on observations of the pressures shown by the gauges on the inlet of each meter.[16]

This method of testing a wet-station meter has been questioned by some because the capacity of the test meter is but a small frac-

[16] For a complete discussion on the station meter, see "Station meter," a paper by Donald McDonald presented to the Congress of American Gas Association, June, 1904.

tion of the capacity of the station meter. Undoubtedly it does leave much to be desired. However, in a good many cases this is the only test that it is possible, or at least practicable, to make. Also, in such cases as have come to the bureau's notice where tests against some other reliable meter or a holder have been made, no important differences have been found between the results of such tests and those made at the low rate with the small-test meter.

(3) Care of Wet Gas Meters.—A few points that experienced operators have given regarding the care of wet meters, particularly station meters, are as follows: The stuffing box should not be packed too tightly. Leather washers, yarn, tallow, and graphite make a good packing combination. Only enough water should be fed to the meter to keep the overflow dripping. It is desirable that the water pipes for filling and emptying the meter should be as large as possible. The pressure drop across a meter should seldom exceed 1½ inches of water; if it does, the parts of the meter are binding or the meter is overloaded. Overloading a meter may cause it to blow or to break the seal. However, if the overflow is working properly, it may be possible to overload the meter so as to have a pressure drop of 3 to 4 inches of water across the meter without injury to the meter. Proper intervals between cleanings vary with the quality of the gas and the character of the water used. It is always best to remove the plugs in the drum when filling or emptying the meter. The drum may be tested for leaks by sealing the inlet valve with water and passing gas into the meter inlet through a very small pipe or tube until the drum makes one complete revolution. If there is a puncture in the drum having an area equal to or greater than the cross-section area of the supply tube the drum will stop when the faulty part of the drum leaves the water surface.

(4) Uses of Wet Meters.—Wet meters of the small sizes are generally used in laboratory work where fairly accurate results are desired. When proper care is taken, one of the small 1/10 cubic foot test meters may be made to measure gas correctly within ±0.2 per cent. Wet meters are not used in this country as a consumer's meter, although in some parts of Europe they are used for that purpose to a small extent.

There is on the market a wet meter made entirely of monel metal so that it may be used for measuring gases which cause rapid corrosion of ordinary materials.

While the large wet station meter is still the standard station meter for artificial gas plants, a number of other types of meters have come to be used quite widely for this purpose. Except possibly for some unusual situation, large wet meters are not used for any other purpose than that of a station meter.

(c) NUTATING BELL GAS METERS

There is another class of positive displacement gas meters which may be considered as a form of wet meter, since a liquid is employed for sealing the measuring chambers. Figure 37 shows a sectional view of a meter of this type. The operation of this meter is as follows: The gas enters the inlet *1*, passes up through the passage *2* into the inlet chamber *3*. From this inlet chamber the gas passes through the valve inlet *4*, and valve passages *5*, into the measuring compartments *6*. Since the incoming gas is under a slightly greater pressure than the outgoing gas, the pressure of the gas within the drum *7* will be greater than that outside in the outlet chamber *9* and thus will tend to raise the side of the drum to which the inlet side of the valve directs the gas out of the sealing fluid. Now, since the drum is carried upon the inclined shaft which is supported and rests in the universal joint *10*, and is held in position at the top by the link *11*, any force tending to cause the drum to assume an upright position will produce a turning movement causing the drum to nutate with the inclined shaft resting in the universal joint and also causing the shaft attached to the lower end of the link *11* to gyrate about the spindle *12*. This nutating of the drum and outer ring of the valve seat brings the six valve seat ports or passages *5* alternately in communication with the valve inlet *4* and valve outlet *8*, thereby successively filling and emptying the measuring compartments *6*. Upon leaving the outlet valve *8*, the gas passes up through the outlet chamber *9* and leaves the meter through the outlet *13*. As the top of the drum shaft is linked by *11* to the spindle *12*, the gyrations of the shaft will turn the spindle. Attached to the top of the spindle is the worm *14*, which drives the worm wheel *15*, and this in turn drives the register.

Adjustment of this meter is made by changing the radius of the circle described by the top of the drum shaft about the spindle *12*. This may be done by changing the length of the link *11* or by raising or lowering the spindle end of the link. Increasing the length of the link, or lowering the spindle end, will make the meter slower, while shortening the link of raising the spindle end will make the meter faster.

Unlike the more common type of wet meters, the height of the surface of the sealing fluid may vary over rather a wide range without causing an error in the meter registration of over 1 or 2 per cent. Most meters of this type are provided with a sealing fluid overflow (not shown in fig. 37) which will prevent more than the required amount of liquid remaining in the meter. An occasional inspection will be sufficient to see that it does not become too low.

It would, therefore, seem likely that these meters might be continued in service for a long period after once being adjusted, the occasional inspection of the sealing fluid being the only attention necessary.

For use with some gases this meter has an advantage over the dry meters in that there are no diaphragms to be injuriously affected by constituents of the gas. Neither will exposure to cold or heat injure the meter itself. Of course, it is necessary to select the sealing fluid with due regard to the composition of the gas to be measured, as well as to the location in which the meter is to be placed, and the temperatures to which it may be subjected. Also, as the meter case can be made as heavy as desired the meter may be safely used for measuring gas under very high pressures. A disadvantage of this meter is that it is extremely heavy for its capacity.

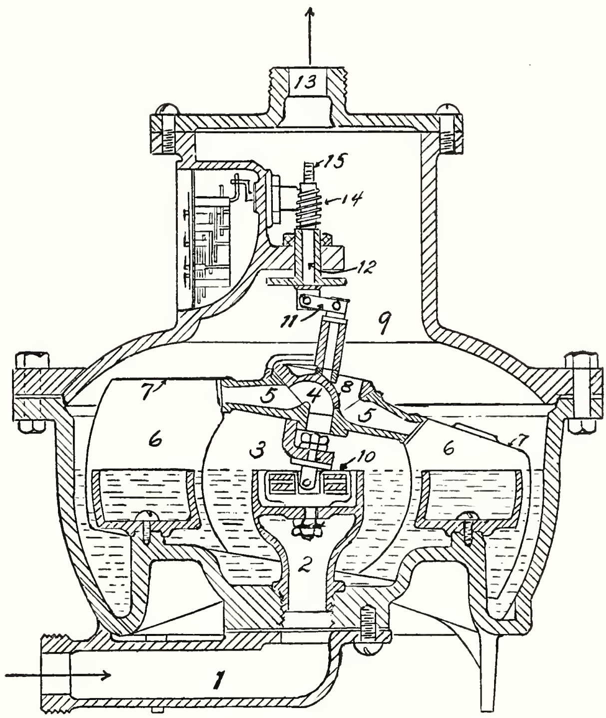

FIG. 37.—*Nutating bell positive displacement gas meter*

Meters of this type have been made for passing from 300 to 30,000 cubic feet of gas per hour. While ordinarily constructed to withstand line pressures of 20 pounds or less, they have sometimes been built to withstand very much higher line pressures.

(d) ROTARY POSITIVE DISPLACEMENT METERS

A third type of displacement meter is the rotary positive displacement meter (also called the cycloidal and the lobed impeller meter) shown in Figures 38, 39, and 40. It is an adaptation of the positive gas booster to a metering problem. Figures 39 and 40 show the general shape of the rotors, the lobed portions of which are hollow. These rotors are so placed with respect to each other and the outside casing as to have just sufficient clearance to permit them

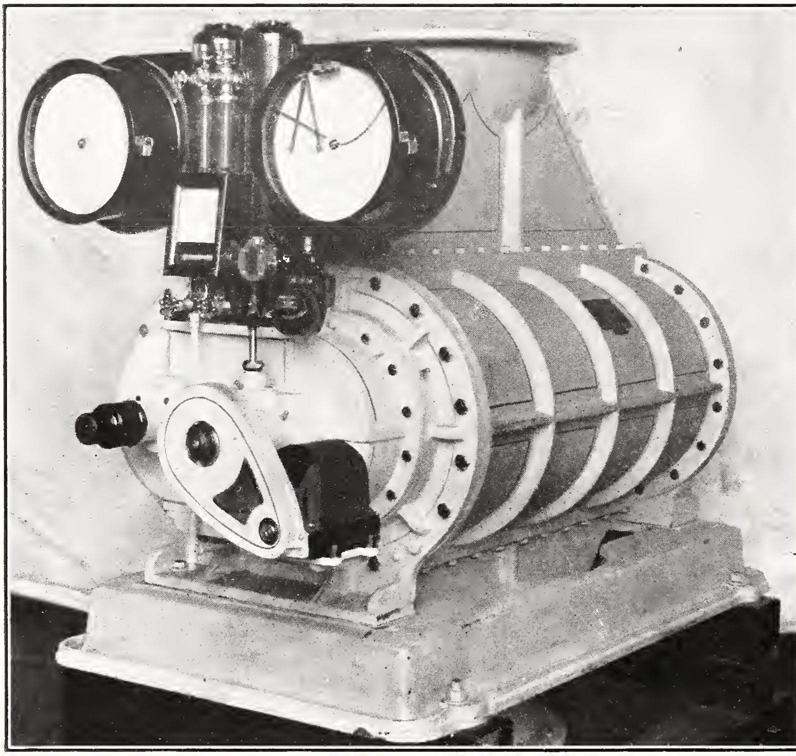

Fig. 38.—*A rotary positive displacement meter*

to rotate freely. The rotor shafts are carried in ball or roller bearings which are mounted in the ends of the meter case. Gas is prevented from escaping around the shafts by stuffing boxes placed between the bearings and inner face of the casing ends. Mounted on the outer ends of the shafts are four equal-sized gears (fig. 39), the two at either end meshing, thereby insuring that the rotors will revolve at equal speeds and in opposite directions.

When the lobes of a rotor are in a vertical position with respect to each other and the shaft so that the extremities of the rotors are adjacent to the ends of the semicylindrical portion of the case walls, a closed pocket or measuring compartment is thus momentarily formed between the rotor and semicylindrical wall of the case. The cubical content of this compartment may be obtained from direct measurement of the rotor and case or from the meter drawings which are to scale. Four such compartments are formed with each revolution of the meter (that is, a revolution of either rotor). Recording of the volume of gas measured out by these compartments (that is, the volume of gas passed by the meter) may be by means of a dial or counter train connected to the end of one shaft and geared to read in cubic feet. Sometimes an ordinary

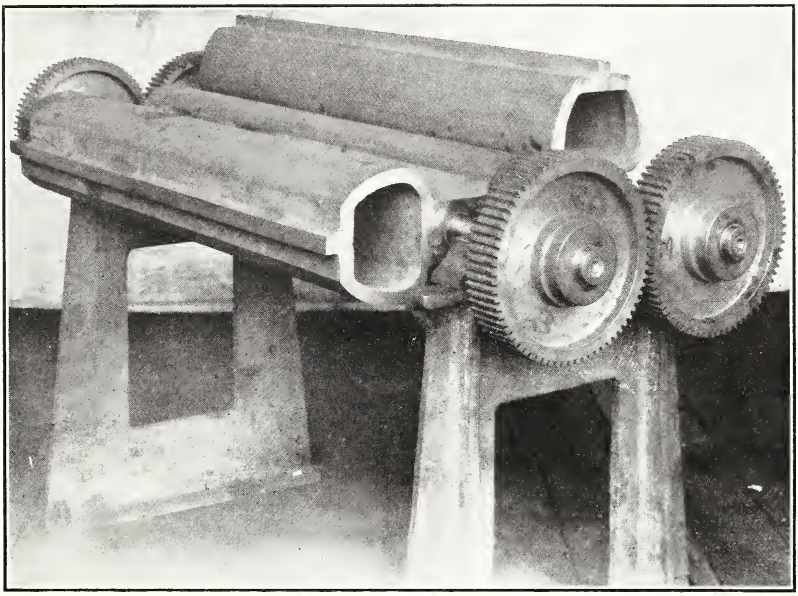

FIG. 39.—*Rotors and gears of a rotary positive displacement meter*

revolution counter is used, and the difference between any two readings multiplied by the displacement per revolution gives the volume passed between the readings.

In order to have more complete records of the gas flow, recording pressure and temperature gauges may be attached to the meter. This data will be essential if it is necessary to refer the gas volumes to standard conditions. Also, it may sometimes be desirable to use an additional recording gauge which will record the various rates at which the meter has been operating.

These meters are always built so that the shafts will be in a horizontal plane and thus make the passage of the gas through the meter downwards, as shown by Figure 40. This is to insure that any dirt or liquid carried by the gas will be swept through the meter instead of accumulating in it.

It is obvious that the rotors can not actually touch each other or the casing since a slight clearance is necessary in order that they may revolve freely. Because of this clearance there will be some leakage or "slippage" of gas past the rotors. A brief consideration will show that the magnitude of this "slip" will depend upon a number of factors, the two most important being the pressure drop across the meter and the condition of the surfaces of the rotors and case. In order that the indications of the meter may be corrected for this "slip" it must be determined in some way. One of the ways which has been used in practice is to connect a differential pressure gauge across the meter; then with either the inlet or outlet closed the meter is rotated by external means at a rate just sufficient to maintain a particular pressure difference across the meter. Doing this for a number of different pressure drops will give the data for determining a "slippage curve" which will show pressure drops as ordinates, against revolutions per minute, or displacement per hour, as abscissas. Then to correct for "slip" by the use of this curve we determine from it the revolutions per minute or displacement per hour, corresponding to the pressure drop at which the meter was operating, and add the product of this rate multiplied by the time interval between the

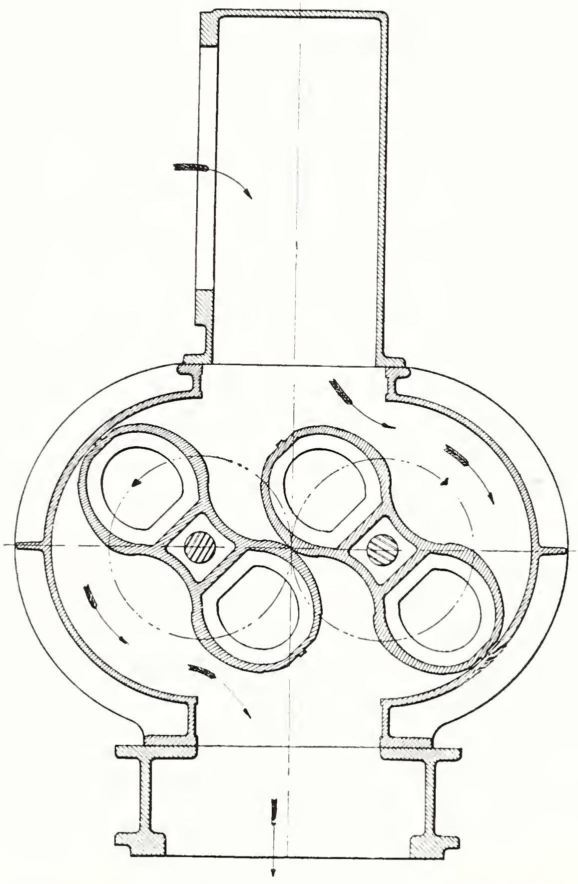

FIG. 40.—*Cross section of a rotary positive displacement meter*

meter readings to the meter indications. That is, it is assumed that if there had been no "slip" the meter would have indicated more than it actually did by an amount equal to the slippage correction.

The method just described for determining the "slippage" correction curve is usually made with the meter clean and dry and with air. It is assumed that the slippage corrections for a gas, other than air, will be greater (or less) than that for air in direct proportion to the ratio of the square roots of the density of air to the density of the gas (that is, proportional to $\sqrt{\text{density of air}}/\sqrt{\text{density of gas}}$). The assumption of this relation involves the additional assumption that the interior of the meter remains clean and dry as when tested. But in actual practice the last-stated assumption does not hold, because the surfaces of the rotors and case are very soon coated with grease, moisture, and dust, thus decreasing the clearance area. In order to counteract this it has been the practice to assume that the effect of the decrease in the clearance area upon the magnitude of the "slip" will be approximately equal to that due to the difference in the densities of the gas and air, but of opposite sign. This practically amounts to assuming that the "slip" for gas when the meter is in the condition resulting from use with ordinary gas is the same as that determined for air when the meter was clean.

This method of determining and applying a "slippage" correction probably does make an approximate adjustment for the uncertain amount of "slippage" or leakage around the rotors. It is, however, open to question. In order, therefore, to determine the reliability of this and other possible methods for determining the "slip" it would be very desirable to have meters of this type carefully compared with other reliable meters or methods of measurement under a variety of rates and conditions. It will be well to note, however, before leaving the subject of slippage that the slippage correction is seldom large, rarely, if ever, exceeding 3 or 4 per cent, and in most cases will probably be less.

The pressure drop or loss across these meters is generally low when their capacities are considered. Also the range of rates of one of these meters is large, as the minimum rate at which they will operate reliably may be well under one-twentieth the full-load rate.

These meters are made in a number of sizes, which range in capacities from a few thousand cubic feet per hour up to about 1,000,000 cubic feet per hour. They are recommended by the manufacturers for use as station meters, meters to large industrial consumers, and for the wholesale measurement of gas between companies.

(e) COMMENTS UPON POSITIVE DISPLACEMENT METERS IN GENERAL

With the possible exception of the rotary positive displacement meter, positive displacement meters will register the passage of gas at any rate between their maximum capacity and zero flow. Moreover, the gas flow may be intermittent, fluctuating, pulsating, or a combination of any or all of these without seriously affecting the accuracy of these meters' indications. As already noted, positive displacement meters are made in a large variety of designs, sizes, and strengths. Thus the variety of conditions of gas measurement to which they may be successfully applied is very large.

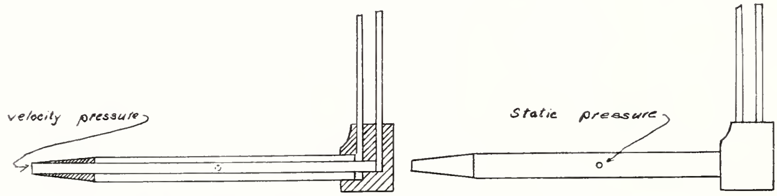

FIG. 41.—*Pitot tube with small hole for static pressure*

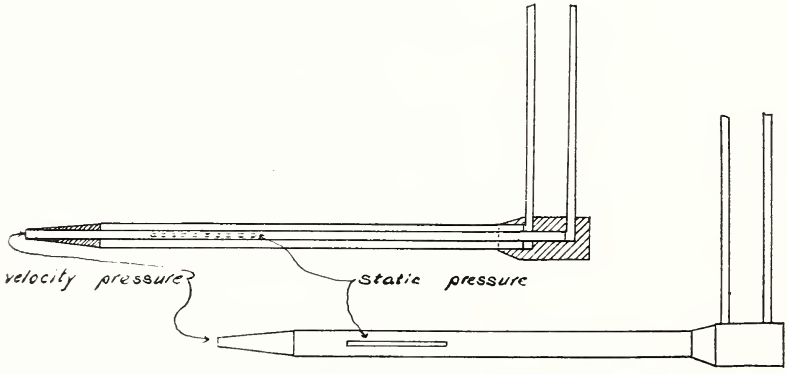

FIG. 42.—*Pitot tube with a slot for taking static pressures*

2. VELOCITY OR INFERENTIAL METERS

Meters of this class do not directly measure the volume of gas passed; but instead means are employed for determining the velocity of the gas as it passes a particular section of its channel, the area of which is known, and this measurement is used as the basis for computing the volume of gas passed during any given interval. These means usually consist in measuring either directly or indirectly the difference between the static pressure of the flowing gas and the dynamic or velocity pressure, since this difference in pressure has a definite relation to the velocity of the gas at the point where the measurements are made. The Pitot tube, orifice meter, Venturi meter, and funnel meter are of this type.

In some cases the energy of the moving gas may be utilized to operate some mechanical device which will indicate the speed or volume rate of flow of the gas passing. The rotary meter and the float meter are constructed on this principle.

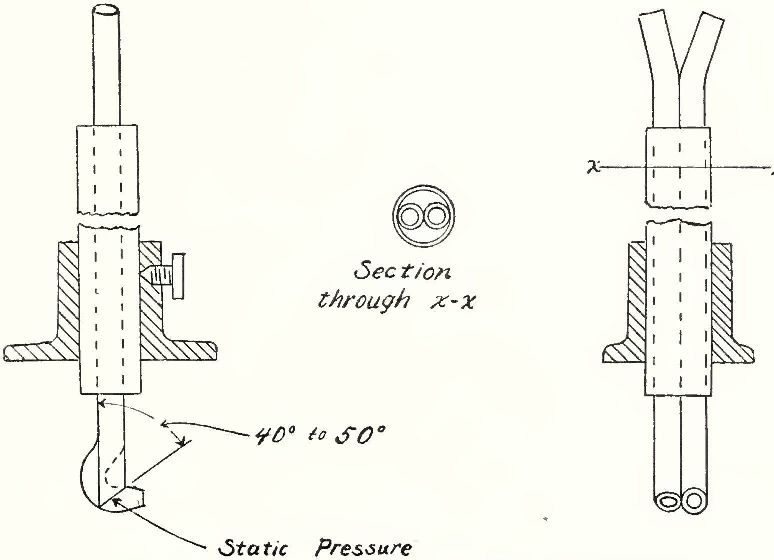

Fig. 43.—*Pitot tube using a slant opening for static pressures*

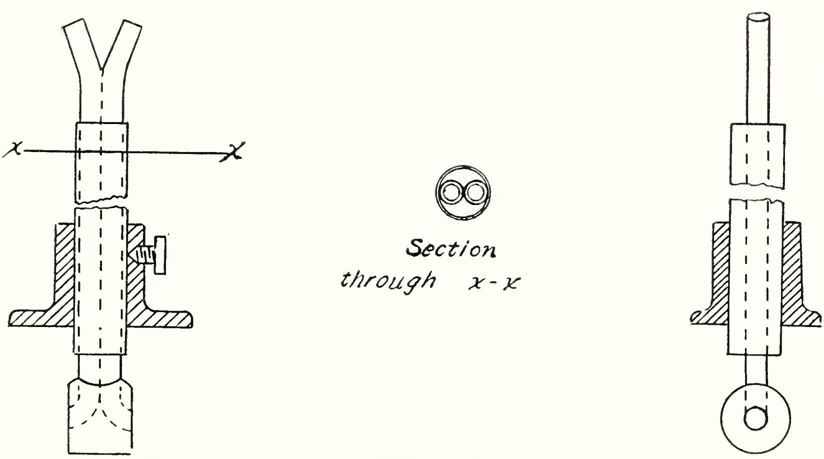

Fig. 44.—*Pitot tube with openings facing in opposite directions*

(a) PITOT TUBE

Figures 41, 42, 43, and 44 show several forms of the Pitot tube used in gas-measurement work, the essential parts of each being the dynamic tip and the static-pressure tip. Usually the tubes are fitted into sockets so that the location of the tips with respect to the center of the pipe may be varied when making a traverse of the pipe. In some instruments the static tip is replaced by a piezometer tube or ring (fig. 45). The upper ends of the pressure tubes are connected to pressure gauges or manometers. The difference in the readings of the two gauges gives the differential pressure or the pressure causing the gas flow. However, the more usual form of connecting the pressure gauges is to branch the connection leading from the static tube, one branch going to the static gauge as before, and the other going to the opposite side of the manometer or U gauge to which the dynamic tip is connected. The reading of this second gauge then gives us directly the differential pressure, and the static gauge reading is used only in referring the volumes to standard or basic conditions.

The usual equation used for the Pitot tube is—

$$s_1 = \sqrt{\frac{2(P_2 - P_1)}{\delta_1}} \tag{1}$$

in which in absolute length-mass-time units

s_1=the speed of the fluid at the point of the impact tip
δ_1=the density of the fluid at pressure P_1
P_1=the absolute pressure indicated by the static tube
P_2=the absolute pressure indicated by the impact tube.

As engineering or gravitational units are more generally used, and the difference in pressures is usually expressed as a head, h, in inches of a liquid of density δ_w we have

$$(P_2 - P_1) = g \frac{h}{12} \delta_w,$$

and equation (1) becomes

$$s_1 = \sqrt{2g \frac{h}{12} \frac{\delta_w}{\delta_1}} \qquad [17] (2)$$

in which s is in feet per second and the densities are expressed in pounds per cubic foot.

It is well at this point to call attention to the fact that a Pitot tube is essentially a speed-indicating instrument, and that the speed indicated by it is that of the fluid at the particular location of the impact tip. The use of the Pitot tube for determining the time-volume flow of a gas flowing within a closed channel is dependent upon certain assumptions regarding the uniformity of the flow.

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[17] For the derivation of this equation and a discussion of it see any standard textbooks on engineering physics. Also, Report No. 2, "The Theory of the Pitot and Venturi tubes," by E. Buckingham, in First Annual Report of National Advisory Committee for Aeronautics, 1915; and "The measurement of natural gas," by T. H. Weymouth, in J. of A. S. M. E., 34, p. 1639; 1912.

Suppose Q represents the volume of gas per unit time which flows across a right section of area A_1 of a closed channel. Then S_1, the arithmetical mean speed normal to section A_1, will be given by $S_1 = Q \div A_1$. Furthermore, if s_1 is the fluid speed at any point in the stream where the impact tip may be placed, then the relation between s_1 and S_1 may be expressed by $S_1 = \phi s_1$ (if the form of the speed-distribution curve does not vary with the average speed), and combining these two relations we have

$$Q = S_1 A_1 = \phi A_1 \sqrt{\frac{2gh\delta_w}{12\delta_1}} \tag{3}$$

Usually in circular pipes the Pitot tube is placed so that the impact tip is in the center. The value ϕ for this case may be found by making a careful traverse of the pipe. For this purpose we imagine the pipe divided in three or preferably more concentric rings of equal area, and a determination of the gas speed is made at four points on the center line of each ring. The ratio of the mean speed thus determined to the speed at the center is the desired value of ϕ. An alternate procedure would be to plot on cross-section paper the speeds obtained for the several traverse points, and from the speed-distribution curve thus obtained one may determine the radius of the circle of mean speed. Obviously if the impact tip is centered upon this circle, the value of ϕ will be 1.

Authorities differ as to the value of the ratio ϕ between the mean speed and the speed at the center, some giving a value as low as 0.81 while others give 0.91, an average of the values noted being about 0.86 for ordinary pipes. A like difference exists in regard to the value of the radius of mean speed, the average of the figures given indicating that the radius of the circle of mean speed is approximately 0.74 of the radius of the pipe in which the gas is flowing. It is obvious that both the value of ϕ and the radius of mean speed will depend to a considerable extent upon the size of the pipe, the condition of the inner surface, and mean gas speed.[18]

In measuring the speeds in rectangular pipes the pipe should be divided into a number of smaller rectangles, preferably squares of not over 2 inches on a side, and the speeds at the center of each rectangle determined. No general relation between the mean speed in a rectangular channel and the speed at any one position has ever been given, nor is it practicable to do so owing to the many possible variations in the relative dimensions of rectangular pipes. However, for any individual case it may be possible after making a few traverses of the pipe to determine the approximate location of the

[18] References to velocity distribution in pipes, Stanton and Pannell, Philo. Trans. of Royal Soc. (London), A. **214**, p. 203; 1914. Stanton, Proc. Royal Soc. (London), A. **85**, p. 366; 1911. Thomas J. Franklin Inst., **172**, p. 422; 1911.

mean speed. Having once obtained this location for a given pipe, we may use it with some assurance of obtaining acceptable results and thus eliminate the necessity of making a complete traverse of the pipe each time.

In determining the mean velocity across a particular section one must remember that it is an average of the velocities at the several points that is desired. There are two methods that may be used for doing this correctly. One is to compute separately the velocity for each one of the several points at which pressure readings were taken and average these values. The other way is to obtain the average of the square roots of the differential pressures and the square of the figure thus obtained will be the differential pressure of the mean velocity and may be used in the regular velocity formula for calculating the velocity. It must be remembered that since the velocity varies as the square root of the differential pressure the correct velocity can not be obtained by averaging the differential pressures directly and using this average in the velocity formula.

The range of velocities for which a Pitot tube may be used extends from about 30 feet per second upward to about the velocity of sound in the gas under the line conditions.[19] The maximum velocity within this range under which the tube may be used will probably depend more upon the strength of the instrument to withstand the necessary pressures than upon the physical principles involved. Velocities below 30 feet per second may be measured if a sufficiently sensitive differential gauge is used, such as an inclined manometer. For that matter, it will probably be desirable to use an inclined manometer when measuring velocities up to 100 feet per second to obtain reliable results.

There has been some question among experimenters as to how accurately the above formula represents the conversion of velocity head into a static head within the tube. To answer these questions there have been a number of experiments made, including several by this bureau, to test the correctness of the relation. In each case the results have shown that the impact tip does give a true indication of the impact or kinetic head of the moving fluid, and that this holds for all speeds under the critical speed which is equal to the velocity of sound (about 1,100 feet per second).[20]

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[19] When the gas velocity reaches that which a sound wave would have in that gas when under the temperature and pressure then existing in the line a pressure wave forms over the dynamic tip of the Pitot tube. This pressure wave is called a "bow wave" because of its resemblance of the wave formed across the bow of a boat and it seems to have the effect of draining energy away from the dynamic tip so that the relation expressed by equations (1) and (2) no longer holds.

[20] See W. M. White's paper "The Pitot tube; its formula," in the J. of the Assoc. of Eng. Societies, Aug., 1901. Also R. Trelfall's paper "Gas flow in pipes by Pitot tube measurements," Trs. of British Inst. of Mech. Engs., pt. 2; 1904.

In some cases the impact tip is permanently fitted into the pipe and the static pressure is obtained from a piezometer tube or ring, as illustrated by Figure 45. In such an arrangement the pipe and pressure tubes together form a complete unit. Since a traverse of the pipe with the impact tube would be impossible in this case, a calibration of the complete unit must be made by a comparison with a gas holder or some other meter, the accuracy of which has been established. When such calibrations are made, they should, if possible, be carried out over a pressure range as extensive as that to which the tube will be subjected in actual use.

A large number of investigations have been made to determine the best form of tubes and shape of static openings. The results obtained by the different investigators do not agree in every case. Perhaps as carefully performed experiments as any were those by W. C. Rouse, an account of which was published in the Journal of

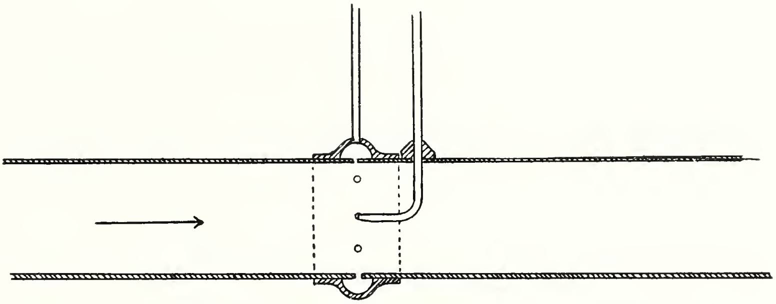

Fig. 45.—*Dynamic tip with piezometer ring for static pressures*

the A. S. M. E. for March, 1914. The principal points brought out in his paper may be summarized as follows:

1. Gas flows through a pipe in a wave or spiral motion and at no time is the velocity distributed uniformly across the pipe, being greater in one quarter than in the other three quarters.

2. The velocity on the diameters where the Pitot tube readings are being taken may be constantly changing during the time necessary to obtain the readings.

3. The gas flow can only approach, never reach, the ideal condition of parallel flow, and the Pitot tube is correct, theoretically, only when the tube is exactly parallel to the current of gas.

4. The Pitot tube as a means of measuring gases is reliable within approximately 1 per cent when the static pressure is correctly obtained and when all readings are taken with a sufficient degree of refinement; in order to obtain this degree of accuracy the Pitot tube should be preceded by a straight run of pipe 20 to 38 times the

pipe diameter in order to make the flow of gas as nearly uniform across the section of pipe as possible.

5. All the methods of obtaining the dynamic head (used in his experiments) give accurate results.

6. The most reliable and accurate means of obtaining the static pressure is the piezometer or its equivalent. The results showed beyond any doubt that the static pressure is constant across any section of pipe in which gas is flowing at a uniform rate.

7. In obtaining the static pressure by the Pitot tube itself the best means is a very small hole in a very smooth surface.

8. The results obtained when slots (see fig. 42) are used for static pressure openings may be in error from 3.5 to 10 per cent. The length of the slot or the thickness of the tube do not appear to affect these results.

9. The beveled tube (fig. 43) for obtaining the static pressure is not reliable. A very slight change in the angle of bevel produces an appreciable change in the results. In taking a traverse of a pipe the sides of the pipe affect the readings. The greatest error is produced by the uncertainty as to whether the tube is pointing directly upstream. The effect of allowing this form of Piot tube to point at an angle of 20° off the direction of flow is to introduce an error of 85 per cent in the velocity head.

10. It appears that an approximate relation exists between the mean speed head of a gas flowing through a pipe and the speed found by placing the tube at the center of the pipe. For ordinary iron pipe results within 2 per cent may be expected by using the formula $s=\sqrt{2g \times 0.80H}$, in which s is the mean speed in feet per second and H is the velocity head at the center of the pipe in feet of the gas, and $\phi=0.895$ (compare this value of ϕ with those on page 59).

Because of the accuracy which may be obtained with a Pitot tube it is extremely useful in studying the flow of gas in pipes and also for the investigation of the distribution of steam in heating and power plants. Many of its forms are so compactly made that it is very easy to move it from one position to another, and the only mounting necessary for its use is a threaded opening into the pipe where the measurement is to be made. The use of Pitot tubes as continuous recording instruments has never been very extensive, possibly because attempts made to use recording gauges in connection with them do not seem to have been altogether successful. When these tubes are employed it has therefore been common practice, at least in natural-gas work, to read the static and differential gauges at regular intervals, usually every 15 minutes.

One of the chief difficulties in the use of the Pitot tube is to determine accurately the static pressure at the desired location in the gas stream. The best-known methods of doing this have already been mentioned. Again, in many cases, the differential pressure obtained with a Pitot tube is so small that a small numerical error in its reading will be a large percentage of the differential itself, thus making the possible error in the velocity or volume determination large.

(b) ORIFICE METER

When the flow of a fluid within a pipe is hindered by some obstruction, such as a partly closed valve or a diaphragm containing an opening materially smaller than the size of the pipe, it is a matter of common observation that the fluid will not readily flow through the small passage of the diaphragm unless forced through by the application of pressure. That there is a definite relation between the area of the passage, the form of the opening, the rate at which the fluid flows through it, the density of the fluid, the amount of the pressure drop, and several other variable factors is not so obvious but may be shown by suitable experiments. This relation has been extensively studied, particularly for the special case in which the obstruction is a diaphragm containing a circular opening or orifice, for it has been found that it may be used as a means of measuring the rate of flow of the fluid. During recent years the flow of gas through an orifice placed in a pipe has been given considerable study, and orifices so placed are being used in the measurement of both large and small rates of gas flows. Thus the use of an orifice in this manner is now important and will, therefore, be discussed in some detail.

Before describing the orifice meter it should be pointed out that the orifice meter as spoken of and used in practice consists of two distinct parts. What may be termed the "primary" part includes the adjacent sections of pipe, flanges, orifice plate, and the pressure taps or openings. The "secondary" part includes all instruments used to indicate, measure, or record the pressures. In commercial discussions emphasis is usually placed upon the secondary part. The discussion here, however, will be confined almost entirely to the elements and physics of the primary part.

The essential primary parts of an orifice meter are illustrated in Figure 46, in which *A* is a section of pipe of uniform diameter and *B* is a plate placed across the pipe at right angles to it, and in which there is an opening or orifice *C*. In order to obtain a knowledge of the pressures on each side of the orifice plate the pressure connections E are necessary. While the details of design and arrangement will vary according to the individual ideas of the builder, these essential features will be embodied in any device that may be strictly termed an orifice meter. Figures 49 and 51 illustrate two of the

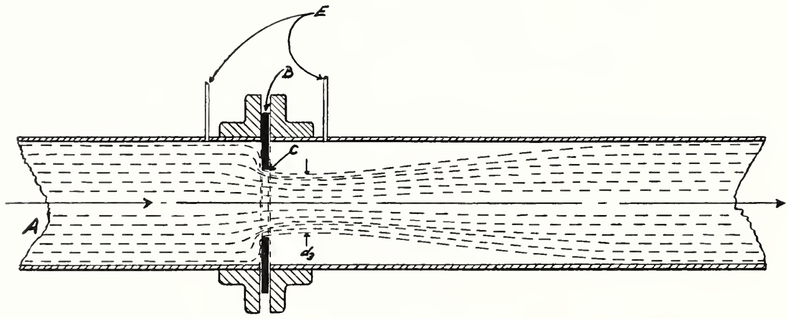

Fig. 46.—*Longitudinal section through an orifice meter*

This shows the primary part of an orifice meter, which includes the adjacent sections of pipe with their flanges, the orifice plate, B, and the pressure openings, E.

designs found in commercial installations, and orifice plates used in some installations are shown by Figures 50 and 52.

While it is very difficult to make direct observations on the shape of the stream issuing from a sharp edge orifice, as shown in Figure 46, some experiments have been made, notably with water, which indicate that the form of the stream issuing from the orifice is that shown by the dotted lines in the figure. The section of minimum diameter, d_3, is termed the vena contracta, and it is at this section that the greatest velocity and the minimum static pressure occur. As it is usually desirable to have the greatest possible difference between the pressures observed on the two sides of the orifice, it would appear that the best location for the downstream pressure connection would be in the plane of the vena contracta. While the location of the vena contracta will depend in part upon the relation between the diameters of the pipe and orifice, several investigators have found that it is usually located between 4/10 and 5/10 of the diameter of the pipe below the upstream face of the orifice when the diameter of the orifice is between one-fourth and one-half the pipe diameter. The upstream pressure connection should be located far enough above the orifice plate so that the increasing speed of the gas close to the

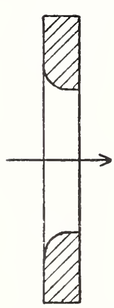

Fig. 47.—*An orifice with rounded approach*

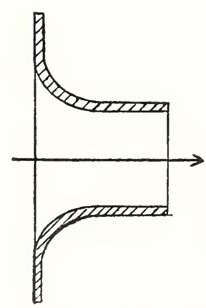

Fig. 48.—*A formed orifice or nozzle*

plate will not have an influence upon the readings. To obtain this, the connection should be at least one-fourth pipe diameter above the orifice.[21] Up to the present time the practice of locating the pressure connections at these points has not been closely followed. In one type of orifice meter on the market the pressure connections are placed 1 inch on each side of the orifice plate regardless of the size of pipe or orifice. In such an arrangement one may not obtain the minimum pipe line pressure above the orifice, and only in certain cases would the minimum pressure existing below the orifice be measured by the downstream connection. However, it is possible that in this arrangement the differences between the maximum and minimum pressures actually existing and those recorded by the gauges will not be very large in most cases.

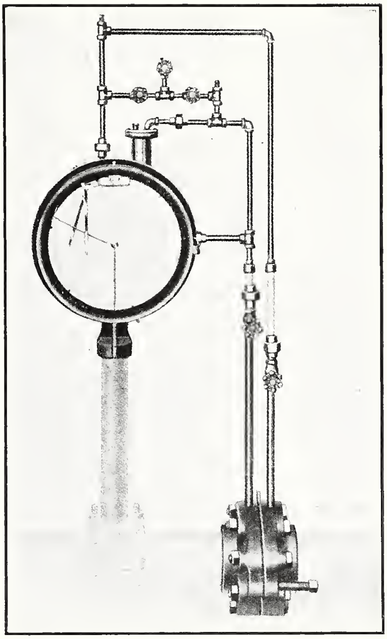

Fig. 49.—*A commercial orifice meter installation*

Here the pressure connections are in the flanges (flange connections), and the static pressure is taken from the downstream connection.

In another commercial orifice meter installation the upstream connection is placed 2½ pipe diameters above the orifice and the downstream connection is placed 8 pipe diameters below the orifice plate. In this case, then, from the upstream connection we obtain the true pipe line pressure above the orifice, while on the downstream side, since generally steady flow conditions will have been restored, we will obtain the pipe line pressure below the orifice. Hence, the difference between the two pressures will be a measure of the friction and eddy loss caused by the orifice instead of a measure of the conversion of energy produced by the orifice.

A comparison of the several combinations of pressure tap locations shows that when the pressure taps are close to the orifice, or at least when the downstream one is not over 0.6 pipe diameter from the orifice, the differential pressure will be relatively large, but possibly subject to some unsteadiness. This unsteadiness is due to

[21] See "Orifice measurement of water-pipe discharge," by R. E. Davis and H. H. Jordan, Univ. of Illinois, Bull., **16**, No. 14, Dec. 2, 1919; also, "Experiments on water flow through pipe orifices," by Horace Judd, in paper presented to A. S. M. E. meeting at New Orleans, Apr. 11, 1916.

turbulence surrounding the jet from the orifice. For the more distant pressure taps (or so-called pipe connections in contrast to the connections in the flanges) the differential pressure is relatively small but more nearly steady. Hence the advantage of a higher differential for the close-up connections is largely offset by the greater unsteadiness. So far as it has been observed the accuracy and reproducability of results is about the same for both of these pressure-tap locations. However, when the pressure taps are located in the flanges the work may be done in a shop where due care can be taken to locate the holes correctly and to have the inner edges free from burrs and slightly rounded. This is an important consideration, since it insures uniformity. The shape of the orifice is very important and has a large effect upon the volume rate of flow corresponding to a given differential pressure. The two general types used are the square-edged orifice (figs. 50 and 52) and the orifice of rounded approach (fig. 47). In some instances, particularly in the measurement of steam, short nozzles, similar to that shown in Figure 48, have been used, and may be considered as a modified form of round-edged orifice. With

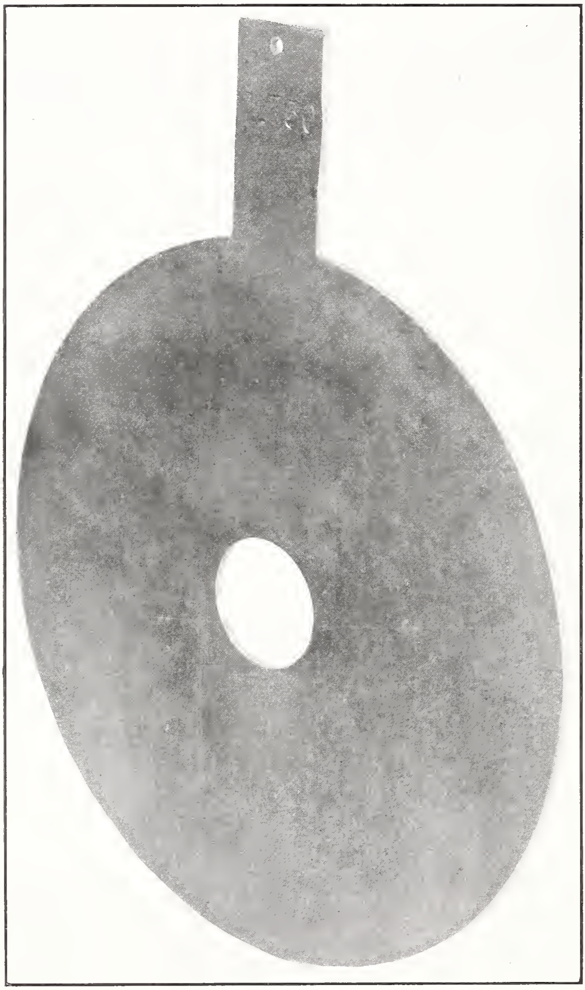

FIG. 50.—*A commercial orifice meter plate*

This is known as a thin-plate orifice. The edges of the orifice should be square and free from burrs.

round-edged orifices the stream does not continue to contract to form a vena contracta after leaving the orifice, hence the plane of minimum jet diameter is coincident with the downstream face of the orifice or nozzle. For this reason, with a given differential, the minimum area of the jet from a round-edged orifice is much larger than that of a jet from a square-edged orifice of the same diameter, and hence the volume rate of flow through the round-edged orifice will be correspondingly larger than that through the square-edged orifice. Therefore, it would be advantageous to use a round-edged orifice in cases where the differential pressure must be kept as low as

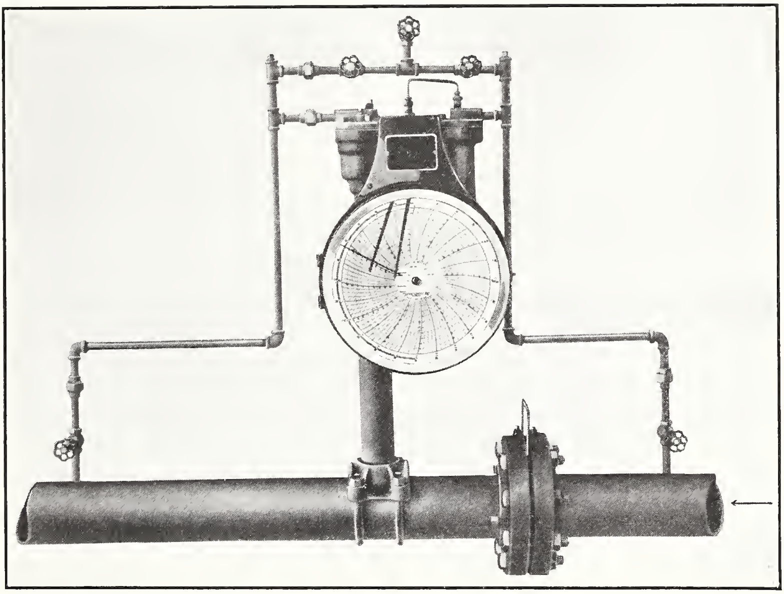

FIG. 51.—*Commercial orifice meter installation*

In this installation the pressure connections are about 2½ pipe diameters upstream and 8 downstream from the orifice plate. These are termed "pipe connections." The static pressure is taken from the upstream connection.

possible. On the other hand, it is difficult to produce two round-edged orifices just alike, while it is a relatively simple matter of machining to duplicate square-edged orifices. This makes the square-edged orifice the more practical of the two and accounts for its very general use.

In the case of very small orifices, one-fourth inch or less in diameter operating under low pressures, it has been found that as the thickness of the orifice plate increases with a corresponding increase in the length of the tubular passage which is the orifice the quantity of the gas discharged under a given pressure drop increases until a maximum discharge is attained. The maximum discharge occurs with a plate about 0.1 inch thick and thereafter slowly decreases again. This is due to the fact that for a plate thickness of 0.1 inch the sides of the orifice face—that is, the walls of the tubular passage—tend to prevent further constriction of the stream after it

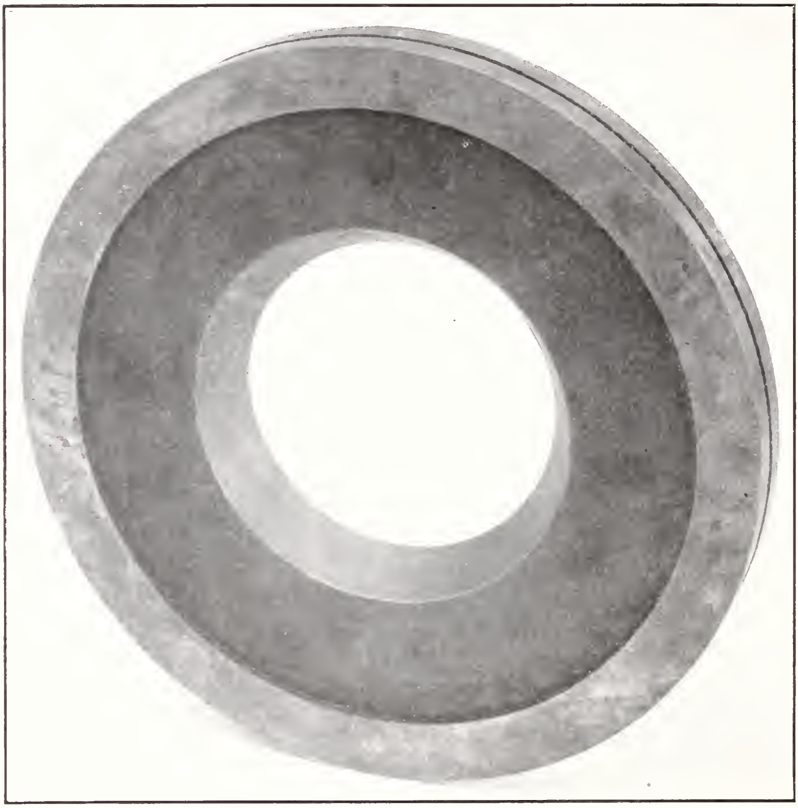

FIG. 52.—*An orifice plate*

The upstream edge of the orifice is square but the downstream edge is beveled, as shown.

leaves the orifice, thus causing a stream of larger area at the section of maximum velocity. The decrease in the rate of discharge for thicker plates is, of course, due to friction.[22]

(1) ORIFICE METER EQUATIONS.[23]—In deriving an equation by which to compute the theoretical discharge through an orifice

[22] See B. S. Tech. Paper No. 193, The Design of Atmospheric Gas Burners, p. 17.

[23] An extensive discussion of velocity meter equations and their development is given in Appendix C of Fluid Meters, Their Theory and Application, Part I, Report of A. S. M. E. Special Research Committee on Fulid Meters. See also Experimental Engineering, Ch. XII, by Carpenter and Diedericks; The measurement of natural gas, by T. R. Weymouth, J. A. S. M. E., 34, p. 1639; 1912.

there are two assumptions on which a theoretical equation may be based. These assumptions are:

(*a*) There is no change in the density of the fluid in flowing from the large stream section, which fills the pipe above the orifice, to the smallest section of the jet below the orifice. This is the case of an incompressible fluid like water.

(*b*) There is no exchange of heat to or from the surrounding bodies; that is, in flowing from the upstream section to the jet section an expansion takes place adiabatically.

In giving equations for these cases the following notation [24] will be used:

A=area of pipe, in square feet.
a=area of orifice, in square feet.
C=discharge coefficient defined by $\frac{\text{actual mass rate of discharge}}{\text{theoretical mass rate of discharge}}$
D=diameter of pipe, in inches.
d=diameter of orifice, in inches.
g=acceleration of gravity, in feet per second per second.
h=effective differential head, in inches of a column of liquid of density δ_w.
P=absolute pressure of gas, in pounds per square inch.
Q=volume rate of flow, in cubic feet per second.
$r=P_2/P_1$.
s=speed of gas, in feet per second.
W=mass rate of flow, in pounds per second.
$X=\Delta P/P_1$.
$y=c_p/c_v$, the ratio of the two specific heats of a gas (for air $y=1.4$).
$\beta=d/D$.
δ=density of gas at the temperature and pressure in the line at the section referred to by its subscript, in pounds per cubic foot.
$\Delta p=P_1-P_2$, the differential pressure across the orifice, in pounds per square inch.

Subscript $_1$ refers to first, or upstream, section (with respect to orifice).

Subscript $_2$ refers to second, or downstream, section (with respect to orifice).

The first assumption gives rise to the following theoretical equation, which is commonly called the "hydraulic equation."

$$W=\frac{\pi d^2}{4\times 144}\sqrt{\frac{2gh\delta_w\cdot\delta}{12(1-\beta^4)}} \tag{4}$$

[24] See Section IX for complete table of symbols.

or

$$Q=\frac{\pi d^2}{4\times 144}\sqrt{\frac{2gh\delta_w}{12\delta(1-\beta^4)}} \tag{5}$$

If, as is very frequently done, the velocity of approach; that is, the velocity in the pipe above the orifice is neglected, the term $(1-\beta^4)$ may be dropped from equations (4) and (5) so that we have

$$W=\frac{\pi d^2}{4\times 144}\sqrt{\frac{2gh\delta_w\delta}{12}} \tag{6}$$

and

$$Q=\frac{\pi d^2}{4\times 144}\sqrt{\frac{2gh\delta_w}{12\delta}} \tag{7}$$

If h and δ_w refer to ice-cold water, and a standard value for g of 32.17 ft./sec./sec. is used, equation (4) becomes

$$W=0.0997d^2\sqrt{\frac{h\cdot\delta}{(1-\beta^4)}} \tag{8}$$

If in equation (4) we replace $\frac{h\delta_w}{12}$ by Δp we may reduce the equation to

$$W=0.525d^2\sqrt{\frac{\Delta p\cdot\delta}{(1-\beta^4)}} \tag{9}$$

Equations (5), (6), and (7) may be simplified in a similar manner, the numeric will be the same as in (8) or (9).

By the second assumption (*b*) one may derive the following theoretical equation, which for convenience will be termed the "adiabatic equation."[25]

$$W=\frac{\pi d^2}{4\times 144}\sqrt{\frac{2g\cdot\Delta p\cdot\delta_1}{(1-\beta^4)}}\cdot Z_1\cdot Z_2 \tag{10}$$

and

$$Q=\frac{\pi d^2}{4\times 144}\sqrt{\frac{2g\Delta p}{\delta_1(1-\beta^4)}}\cdot Z_1\cdot Z_2 \tag{11}$$

in which

$$Z_1=\sqrt{\frac{y-1}{y}\, r^{2/y}\,\frac{(1-r^{\frac{y-1}{y}})}{1-r}}$$

$$Z_2=\sqrt{\frac{(1-\beta^4)}{(1-\beta^4r^{2/y})}}$$

equation (10) may also be written

$$W=0.0997d^2\sqrt{\frac{h\delta_1}{(1-\beta^4)}}\cdot Z_1\cdot Z_2 \tag{12}$$

or

$$W=0.525d^2\sqrt{\frac{\Delta p\delta_1}{(1-\beta^4)}}\cdot Z_1\cdot Z_2 \tag{13}$$

[25] It should be noted that the form of writing the hydraulic and adiabatic equation varies with different writers.

according as to whether the differential pressure is h (inches of ice-cold water), or Δp (lb./in.^{2}).

The use of equation (13) may be greatly simplified by tabulating or plotting the values of several of the factors. Thus when the composition of the gas is fairly constant and the value of y is known, we may plot the values of Z_1 and Z_2, or better the logarithms of the values against values of r or $X=1-r$. Also, for a particular series of orifice plates, the values of $0.525\ d^2/\sqrt{1-\beta^4}$ might also be prepared, and the values of C corresponding to several values of β and r could be either plotted or tabulated. In this way the use of equation (13) reduces to combining several factors taken from tables or plots. The general use of logarithms may prove helpful in computing the flow by this equation.

Figures 53 and 54 give curves for the values of the logarithms of Z_1 and Z_2 for such gases as air where $y=1.4$.

(2) Orifice Coefficients.—The theoretical equations given above are applicable only to the ideal condition in which there is no surface friction, internal friction (viscosity), nor jet contraction to retard the flow. Since in all actual cases two or more of these retarding influences are present it is necessary to introduce into these equations a factor to compensate for their effects, in order that we may compute the actual flow. This factor, which will be called the "discharge coefficient" and represented by C, may be concisely defined by $C=\frac{\text{actual discharge}}{\text{theoretical discharge}}$. Thus, the actual mass rate of flow by the "hydraulic" equation will be, from (9)

$$W=0.525C_h d^2\sqrt{\frac{\Delta p\cdot\delta}{(1-\beta^4)}} \tag{14}$$

and by the adiabatic equation, from (13)

$$W=0.525C_a d^2\sqrt{\frac{\Delta p\cdot\delta}{(1-\beta^4)}}\cdot Z_1\cdot Z_2 \tag{15}$$

It is evident from the above definition of C that its numerical value will be independent of the system of units in which the measurements of pressures, temperatures, volume, and mass are expressed. On the other hand, the numerical value of C will change with changes in any one of a number of factors, and its value in any given case will depend upon the particular combination of these factors there existing. The most important of these factors are:[26]

1. The equation used for computing the theoretical discharge.
2. The value of β; that is, the ratio of the orifice diameter to the pipe diameter.
3. The size of the orifice; that is, the value of d.

[26] The order in which they are given has no significance as to magnitude of their effect.

4. The shape of the orifice, which may vary from a square-edged hole (fig. 50), to a carefully formed nozzle (fig. 48).

5. The rate of flow, which may be represented by r or X.

6. The location, with respect to the orifice plate, of the pressure connections.

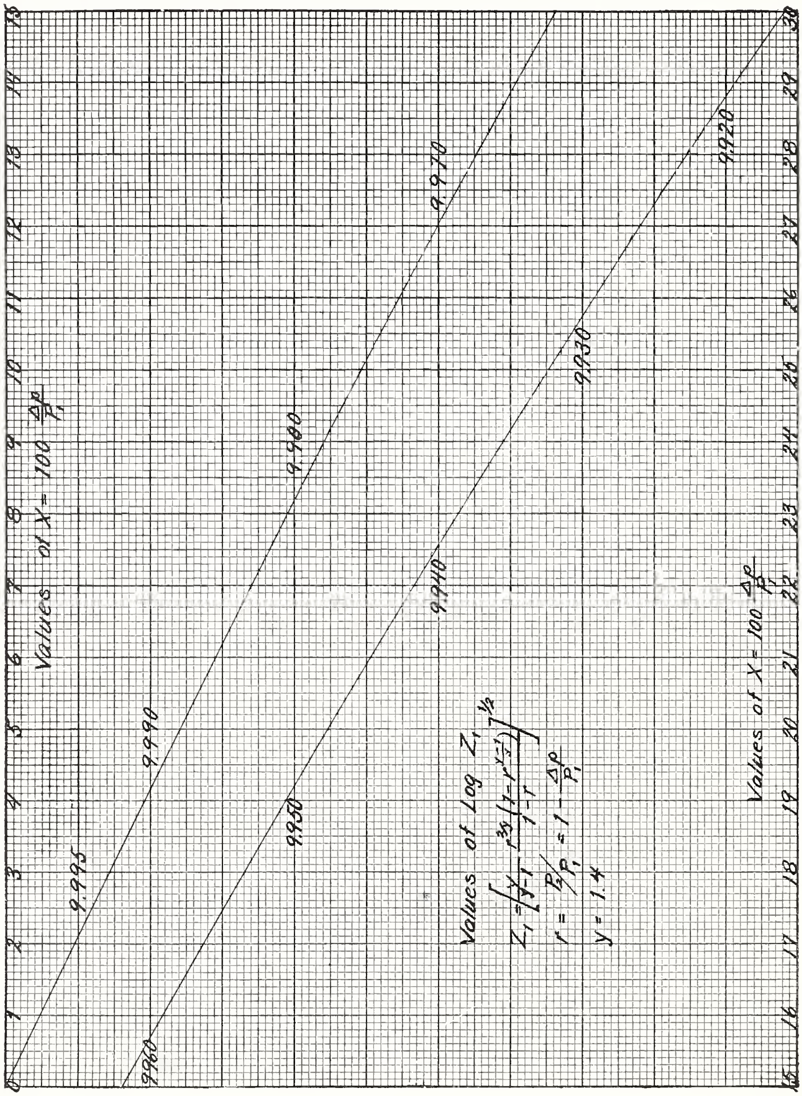

Fig. 53.—*Curve to be used with the adiabatic equation*

7. The static pressure used for determining δ; that is, whether P_1 or P_2. (This applies particularly to the hydraulic equation.)

It is therefore very important to state in detail the combination of conditions to which any value of C may be applicable. However, the scope of this circular does not permit extensive discussion of the variations of C with variations of the above factors.

(3) Determination and Value of Orifice Coefficients.—To determine the value of orifice coefficients a large number of experiments

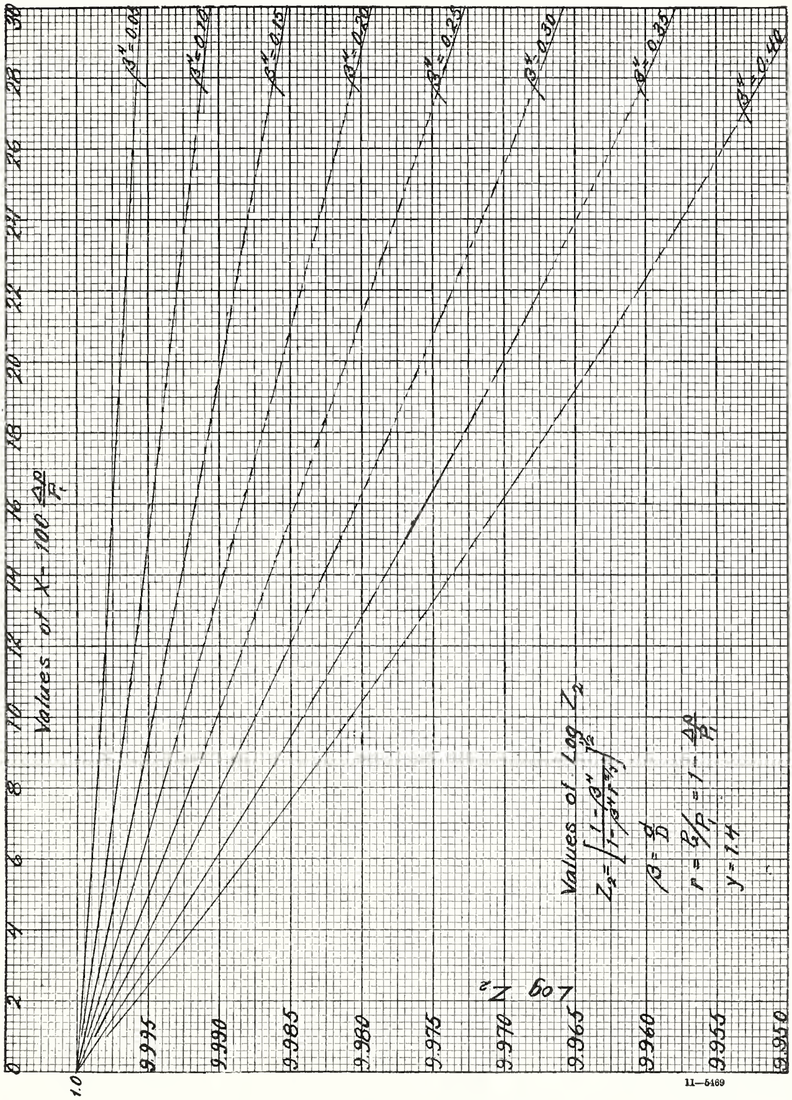

Fig. 54.—*Curve to be used with the adiabatic equation*

have been made and several papers and booklets have been published on the results.[27] Briefly, the common procedure for making these determinations is to operate the orifice in series with some other form of measuring device which is used as the reference or standard

[27] A number of these are listed in the bibliography.

meter and which can be relied upon to as high a degree of accuracy as is desired of the orifice. Simultaneous readings are made at the two meters, those at the orifice being usually the static and differential pressures and the temperature, while those at the reference meter are such as are called for by the particular meter. From these observations we may determine the actual flow indicated by the reference meter and compute the theoretical flow indicated by the orifice by using one of the equations given above, using $C=1$ for the time being. The actual value of C will then be the ratio of the actual discharge to the theoretical discharge as computed for the orifice. A sufficient number of such comparisons or coefficient determinations should be made under different conditions so as to cover the range of conditions that the orifice will probably be subject to in actual use.

Because of its importance, attention is again called to the fact that strictly each value of C applies only under those conditions which existed at the time of that particular comparison. The important factors of these conditions have been stated above.

For most cases the value of C for a square-edged orifice in a thin plate will be between 0.58 and 0.62. The particular value for any given case will depend upon the equation being used and also upon the particular combination of all of the variable conditions enumerated in the above paragraph. However, the following values of C will probably give results which will be correct within 2 per cent when used in connection with the conditions specified:

Equation	Hydraulic using δ_1	Hydraulic using δ_2	Hydraulic neglecting velocity of approach using δ_1	Adaibatic
Equation number	(4)	(4)	(6)	(10)
Orifice, shape and size	Square edged, in plate ⅛ inch or less thick; orifice diameter 0.75 inch or over.			
Location of pressure taps	Upstream within 1 pipe diameter of orifice plate. Downstream within 0.5 pipe diameter of orifice plate.			
Static pressure used to determine δ	P_1	P_2	P_1	P_1
Value of $r=P_2/P_1$	1.0–0.975	1.0–0.975	1.0–0.975	1.0–0.975
Maximum value of $\beta=d/D$	.40	.40	.40	.40
Value of C	.601	.603	.605	.604

(c) FUNNEL METER

The funnel meter is strictly a special form of the orifice meter but is never used in a closed channel, the gas always being discharged into the air. Three types common to commercial use are shown in Figures 55, 56, and 57. The essential features of this type of meter are a side or face containing a number of holes of the same or different sizes and some means of measuring the pressures of the gas just inside of this face.

The theory on which these meters operate is as follows:

1. Assuming a homogeneous gas, such as air, at a constant temperature and pressure the volume discharged per second will be directly proportional to the total area of the holes which are open.

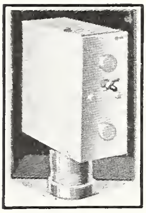

FIG. 55.—*Funnel meter*

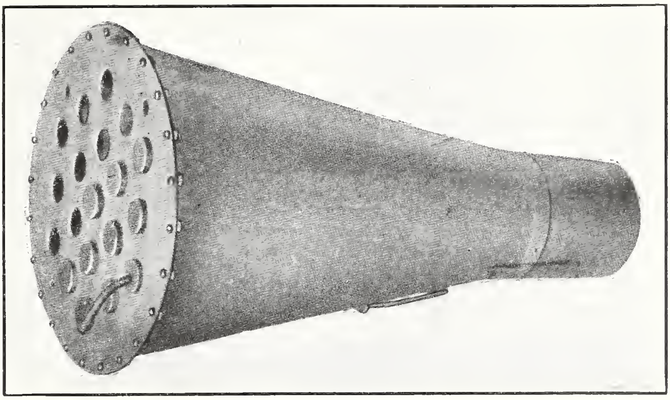

FIG. 56.—*Funnel meter*

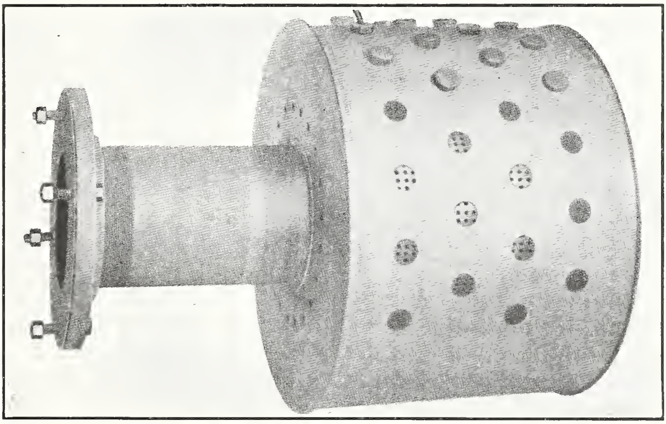

FIG. 57.—*Funnel meter*

These are sometimes used as working standards or test meters for testing large meters in the field.

2. The pressure (above atmosphere) which will be required to discharge gas from the same opening at a given rate for different temperatures and atmospheric pressures varies directly with the atmospheric pressure and inversely with the absolute temperature.

3. The pressures (above atmosphere) which will be required to discharge different gases at the same rate will vary directly with the specific gravity of the gases (air assumed as 1).

In commercial work the basic size orifice is 1½ inches in diameter, and the pressure required to cause a flow of 1 cubic foot per second is determined from the equation,

$$p=\frac{B \times G}{0.0138 \times T} \tag{16}$$

in which

p=the required pressure in inches of water
B=corrected barometer reading in inches of mercury
G=specific gravity of the gas, air=1
T=absolute temperature of gas in Fahrenheit degrees
=temperature of gas in degrees F.+460.

In actual practice the method of using this meter and equation (16) is as follows: The temperature and specific gravity of the gas are determined and the barometric pressure is noted (usually an aneroid barometer is used). These values for B, G, and T are then substituted in equation (16) and the corresponding value of p determined. The rate of flow through the meter is then adjusted until the pressure within the funnel meter is equal to p, as indicated by a manometer attached to the pressure connection provided on the meter. With this pressure and a 1½-inch hole open it is considered that the rate of discharge from the meter is 1 cubic foot per second or 100 cubic feet in 100 seconds. If a ¾-inch opening is used, the area is ¼ as large as before, hence the discharge will be ¼ cubic foot per second, or 100 cubic feet in 400 seconds. If, on the other hand, both the 1½ and ¾ inch holes were used together, the total area would be 1¼ that of the 1½-inch hole, hence the discharge will be 1¼ cubic feet per second or 100 cubic feet in 80 seconds.

While this type of meter has been used extensively and numerous tables have been prepared based on equation (16), there has been found no published account of tests which may have been made to confirm the relations given in the equation. Moreover, it is not probable that the true static pressure is obtained by the construction used. In the three types of funnel meters shown in the preceding figures the static pressure within the funnel meter is obtained from a pressure connection, the opening of which faces more or less directly into the stream of gas as it approaches the orifices, thus corresponding to a small extent to the dynamic tip of a Pitot tube. The pressure indicated by the manometer is, therefore, probably made up of two components, one the true static pressure of the gas ahead of the orifice face and the other a velocity component, which may be approximately represented by the term $K\frac{v_1^2}{2g}$, where K is a factor depending upon the quantity of gas flowing and the characteristics of the particular instrument.

These instruments have been used largely as working standards for testing large-capacity positive displacement meters and proportional meters in the field. However, in view of the points brought out in the above paragraph, their use as standards can not be considered advisable, and when it is necessary thus to use one of these meters it should be given a very thorough calibration for the entire range over which it will be used.

A very careful and critical study of the funnel meter would undoubtedly be highly desirable, since it would add to the present knowledge of their characteristics and demonstrate whether or not they are a satisfactory form of instrument. If they were found to be not satisfactory, the facts developed by the investigation might lead to improvements over the present design.

(*d*) VENTURI METER

Figure 58 illustrates the essential features of a Venturi meter as usually found in use to-day. The principal parts are two funnel-

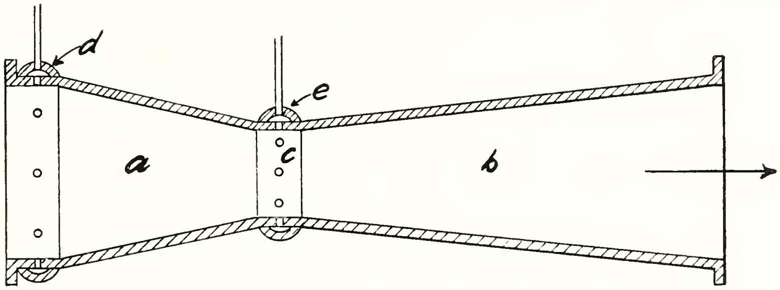

FIG. 58.—*A venturi tube*

shaped sections, *a* and *b* in the figure, called the upstream and downstream sections. The small ends of these sections are nearly equal in diameter and are joined together by a short section *c*, called the throat section. The inner surface of this throat section is slightly bowed, so that the diameter at the center is less than at the ends. This bowed surface is finished smooth. Around the large end of the upstream section, before it begins to taper, is an annular ring *d*, called a pressure chamber or piezometer ring. A number of small holes, evenly spaced about the circumference, connect this chamber with the inside of upstream section. A similar chamber *e* surrounds the throat, and the pressure holes connecting this chamber with the inside of the throat are in the plane of the smallest throat diameter. These pressure chambers may be connected to separate gauges or to the two ends of a U-tube manometer. In order to diminish as much as possible the pressure losses incurred by the passage of a fluid through the tube the downstream section is made from one and one-half to two times the length of the up-stream section.

The theory and development of the equation for the Venturi meter[28] is identical with that of case (*b*) for the orifice, and need not be repeated here, except for the convenience of the reader, to rewrite equation (15)

$$W=\frac{\pi d^2}{4\times 144}C\sqrt{2g\Delta p\cdot\delta_1}\left[\frac{r^{2/y}}{1-r}\,\frac{y-1}{y}\,\frac{1-r^{\frac{y-1}{y}}}{1-\beta^4 r^{2/y}}\right]^{1/2} \qquad (17)$$

In this case a and d are respectively the minimum area and diameter of the throat section. The values of the coefficient C, for well designed and carefully made tubes for measuring gas, will generally be between 0.98 and 1.00.

As mentioned under case (*b*) for the orifice meters the use of this equation requires a knowledge of the specific heats of the gas, to obtain which may require careful laboratory work. If the composition of the gas is not constant, as is the case in some natural-gas works where the gas is being drawn from different wells in varying proportions, this will add further difficulties to the use of a Venturi meter. Another disadvantage of this meter is that it is more expensive to make than the orifice meter, and also it can not be so easily installed in an existing piping system without considerable alteration of the piping.

On the other hand, it is very accurate, probably always giving results correctly within 1 or 2 per cent. In fact, there have been several cases reported where Venturi meters connected in series with large wet-station meters, have, over long periods of time, shown variations of less than 1 per cent as compared to the wet-station meters.[29] Another advantage is that these meters are not subject to excessive wear and foreign substances in the gas, such as sand, salt water, and oil, have practically no effect on the indications of the meter.

In most commercial installations a recording instrument is provided with the Venturi meter. In some cases these recorders merely record the pressures, usually p_1 and p_1-p_2, or Δp, and sometimes the temperature t_1 may be also recorded. In other instances the recording instrument may be so constructed as to record the rate of flow in cubic feet per hour or other units and also, by means of an

[28] For the full development and discussion of the Venturi meter equation, see Appendix C, Fluid Meters, Their Theory, and Application, Part 1, Report of A. S. M. E. Special Research Committee on Fluid Meters. Also see The Theory of the Pitot and Venturi Tubes, by E. Buchingham, Part 2, Report 2, First Annual Report of the National Advisory Committee for Aeronautics.

[29] See Proceedings of American Gas Institute, 9th annual meeting, October, 1914.

integrating attachment, give the total amount of gas passed. Instruments of this later kind are ideal for use on gas which has practically constant physical properties, but in cases where the physical properties of the gas vary frequently this recorder would not be of so much advantage.

(1) USING VELOCITY METERS.—The uses to which flow or velocity types of meters can be put are so varied that it is out of the question to attempt to enumerate them. However, it will undoubtedly be very helpful to note a few conditions under which no type of flow meter can be expected to give reliable results and which should, therefore, be avoided. These conditions are:

1. Avoid pulsations. Up to the present time there is no satisfactory method known for using any type of velocity meter which will give reliable results when the gas flow is pulsating.

2. Do not have bends near the meter. It is essential, particularly with orifice meters and Pitot tubes, that these meters be preceded and followed by as long a length of straight pipe as possible, at least 20 to 30 pipe diameters being desirable. While not essential it is very desirable to place a honeycomb section, or straightening vanes, in the pipe 12 to 15 feet upstream of the orifice plate. These should be fastened securely in the pipe so that they can not be blown down the pipe.

3. Do not use a ratio of differential to static pressure ($\Delta p/P_1$) which is in excess of that used when determining the meter coefficient. One writer on orifice meters recommends that the differential pressure, in inches of water, should never exceed twice the absolute static pressure in pounds per square inch.

4. Determine the density or specific gravity of the gas often enough to insure using the correct value.

5. For orifice meters be sure that the locations of the pressure taps are in accord with those of the installation at which the coefficients which you are using were established. With thin plate orifices see that the orifice edges, particularly the upstream edge, are square and free from burrs. The minimum rate of flow at which satisfactory results can ordinarily be obtained with a given orifice will be approximately that corresponding to a value of the differential to absolute static pressure ratio which is about one-fifth the value (of this ratio) corresponding to the maximum rate of flow for which the orifice is to be used.

(e) ROTARY METER

The general plan of a rotary or turbine gas meter is clearly illustrated by Figure 59. As is shown by the figure the principal feature of a rotary gas meter consists of a turbine or fan wheel with inclined vanes so held within the gas passage that it will operate a chain of recording dials. Meters of this type offer but little resistance to the passage of the gas and may be made to handle very large volumes. Since the size of one of these meters is very much less than that of a wet station meter capable of handling the same volume, they are occasionally used in place of a wet station meter.

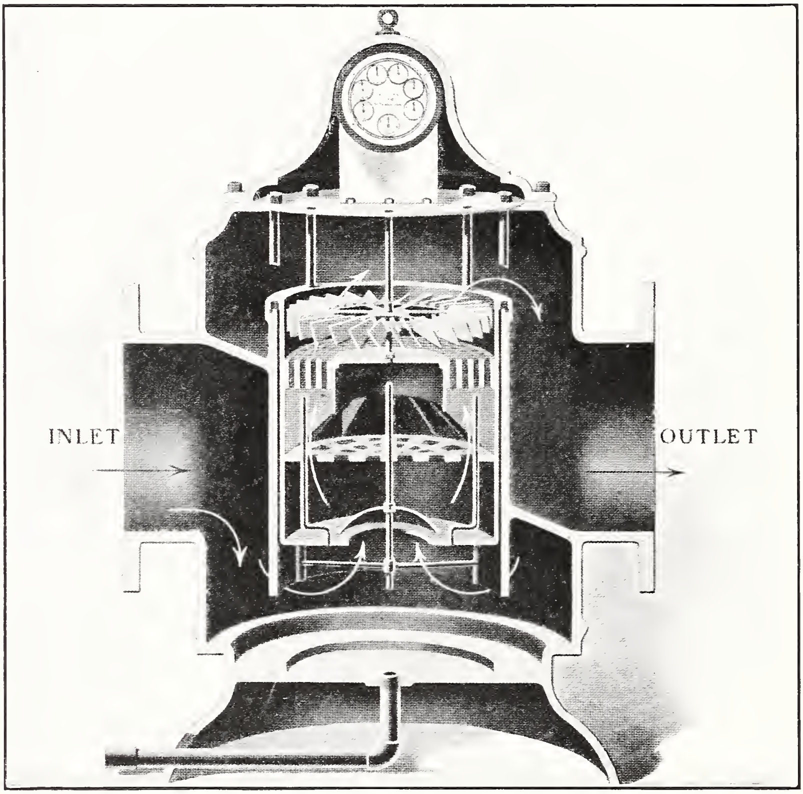

Fig. 59.—*Rotary meter, anemometer type*

There are two disadvantages which seem to be inherent in meters of this type. Like a turbine water meter they will not register on very low flows since the gas must have sufficient velocity in order that it may exert enough force on the moving vanes to overcome the resistance of the moving parts. Also these meters register low when measuring gas at rates considerably below their capacities. Another disadvantage which some observers have reported is, that when used to measure manufactured gas containing large quantities of oil vapors, grease and dirt are likely to collect on the vanes and cause a slowing down of the meter.

(f) FLOAT METERS

A large variety of float meters or flow meters have been devised for measuring or indicating the rate of flow of a gas. Figures 60, 61, 62, and 63 illustrate some meters of this type which have been put on the market. In each case an attempt is made to use the kinetic energy of the flowing gas to operate some kind of an indicating device which will show the rate at which the gas is flowing. For the most part these meters have been used on relatively small gas flows, although meters of the type shown in Figure 63 may be used on larger flows.

Tests made at this bureau on a meter like that shown in Figure 60 indicate that while one of these meters may be reasonably accurate when used on air measurement the calibration does not hold when the meter is used to measure a gas of a different density. The ratio of the actual to the indicated discharge seems to be very nearly directly proportional to the square root of the ratio of the density of air to that of the gas flowing. Expressed mathematically, that is

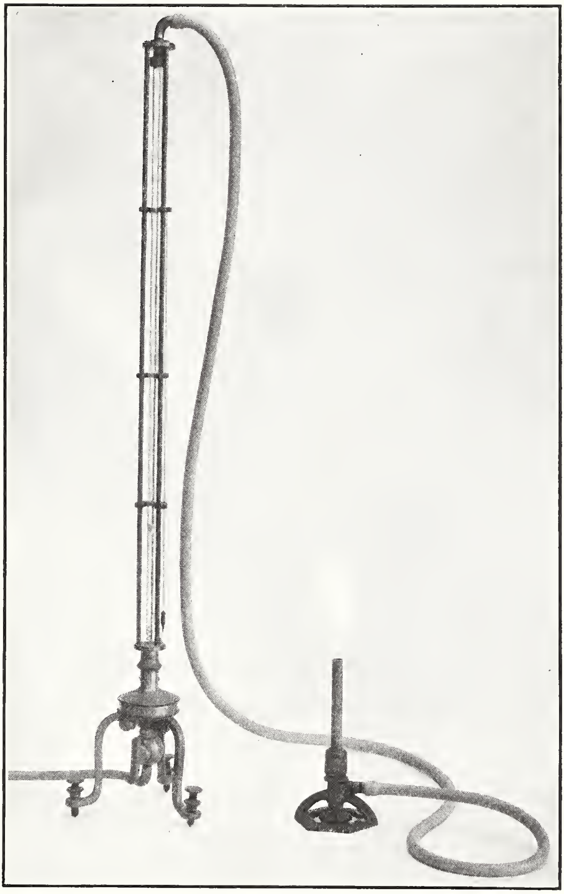

Fig. 60.—*Float type meter for small rates of flow*

The float may be seen about one-fifth of the way up the tube.

$q_a/q_i=f\sqrt{\frac{\delta_a}{\delta_g}}$ where q_a is the actual flow, q_i the indicated flow, δ_a and δ_g the densities of air and the gas, respectively, and f a proportionate factor of nearly unity. Whether this approximate relation

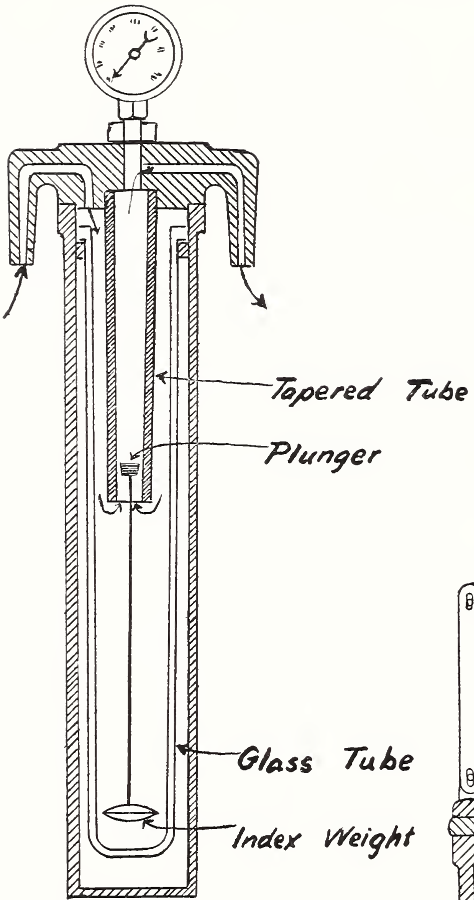

FIG. 61.—*A float type gas meter*

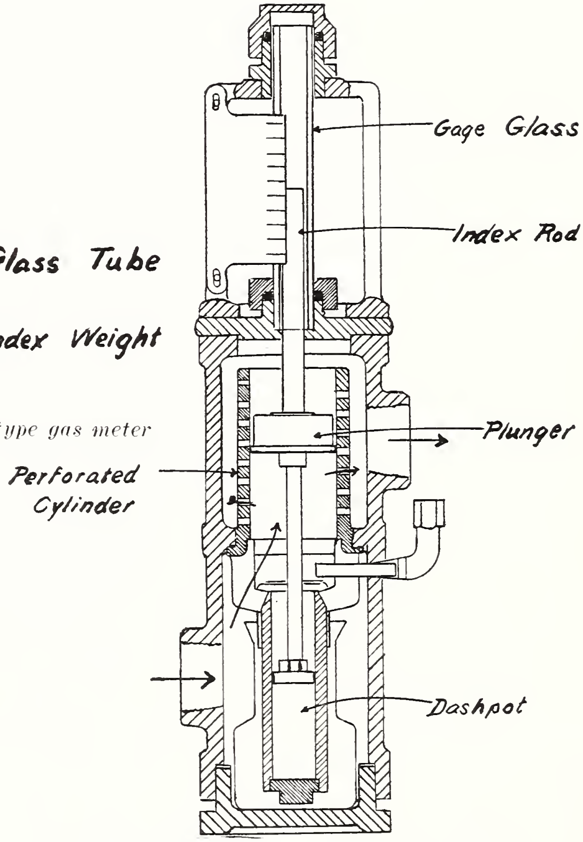

FIG. 62.—*A float or plunger type gas meter*

Such meters as shown in Figures 61 and 62 may be used for measuring the air supplied pneumatic tools or for regulating the feeds to oxyacetylene torches holds for all types of float meters or applies only to the type used in the tests has not been determined.

The chief use to which meters of this type seem to be adapted is in regulating the flow of gases into mixtures, as, for example, to regulate the quantity of oxygen and acetylene supplied to a torch and in the measurement of air supplied to pneumatic tools. In some instances float and gate type meters have been used to measure air flows in which there were compressor pulsations.[30]

3. MEASUREMENT OF GAS BY HEATING

These meters make use of the principle that the specific heat of a gas at constant pressure is practically constant at all ordinary tem-

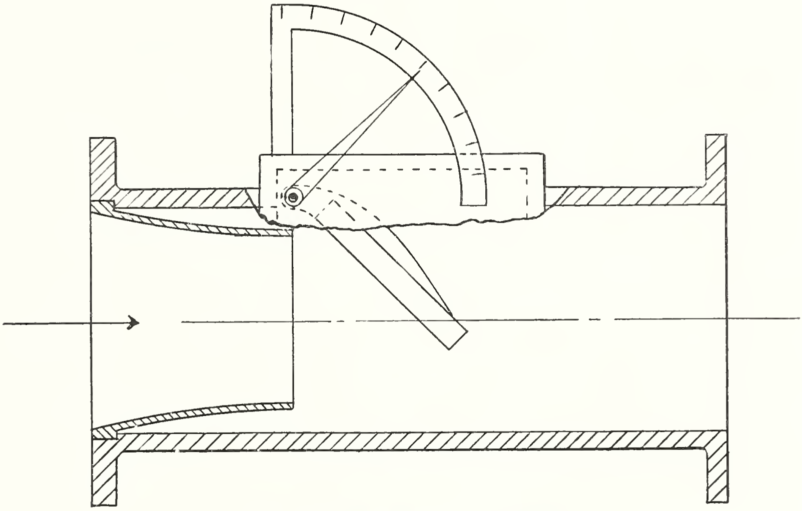

Fig. 63.—*Gate type gas meter*

This illustrates the primary features of a gate type gas meter which may be used for measuring large rates of flow.

peratures. Hence the heat energy required to change the temperature of a given mass of gas by a definite amount will be practically constant regardless of the initial temperature and pressure of the gas within the range of temperature and pressures ordinarily encountered. To use this principle means are provided to heat the gas.[31] The amount of heating is determined by measuring the rise in temperature by suitable thermometers placed ahead of and beyond the heater. Then if the amount of heat energy supplied to the heater per unit time and the specific heat of the gas at constant

[30] The commercial metering of air, gas, and steam, by J. L. Hodgson, Proc. Inst. of C. E., 204, pt. 2.

[31] Theoretically the gas could just as well be cooled as well as warmed, but practically it is not convenient to do so and is never done.

pressure is known the weight of gas flowing per unit time may be calculated by

$$b = W c_p \Delta t \qquad (18)$$

Or

$$W = \frac{b}{c_p \Delta t}$$

where

b=the heat energy supplied the heater in B. t. u. per second.

c_p=specific heat of the gas at constant pressure in B. t. u. per pound.

Δt=rise in gas temperature, in °F.

W=mass rate of gas flow, pounds per second.

If the density of the gas is known the volume of gas flowing per unit time may easily be found, if desired.

In using this method of gas measurement it is important to remember that, in general, the speed of gas flowing within a pipe is not uniform over a cross section of the pipe but varies from a minimum at the sides to a maximum at the center. For this reason if, for example, an electrical resistance thermometer of grid form is placed within a pipe in such a way that the resistance wire is uniformly distributed with respect to the cross sectional area the temperature indicated by it will be a space average and not a mass average. Also if the heater is so built as to distribute the heat uniformly with respect to the cross sectional area the heat received by a unit mass near the side will be greater than that received by a unit mass at the center because it will be in contact with the heater longer. For these reasons the heater and thermometers should be so designed and spaced with respect to the cross sectional area as to take account of the distribution of gas speed across the section.[32] This will necessarily involve a great deal of experimenting and since the distribution of gas speed is rarely the same in any two cases we can expect only to approximate the ideal of equally heating each unit mass and of determining the average temperature of this mass. While theoretically we could secure the uniform heating of the gas and determine the average temperature by causing such a complete mixing of the gas, as it passes the heater and thermometer, that the component velocity parallel to the axis of the pipe will be very nearly constant over the entire section, such a method is, of course, impractical.

(a) ELECTRICAL GAS METERS (THOMAS METER)

Up to the present time practically the only meter on the market of the heat-exchanging type is the Thomas electric gas meter, illus-

[32] For a discussion of the distribution of gas speed within pipe, see the section on Pitot tubes, page 59.

trated by Figure 64. Sufficient electrical current is supplied the heater to raise the temperature of the gas a definite amount, usually 2° F. The entrance and exit electrical resistance thermometers measure the temperature of the gas both before and after it passes the heating grid. These thermometers are also interconnected with the rheostat regulating the current to the heating grid by means of a Wheatstone bridge connection so that the amount of current supplied the grid will be just sufficient to produce the 2° F. change of temperature. The electrical energy supplied the heater is measured by an intergrating wattmeter, or by a wattmeter.

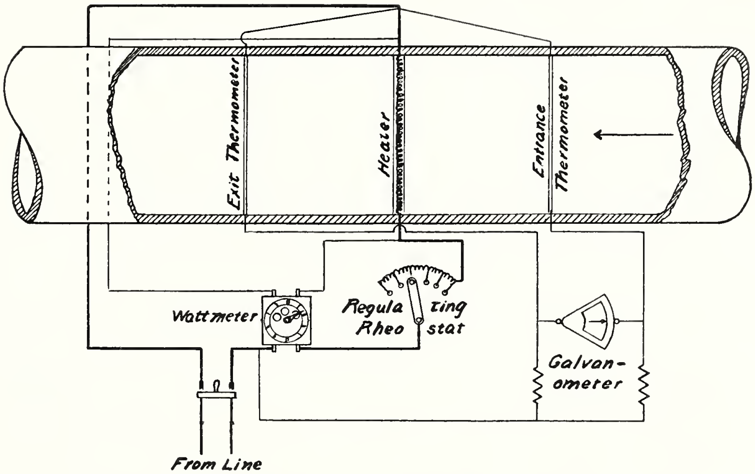

Fig. 64.—*Connections of a Thomas electrical gas meter*

The equation for the gas flow is

$$W = \frac{0.0009486 \times J}{c_p \Delta t} \tag{20}$$

where

W=the rate of flow in pounds per second

J=electrical energy in joules (watt-seconds)

and

c_p is in B. t. u.'s per pound and Δt is in ° F.

In the complete instrument, as set up by the manufacturers, the integrating wattmeter which measures the current supplied to the heating grid is usually geared to indicate the volume of gas passed in cubic feet under whatever conditions of temperature and pressure have been determined upon for a measuring base. The mechanical features of the mechanism connecting the thermometers with the regulating rheostat are elaborate and carefully worked out so that, according to reports, there is very little lag between changes in the rate of flow of the gas and the corresponding change in the meter indication.

One of the chief advantages of this type of meter is that for many commercial gases the specific heat of the gas at constant pressure is practically constant, and the accuracy of the meter will, therefore, be unaffected by variations in the initial temperature and the absolute pressure of the gas passing. Another advantage is that the gas passage of the meter may be placed in a position not easily reached and the regulating and recording mechanism placed at some distance in a convenient position.

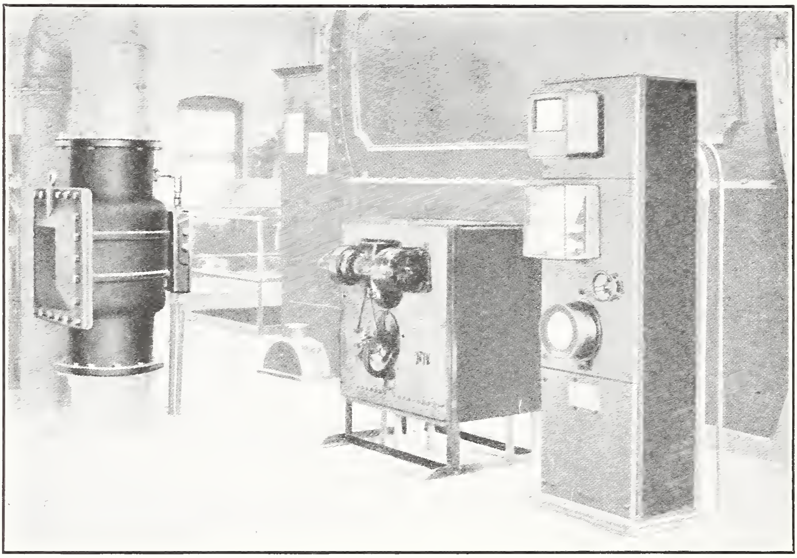

FIG. 65.—*A commercial Thomas meter installation*

The gas passage of the meter is so placed that the direction of gas flow is upward.

On the other hand, it would seem that if the gas carried a considerable amount of dust and oils these would in time collect on the heating and thermometer screens in sufficient quantity to interfere seriously with the accuracy of the meter. In fact, if the gas carries suspended particles of moisture the indications of the meter will be entirely unreliable unless provision is made for vaporizing the suspended particles of free water. Furthermore, the use of this type of meter is restricted to locations at which a sufficient supply of electric energy is available.

For commercial use Thomas meters are made in sizes ranging from a maximum capacity of about 25,000 to 1,500,000 cubic feet per hour. The minimum capacity may in some sizes be as low as one-tenth the maximum capacity,[33] although it would probably be safer in most cases to regard the minimum capacity as about one-eighth of the maximum.

The published reports of some tests on these meters would indicate that they are reasonably reliable.[34]

4. PROPORTIONAL METERS

Meters of this class, as the name indicates, measure only a part of the total amount of gas passing. By means of an automatic adjusting valve a definite proportion of the gas is by-passed through

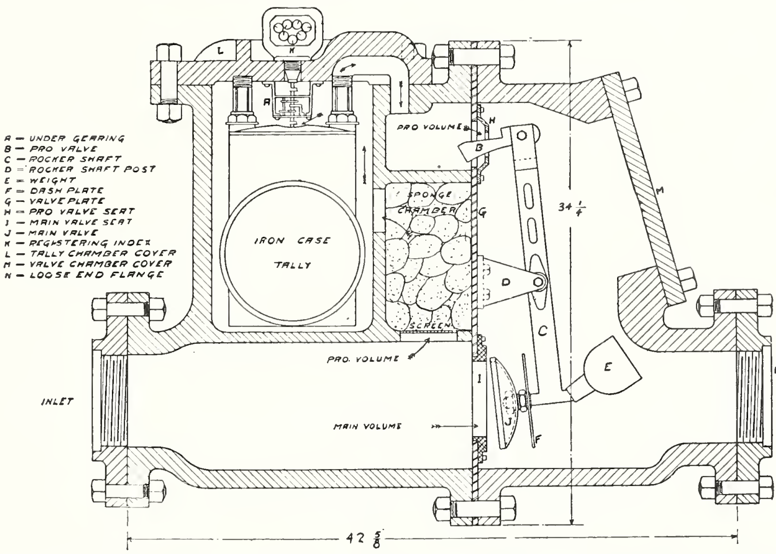

FIG. 66.—*Section through a proportional meter showing one type of proportioning valve*

what is called a tally meter. The relative volume of gas passing through the tally meter to the total volume flowing will depend not only upon the relative area of the two passages through the meter, but also upon the relative resistance which these passages present to the flow of the gas. This ratio of volumes will also vary to some extent with the capacity and make of the meter, and thus no general figures on it are available. The dial mechanism of the tally meter is made to read the total volume of gas passed. In some makes of proportional meters the tally meter is an integral part of

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[33] The maximum capacity is determined by the size of the heating grid and the voltage of the supply line. The minimum capacity will be determined by the size of the resistance of the rheostat in series with the heating coil.

[34] Proceedings Am. Gas Inst., **9**, p. 698; 1914. J. Franklin Inst., **172**, p. 411, November, 1911.

the meter, while in other meters the tally meter is connected to the valve-mechanism case by suitable piping so that it may be disconnected and tested without removing the entire proportional meter. Like all other types of meters, these meters have a minimum as well as a maximum capacity at which they will work accurately, the minimum capacity being from one-sixth to one-seventh the maximum capacity of the meter. Proportional meters may be obtained with capacities up to about 150,000 cubic feet per hour. Many of these meters are built to withstand high-line pressures. These meters have been used mostly in the measurement of natural gas in large quantities.

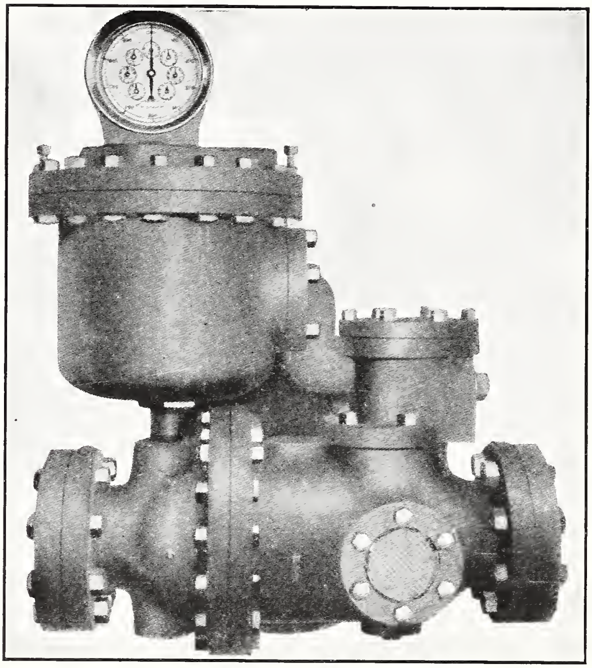

Fig. 67.—*A proportional gas meter*

In the proportional meters shown in Figures 66 and 67 the tally meter is within a special chamber attached to, or forming a part of, the housing of the valve and main gas passage.

One objection that has been made to the proportional meter is that it is very liable to become inaccurate through clogging of the proportioning valve so that the proportion of the total volume going through the tally meter is changed. This will occur most frequently in the case of meters using valve mechanisms in which there are bearings or finely adjusted parts on which dust and grease from the gas may collect. An inaccuracy in the tally meter produces an error of the same magnitude in the indication of the total volume regardless of the proportioning ratio. To illustrate, if the tally meter is inaccurate by 2 per cent then the indicated total volume will be inaccurate by 2 per cent also.

For the purpose of testing, proportional meters are usually connected in series with some other type of large capacity meter, such as an orifice meter, funnel meter, or Pitot tube. Where the testing has been done in the field, the funnel meter has been generally used.

Where the tally meter is removable, it may be removed and tested with the ordinary meter prover. Testing the tally meter alone does not test the accuracy of the proportioning valve.

VI. ANOTHER METHOD OF MEASURING GAS

1. GAS MEASUREMENT BY THE METHOD OF MIXTURES

This method consists of introducing a suitable gas at a known rate into the conductor carrying the gas which is to be metered. After the gases have become thoroughly mixed the percentage of the intro-

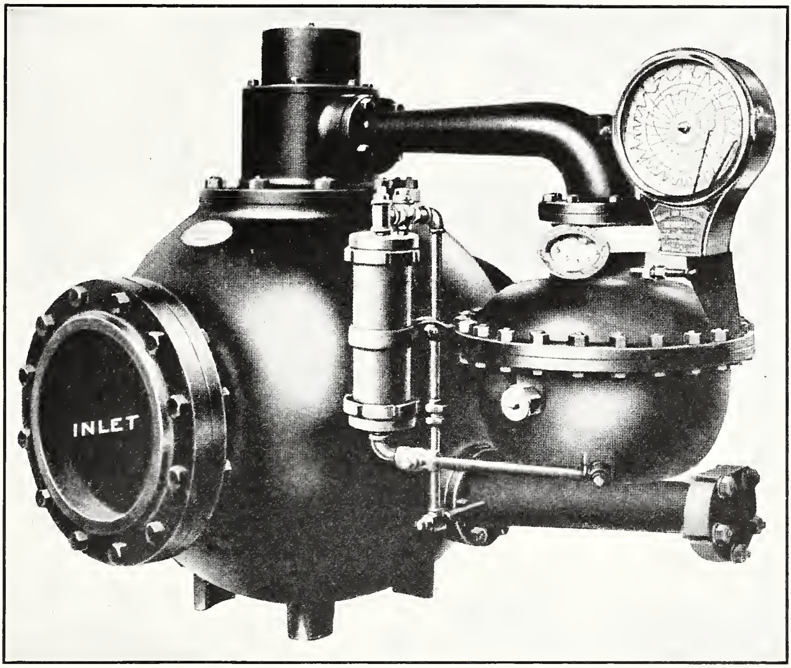

Fig. 68.—*A proportional gas meter*

Here the tally meter is not inclosed in the housing containing the main gas passage and proportioning valve.

duced gas existing in the mixture is determined. From this data it is possible to compute the volume of the gas flowing in the conducting channel.

The calculations involved in this method are simple, and are as follows: Let

Q=the volume of gas to be measured flowing per unit time past any given cross section of the pipe (the volume per unit time which is to be determined).

q=the volume of testing gas introduced per unit time.

F=the fraction of the testing gas existing in the mixture.

Then

$Q+q$=the total volume of gas flowing per unit time past a second section below the point of introducing the testing gas.

And therefore,

$$F=\frac{q}{Q+q}, \text{ or } F(Q+q)=q \qquad (21)$$

and

$$FQ=q-Fq \qquad (22)$$

from which

$$Q=\frac{q-Fq}{F} \qquad (23)$$

$$=\frac{q(1-F)}{F} \qquad (24)$$

The degree of accuracy within which the chemical analysis of the mixture can be made will depend to a large degree upon the compositions of the original gas and the testing gas. By proper selection of the testing gas it is probable that the error in this analysis will be less than 1 part in 100 and under some conditions may be reduced to 1 part in 1,000 or less. However, the rate at which the testing gas is introduced into the original gas stream must also be measured and this may present greater difficulties than the chemical analysis. It is therefore possible that the degree of accuracy with which Q can be determined will depend upon the degree of accuracy with which the rate of introduction of the testing gas can be measured rather than upon the degree of accuracy to which the chemical analysis can be carried.

While there appears to be no record of instances in which this method has been used in actual practice to measure gas flows it has been used in one instance to measure the flow of steam in pipes.[35]

VII. DEFINITIONS

(NOTE.—These definitions relate primarily to the measurement of fuel gases.)

1. A standard *cubic foot* of gas shall be taken as that quantity of gas, saturated with water vapor, which, at a temperature of 60° F. and under a pressure of 30 inches of ice-cold mercury at standard gravity, occupies a space of 1 cubic foot. Unless specifically defined otherwise, for the purpose of measuring gas to a consumer, a cubic foot of gas is considered as that quantity of gas which under the conditions of temperature, pressure, and humidity existing at the time and place of measurement occupies a space of 1 cubic foot.

[35] Steam Flow Measurements; by E. G. Bailey, Journal A. S. M. E., October, 1916.

2. The *standard conditions* of gas measurement are, by common practice and general use, understood to be a temperature of 60° F. (=520° absolute in Fahrenheit degrees) and a pressure of 30 inches of ice-cold mercury at standard gravity. In some cases 0° C. and 760 mm of mercury are used as the standard temperature and pressure, respectively.

3. The *atmospheric pressure* shall be considered as the corrected barometric indication at the place and time the measurements are made and shall be expressed in inches of mercury, pounds per square inch, or in millimeters of mercury. Where a great many routine calculations are to be made involving the atmospheric pressure it is customary to assign it a fixed value and not refer to the barometer on each occasion. For this purpose a value of 14.4 pounds per square inch is frequently used.

4. *Gauge pressure* shall be understood to be the difference between the total pressure of a gas and atmospheric pressure and is commonly expressed in pounds per square inch, inches of water, or inches of mercury. In most cases in actual practice, gauge pressure is taken as the reading of a pressure gauge, which is commonly graduated to read in pounds per square inch, the zero being atmospheric pressure.

5. The *absolute pressure* of a gas is the total pressure exerted by it and is equal to the algebraic sum of the atmospheric and gauge pressures, expressed in the same units.

6. The *absolute temperature* of a gas is its temperature above the zero of the absolute or thermodynamic scale which for an ideal gas is 273.13° C. (=491.6° F.) below the ice point (that is, freezing).[36]

Thus for all ordinary purposes, absolute temperatures are numerically about 460 Fahrenheit degrees higher than the temperatures indicated by an ordinary Fahrenheit thermometer, and about 273 centigrade degrees higher than the temperatures indicated by a centigrade thermometer.

7. The *specific gravity* of a gas shall be taken as the ratio of the weight of a unit volume of the dry gas to the weight of a similar unit volume of dry air free from carbon dioxide, both gas and air being under standard conditions. In actual practice it is common to compare the weights per unit volume under the temperature and pressure conditions existing at the time and place the comparison is made and to neglect any errors introduced by these nonstandard conditions.

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[36] See Table 206, p. 195, Smithsonian Physical Tables, 7th Rev. Ed., 1920.

VIII. RELATIONS BETWEEN PRESSURE TEMPERATURE AND VOLUME FOR AN IDEAL GAS

The volume occupied by a given quantity of gas varies with the temperature and pressure. In order to make two volumes of gas comparable it is therefore necessary either to measure them under the same conditions of temperature and pressure, or to make corrections to determine what volumes would have been occupied if they were under the same conditions. Ordinarily, standard conditions of temperature and pressure are chosen for this comparisan; for scientific work, where the metric system is employed, the standard conditions generally chosen are 0° C. and 760 mm of mercury pressure. In technical work, and especially in the gas industry, 60° F. and 30 inches of mercury pressure are usually chosen.

When the temperature remains constant the volume of a dry gas [37] varies inversely as its pressure.[38] In other words, the product of the pressure and volume remains constant. This is expressed by the equation

$$p_1v_1=p_2v_2 \qquad (25)$$

where p_1 and v_1 represent one pressure and the corresponding volume, and p_2 and v_2 represent any other pressure and the corresponding volume occupied by the fixed quantity of gas. Obviously, if p_1, p_2, and v_1 are known, the volume v_2 may be ascertained from the equation

$$v_2=\frac{v_1p_1}{p_2} \qquad (26)$$

When the pressure remains constant the volume of the dry gas varies directly as the temperature above a certain point called the absolute zero. This point is about −273° C. (or −460° F.). In other words, the volume of a gas increases one two hundred and seventy-third of its volume at 0° C. for every degree rise in temperature on the centigrade scale, or one five hundred and twentieth of its volume at 60° F. for every degree rise in temperature on the Fahrenheit scale. When the volume v_1 is known at any temperature t_1, and pressure p, the volume v_2 which it would occupy at the

[37] The term "dry gas" as used here means a gas that contains no water vapor or other constituent that will be condensed to the liquid condition by the temperature or pressure changes of the magnitude under consideration.

[38] It must always be remembered that the pressure on a gas is equal to the pressure above atmospheric usually observed, plus the barometric pressure at the time of observation. Gas pressures above atmospheric are usually expressed by the height of the water column supported by the gas pressure. This must be divided by 13.6 to reduce it to the height of the equivalent mercury column in terms of which the atmospheric pressure is usually expressed.

temperature t_2, and the same pressure p, may be found from the equation:

$$v_2 = \frac{v_1(t_2+273)}{(t_1+273)} \tag{27}$$

where t_1 and t_2 are in centigrade degrees; or

$$v_2 = \frac{v_1(t_2+459.6)}{(t_1+459.6)} \tag{28}$$

where t_1 and t_2 are in Fahrenheit degrees. For small changes of temperature and pressure, such as ordinarily occur, the variations from these ideal gas laws are far too small to be of any consequence.

These four equations may be combined to give two equations for calculating the volume of dry gas when both temperature and pressure change.

$$v_2 = \frac{v_1 p_1(t_2+273)}{p_2(t_1+273)} \tag{29}$$

where t_1 and t_2 are in centigrade degrees; or

$$v_2 = \frac{v_1 p_1(t_2+459.6)}{p_2(t_1+459.6)} \tag{30}$$

where t_1 and t_2 are in Fahrenheit degrees.

The above equations apply only to dry gas.

When the gas is confined over water there is always some water vapor present which increases the pressure or the volume of the confined gas. If enough time has been allowed for the gas to become saturated the increase in pressure or volume due to the water vapor depends only upon the temperature. Since commercial illuminating gas always contains water vapor and is usually measured over water in testing work, it is customary and most convenient to measure the saturated gas. The effect of the water vapor on the pressure or the volume of the gas is indicated by the following equations; in these the vapor pressure of water, w_1 and w_2, corresponding to temperatures t_1 and t_2, respectively, are subtracted from the total pressures p_1 and p_2.

$$v_2 = \frac{v_1(p_1-w_1)\ (t_2+273)}{(p_2-w_2)\ (t_1+273)} \tag{31}$$

where t_1 and t_2 are in centigrade degrees; or

$$v_2 = \frac{v_1(p_1-w_1)\ (t_2+459.6)}{(p_2-w_2)\ (t_1+459.6)} \tag{32}$$

where t_1 and t_2 are in Fahrenheit degrees.

By these equations the volume v_2 of any amount of gas saturated with moisture under any conditions, such as p_2 and t_2, can be calculated if the volume of this gas v_1 is known for pressure p_1 and temperature t_1. If it is desired to find the volume occupied by this amount of gas when dry, it is only necessary to consider w_2 as equal to zero and proceed with the same equations. Similarly, if the gas is dry when at p_1 and t_1, w_1 is considered as equal to zero.

IX. CAPACITY TESTING CONSUMERS' DRY GAS METERS

In order that there might be a uniform method for determining and rating the capacities of dry gas meters the American Gas Association directed its Consumers' Meters Committee for 1922 to prescribe such a method which the association might adopt as a standard. In accordance with this direction the committee drew up the following outline, which was adopted by the association at its annual meeting of 1922:

DETERMINATION OF METER CAPACITIES

(a) DEFINITIONS

1. *Air capacity of meter.*—The air capacity of a meter is the volume of air which a correctly adjusted meter will indicate has passed through it in one hour when the pressure drop between inlet and outlet of the meter has been maintained uniform and equal to ½ inch of water column.

2. *Gas capacity of meter.*—The gas capacity of a meter is the volume of a gas other than air which a correctly adjusted meter will indicate has passed through it in one hour when the pressure drop between inlet and outlet of the meter has been maintained uniform and equal to ½ inch of water column.

3. *Relation between air and gas capacity.*—For all practical purposes the gas capacity of a meter may be expressed in terms of the air capacity by the following equation:

$$(\text{Gas capacity}) = (\text{Air capacity}) \times \sqrt{\frac{1}{\text{Sp. Gr. of gas}}}$$

4. "*Rated*" (*or badged*) *gas capacity of meters.*—For the purpose of marking the capacity of a meter upon a badge on the front gallery plate of the meter the capacity thus indicated shall be 1.25 times the air capacity of the meter.

(b) METHOD OF DETERMINING METER CAPACITIES

(1) CONDITIONS.—1. The medium used when making capacity tests of meters shall be air (unless it is unnecessarily difficult or impracticable to use air).

2. The pressure of the air (or gas) supply at the meter inlet shall not exceed a pressure of 10 inches of water column above atmospheric, and it is recommended that whenever possible it be maintained between 1 and 2 inches.

NOTE.—Due to the decrease in the atmospheric pressure at localities of relatively high elevation (2,000 feet and over) the density of the air at these localities is less than at those localities of low elevation. Therefore, meter capacity tests made at the higher elevations will not agree with those made on the same meter at lower elevations unless the difference in the average atmospheric pressures, as obtained from barometer readings, is taken into consideration. This may be done by means of the following equation:

$$\text{Capacity (high el.)} = \text{Capacity (low el.)} \times \sqrt{\frac{\text{avg. barometer (low el.)}}{\text{avg. barometer (high el.)}}}$$

When meters are used in localities of the same general elevation as that at which the capacity tests were made, the effects of any difference in the atmospheric pressures may be neglected.

3. The temperature of the air (or gas) shall be maintained as near 60° F. as is reasonably possible under ordinary working conditions.

4. The pipes, hose, valves, and other fittings between the meter and prover shall be of such size that they will carry, without causing more than an appreciable pressure drop, the full capacity of the meter under a one-half inch drop between inlet and outlet.

5. The valves for controlling the flow of air (or gas) into and out of the meter shall be placed at such distances from the meter as not to interfere with the obtaining of reliable pressure readings.

6. A differential water manometer, or gauge, shall be connected across the inlet and outlet of the meter to indicate the pressure drop through the meter. The pressure-gauge connection taps in the inlet and outlet pipes shall be as close to the meter connections as possible. (In place of the differential manometer, separate water manometers, or gauges, may be connected to the inlet and outlet pressure connections, and the difference in the two readings determined. This, however, involves more work and is more open to errors.)

(2) PROCEDURE.—(*a*) Where a calibrated meter prover is used as the air supply.

1. With the meter and differential pressure gauge properly connected, open the inlet and outlet valves and, while the meter is in motion, adjust the outlet valve until the pressure loss between inlet and outlet is one-half inch of water. The fluctuations of the liquid in the differential gauge should be averaged in the determination of the pressure loss.

2. After obtaining the desired average pressure loss allow the meter to remain in operation for a few seconds, then close the inlet valve, leaving the outlet valve in the position just determined. Refill the prover as much above the zero mark as possible.

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3. Open the inlet valve gradually so as not to throw a sudden load upon the meter, but so as to bring it up to speed as quickly as possible. (This should not require more than 0.1 or 0.2 of a cubic foot and will give the meter a flying start.)

4. As the pointer of the prover passes the zero mark of the scale, start a stop watch.

5. As the second hand of the stop watch passes the one-minute point, note the reading of the prover. (When only a 5-cubic-foot prover is available for making meter-capacity tests, one-minute readings may be obtained with meters having hourly capacities of up to 300 cubic feet, and half-minute readings with meters having hourly capacities of up to 500 cubic feet. No meter having a capacity of over 500 cubic feet per hour under a five-tenths loss of pressure, should be capacity tested by means of a 5-cubic-foot prover. When testing meters having hourly capacities of 300 cubic feet or less with a 10-cubic-foot or larger prover, two-minute readings may be obtained if desired.)

6. Multiply the reading of the prover for the first minute by 60, the product being the air capacity of the meter. (The same results should be obtained by multiplying the reading for the half-minute by 120, or the reading for the two minutes by 30.)

7. Multiply the air capacity thus determined by 1.25 to obtain the "rated" gas capacity of the meter.

(*b*) When the air (or gas) supply is not obtained from a calibrated prover.

1. With the meter and differential pressure gauge properly connected, open the inlet and outlet valves and, while the meter is in motion, adjust the outlet valve until the pressure loss between inlet and outlet is one-half inch of water. The fluctuations of the liquid in the differential gauge should be averaged in the determination of the pressure loss.

2. With the meter still going, start a stop watch as the meter test hand passes a "zero" or starting point. (Some operators prefer to use the tangent instead of the test hand for making this test. To use the tangent, however, it is necessary that the top of the meter be removed. When testing meters of the open-top type this would not be feasible.)

3. As the test hand again passes the "zero" point after making one revolution, stop the stop watch and then close the inlet valve to the meter. (If desired, the test hand may be allowed to make two or more revolutions.) Record the volume passed by the meter and the time interval as shown by the stop watch.

4. From the time required for the meter to pass the recorded volume, calculate the volume that would pass in one hour. This will be the air capacity of the meter.

5. Multiply the air capacity by 1.25 to obtain the "rated" gas capacity of the meter.

(*c*) Where gas (other than air) is used as the testing medium.

1. The procedure is the same here as in cases (*a*) or (*b*), except in the calculations, (*a*) 6 and 7 or (*b*) 4 and 5.

2. From the time required to pass the measured volume of gas, calculate the volume of gas that would pass in one hour. This will be the gas capacity of the meter for the particular gas used in the test.

3. Determine the specific gravity of the gas used. (This may be done from a chemical analysis with an Edwards density balance or with an effusion apparatus.) If the specific gravity is approximately 0.64, then the gas capacity as calculated above may be taken as the rated capacity of the meter.

4. If the specific gravity of the gas differs from 0.64 by more than 3 or 4 per cent, then the rated gas capacity should be calculated by the equation:

$$(\text{Rated gas capacity}) = (\text{Gas capacity}) \times \sqrt{\frac{\text{Sp. Gr.}}{0.64}}$$

(3) Reporting.—For the purpose of reporting meter capacities and badging meters with their rated gas capacity, the rated gas capacity of a meter shall be reported to the nearest even 10 cubic feet lower than the calculated capacity. (For example, if the rated gas capacity of a meter is figured to be 273 cubic feet per hour, it shall be reported and marked as having a rated gas capacity of 270 cubic feet.)

X. CORRECTIONS AND ERRORS

1. GENERAL REMARKS

Before discussing the calculation of "corrections" and "errors" we will define these terms as they are used in this circular. A "correction" is that quantity which must be added to or subtracted from an indicated or nominal value in order to obtain the true value; that is, it is the true value minus the indicated value. The "error" is that amount by which an indicated value deviates from the correct or actual value; that is, it is the indicated value minus the true value. The numerical value of the correction and error in any given case will be the same, but their algebraic signs will be opposite. For example, suppose we have a meter stick, the length of which is marked as 1.000 meter, but when we compare it with a standard meter bar we find that its actual length is 1.005 meters. Now the indicated value of the meter stick is 1.000 meter, its nominal length, hence the correction to this indicated value is +0.005 meter (1.005−1.000), and 1.000+0.005=1.005, the "actual" or "correct" length of the meter stick. On the other hand, the "error" of the indicated length of the stick is —0.005 meter (1.000—1.005= —0.005), the amount by which the indicated length deviates from the actual length. Then we may say that since the indicated length of the stick is in error by —0.005 meter its actual or correct length must be 1.000—(—0.005)=1.005 meters (that is, 1.000+0.005). This example is illustrated by Figure 69.

As a second example, suppose that on test a gas meter indicates that 4.0 cubic feet of gas have been passed through it while the prover reading shows only 3.5 cubic feet. Then clearly the "correction" to be applied to the observed value of indication of this meter is —0.5 cubic foot (3.5—4.0=—0.5). If, on the other hand, we first observed the indication of the prover, then we would say that the meter's indication is in error by +0.5 cubic foot.

From a study of the above two examples it will be seen that the relation between the correction and error may be stated as follows: Both correction and error take the reading of the reference standard (in one case the standard meter bar and in the other the prover) as

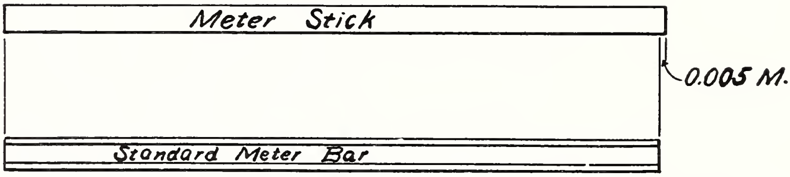

FIG. 69.—*Illustrating the correction to, and error of, a meter bar*

authentic. In the case of the correction we first note the indication of the instrument under test and then compare it with the indication of the standard. To determine the error the indication of the standard is first taken and this is compared with the indication of the instrument under test.

2. CALCULATION OF GAS-METER CORRECTIONS AND ERRORS

There are two methods in common use to-day for calculating the percentage correction and error of a meter, and as there have been some questions about them, they will be discussed in detail. The first method, which will be called "method A" for brevity, expresses the correction as a percentage of the meter indication and consists in dividing the algebraic difference of the prover indication minus the meter indication, multiplied by 100, by the meter indication. The second method, which will be called "method B," expresses the error as a percentage of the true flow as given by the prover readings, and consists in dividing the algebraic difference of the meter indication minus the prover indication, multiplied by 100, by the prover indication. To illustrate, assume that the meter indicated 5.00 feet and the prover 4.81 feet. Then by method A the percentage correction to the meter indication will be

$$\frac{(4.81-5.00)\times100}{5.00}=-3.80 \text{ per cent of the meter indication}$$

indicating that the meter is fast.[39] By method B the percentage of error of the meter is

$$\frac{(5.00-4.81)\times100}{4.81}=+3.95 \text{ per cent of the true volume, fast}$$

In practice these calculations are seldom performed in full, the percentage correction by method A being figured mentally or read direct from the prover scale, as will be explained later, and the percentage error of method B being found from tables given in almost all meter handbooks and catalogues.

Reduced to simple terms, the difference between the two methods is this: "A" determines what percentage of the gas registered actually passed the meter; "B" determines what percentage of the gas passing registers. "A" accepts the meter's indication as the basis, while "B" takes the volume of the gas passing as the basis of the calculation. Now, both of these methods are correct when we keep in mind the basis of calculation as given above. In the illustration recently quoted the meter was found only 3.80 per cent fast by one method and 3.95 per cent fast by the other. If the base of each calculation is remembered, these results are in nowise contradistory or discordant. By method A it is stated that the meter passed only 96.2 per cent (100—3.80) of what the meter dials showed, and 96.2 per cent of 5 feet gives us 4.81 feet, the actual volume of gas passed as shown by the prover reading. By method B it is seen that the meter registered 103.95 per cent of the gas that actually passed, which was 4.81 feet, and 103.95 per cent of 4.81 is 5.00 feet, the amount which the meter registered in the test.

For method B it is urged that the reading of the prover, which is authoritative, is accepted as the standard, but so it is with method A; that is, the reading of the prover is accepted as absolutely correct, but the register of the meter by method A is made the central thought and is taken as the total of 100 per cent. This is very advantageous because this is the only means which a customer possesses of ascertaining his gas consumption and the size of his bill. Almost without exception the vital point of interest to both customer and company is the amount of the customer's gas bill, and

[39] Fast is used to mean that the indication of the meter is in excess of the actual volume passed through it. Slow is used to mean that the indication of the meter is less than the actual volume passed.

this is invariably based upon the indication of the meter. It is therefore desirable to express any adjustment (correction) which must be made to the meter indication, and, therefore, to the customer's bill, as a percentage of the meter indication.

To put it in other words, one statement of percentage by method A answers all questions, and this is not true of method B. For instance, a certain consumer was informed that his meter was 10 per cent fast (this percentage being reached by method A), and he wrote to his public service commission to know what rebate he might expect. The answer was simplicity itself—10 cents on each dollar which he paid. Compare this with a similar case where the percentage was determined by method B. Another meter was tested and reported to the consumer as 42 per cent fast. The attorneys for complainant took this report to the company and were informed that a rebate of 42 per cent could not be granted, but that the correct percentage on which to figure said rebate was the ratio of 42 to 142, or 29.6 per cent, this latter figure being exactly the one which would have been reached in the first place by method A.

The scales on most meter provers are so divided, in the vicinity of the 2, 4, 5, and 10 foot marks, as to enable one to read off the percentage error of the meter direct, if method A is used. For example, the divisions at the 2-foot mark are 0.02 foot, or 1 per cent of the total length of the scale from zero to that point. At the 4-foot marks, the divisions are 0.02 or 0.04 foot; that is, ½ or 1 per cent of the scale length. The use of this feature of prover scales may save some time and labor.

We wish it to be distinctly understood that this discussion is not an attempt to prove that method B is incorrect, for it has previously been shown that both methods are mathematically correct. However, it is believed that method A, namely, the determination of the "correction" to be applied to the meter's reading as a percentage of that reading, involves less labor, is more easily comprehensible, and is therefore far less liable to give rise to difficulties with customers.

XI. TABLE OF SYMBOLS

A=Area of cross section of conduit along which fluid is flowing. (Square feet.)

a=Area of orifice, nozzle throat or Venturi tube throat. (Square feet.)

B=Atmospheric pressure.

C=Discharge coefficient=$\frac{\text{actual discharge}}{\text{theoretical discharge}}$.

c_p=Specific heat of fluid at constant pressure.

c_v=Specific heat of fluid at constant volume.

D=Diameter of pipe. (Inches.)

d=Diameter of orifice, nozzle throat or Venturi tube throat. (Inches.)
f=Function.
G=Specific gravity of fluid; for gases air =1.
g=Acceleration of gravity, 980.665 cm per second per second or 32.174 feet per second per second, international standard value, disregarding local variations.
H=Effective differential head. (Feet.) (The height from which a mass of density δ must fall freely to attain the velocity v.)
h=Effective differential head. (Inches of a liquid of density δ_w.)
I=Internal (or intrinsic) energy of fluid per unit mass. (Foot-pound per pound.)
K=Kinetic energy per unit mass. (Foot-pound per pound.)
P=Absolute pressure of a fluid. ($p+B$) (pound per square inch.)
p=Gauge pressure of a fluid; that is, the pressure of a fluid above or below atmospheric pressure. (Pound per square inch.)
$\Delta p=P_1-P_2$=Differential pressure. (Pound per square inch.)

(NOTE.—H, h, and Δp are all measures of the same quantity, but in different units.)

Q=Volume rate of flow at density δ. (Cubic feet per second.)
$r=P_2/P_1$=ratio of downstream to upstream pressure at orifice or Venturi tube.
S=Interval of time during which flow of fluid is considered. (Seconds.)
s=Speed of fluid, irrespective of the direction of motion, a scaler quantity. (Feet per second.)
T=Absolute temperature of fluid ($t+460$ for an ideal gas, and $t+458$ for air). (Fahrenheit degrees.)
t=Temperature of fluid. (Fahrenheit degrees.)
$V=1/\delta$=specific volume. (Cubic feet per pound.)
v=Velocity of fluid in a definite direction, a vector quantity. (Feet per second.)
W=Mass rate of flow. (Pounds per second.)
$X=\Delta p/P_1$=ratio of differential to upstream pressure.
$\gamma=c_p/c_v$=ratio of specific heats.
$\beta=d/D$=ratio of orifice (nozzle throat or Venturi-tube throat) diameter to full-pipe diameter.
δ=Density of the fluid under conditions defined by P and T (Pounds per cubic foot.)
ϕ=Ratio of the mean speed of a fluid across a given section to the maximum speed across the section.
Subscript $_a$ signifies that the factor applied to air.
Subscript $_b$ signifies that the factor is at the temperature and pressure specified in a given case as defining the base or reference condition. In commercial work this is commonly referred

to as the "storage" condition. Usually the standard conditions are used as the base or reference condition.

Subscript $_g$ signifies that the factor applies to a gas other than air.

Subscript $_o$ signifies that the factor is at the "zero condition" of temperature and pressure.

Subscript $_1$ signifies that the factor represents a condition at the first or upstream section. With orifice meters this refers to any section under consideration which is upstream from the orifice.

Subscript $_2$ signifies that the factor represents a condition at the second or downstream section. With orifice meters this refers to any section under consideration which is down stream from the orifice.

"Standard conditions." This term implies that the fluid is at a temperature of 60° F. and under a pressure equal to 30 inches of mercury at 32° F. These are equal to an absolute temperature, expressed in Fahrenheit degrees, of 520°, and an absolute pressure of 14.74 lbs./in.^{2}

"Zero conditions." This term implies that the fluid is at a temperature of 32° F., and under a pressure equal to 29.92 inches of mercury at 32° F. These are equal to an absolute temperature, expressed in Fahrenheit degrees, of 492°, and an absolute pressure of 14.655 lbs./in.^{2} (In metric units these are equivalent to 0° C. and 760 mm of mercury.)

By "theoretical discharge" and "theoretical mean velocity" is meant the discharge or velocity calculated on the assumption that there is no loss of energy due to friction and viscosity, that the stream lines are parallel at the cross section at which the Pitot tube is placed, or the cross sections between which the differential pressure is measured, that the velocity of flow is uniform across the section or sections, and that either (*a*) the gas density is the same at all sections, or (*b*) that the change in density from one section to the next takes place adiabatically.

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Measurement of velocity of air in pipes, by Bryan Donkin, Engineering News, Dec. 22, 1892. Discusses the use of anemometers for measuring velocities in pipes, results of tests varied very widely.

Gas flow meters for measuring small rates of flow, by A. F. Benton, J. of Indus. and Engr. Chem., July 1, 1919. Describes flow meters for measuring very small rates of flow, which were developed and used by the Chemical Warfare Service and by the United States Fixed Nitrogen Research Laboratory.

The effect of temperature and pressure on a meter for measuring the rate of flow of a gas, by N. W. McLachlan, Phys. Soc. of London, Dec. 15, 1919. A flow meter with a moveable vane on which a jet of air is directed. Deflecting force is a function of the density (and therefore pressure and temperature of the gas) and the pressure difference.

7. SUBJECTS RELATED TO GAS MEASUREMENT

Calculation of the flow of steam through pipes, by F. N. Hatch, Elec. World, Dec. 9, 1916. Discusses Unwin's and Babcock's formulas for the flow of steam in pipes. Gives a chart to be used in calculating the flow.

Graphical solution of some compressed air problems, by C. W. Crispell, Bulletin, A. I. M. E., June, 1917. Presents several charts that may be used in solving equations used in compressed air calculations.

A compressed air paradox, by Frank Richards, Am. Machinist, Apr. 16, 1896. Shows that by using higher pipe-line pressures throughout the (per cent) friction loss is lowered, thus (in some cases) actually permitting a lower inlet pressure.

Flow of gas formulas derived, analyzed, and checked by experimental data, with diagrams for figuring the flow of gas in street mains and service, by J. M. Spitzglass, Am. Gas Light J. (serial, beginning), Apr. 22, 1912. Combines a thoroughly mathematical development of gas-flow formulas with a discsussion of their practical application. Presents diagrams and a description of their use for determining gas flow in mains and service pipes and also for determining the proper size of pipes.

On the discharge of gases under high pressure, by Lord Rayleigh, Phil. Mag., August, p. 177; 1916. A general account of the theory of gas jets. States that experiments of Saint Venant and Wantzel showed that with the pressure in the receiving vessel varying from 0 to 0.4 of that in the discharging vessel the rate of discharge is sensible constant.

A study of air measurement and air flow, by Arthur K. Ohines, J. of Amer. Soc. of Heating and Ventilating Engrs.. July, 1917. Discusses the resistance of different shaped channels to gas flow.

Experiments on water flow through pipe orifices, by Prof. Horace Judd, a paper presented at the spring meeting of the A. S. M. E., Apr. 11 to 14, 1916. Abstract in A. S. M. E. J. for April, 1916, p. 382. Describes some experiments made to determine the pressure variations in the vicinity of the orifice. Presents many curves showing the effects of different area ratios and different orifice shapes.

The flow and measurement of gases, by George Wehrle, The Gas Age, **38**, p. 233; Oct. 2, 1916. An elementary discussion on the flow of gas in pipes, the metering of gas, types of gas meters, gas pressure and pressure gauges.

Differential pressure meters for measuring air, gas, and steam flows, by J. L. Hodson, Chem Indust., **38**, p. 222, July 31, 1919. Describes a curved tube manometer so shaped that equal increments in velocity of flowing fluid will produce equal movements of oil meniscus in the manometer tube.

Effect of pulsations on flow of gases, by Prof. H. Judd and D. B. Pheley. A paper presented at December meeting of A. S. M. E., 1922 (later see Trans. A. S. M. E. **44**, 1922). Discusses work on the study of the nature of pulsations and attempts to find practical means of reducing or eliminating their effect on measuring devices, principally Venturi and orifice meters and Pitot tubes.

The Romance of the Gas Industry, by O. E. Norman. A very entertaining book on the history and development of the gas industry and many gas appliances.

Measurement, Compression, and Transmission of Natural Gas, by Prof. L. C. Lichty. A text book on these phases of the natural-gas industry, prepared in such a manner that both the engineer and practical man in the field may find a guide for the solution of many natural gas problems.

Similarity of motion in relation to the surface friction of fluids by Stanton and Pannell, in Philo. Trans. Royal Soc. (London), A, **214**, p. 199, 1914. One of the most quoted papers treating the laws of the flow of fluids (in pipes) in which are discussed the results of original tests and a comparative analysis of the results of tests by others.

The mechanical viscosity of fluids, by T. E. Stanton, in Proc. Royal Soc. (London), A, **85**, p. 366, 1911. A discussion of tests undertaken to investigate the relation between shearing stress and rate of distortion in fluids which are in eddying motion.

On the flow of viscous fluids through smooth pipes, by C. H. Lees, in Proc. Royal Soc. (London), A, **91**, p. 46, 1914. A discussion of the results of tests on the flow of water and air in pipes, which have been made by other investigators.

WASHINGTON, May 29, 1926.