Designation: D 1071 – 83 (Reapproved 2003)

Standard Test Methods for Volumetric Measurement of Gaseous Fuel Samples[1]

This standard is issued under the fixed designation D 1071; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

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

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Terminology and Units of Measurement

2.1 *Definitions: Units of Measurement*—All measurements shall be expressed in inch-pound units (that is: foot, pound (mass), second, and degrees Fahrenheit); or metric units (that is: metre, kilogram, second, and degrees Celsius).

2.2 *Standard Conditions*, at which gaseous fuel samples shall be measured, or to which such measurements shall be referred, are as follows:

2.2.1 *Inch-pound Units*:

(*1*) A temperature of 60.0°F,

(*2*) A pressure of 14.73 psia.

(*3*) Free of water vapor or a condition of complete water-vapor saturation as specified per individual contract between interested parties.

2.2.2 *SI Units*:

(*1*) A temperature of 288.15K (15°C).

(*2*) A pressure of 101.325 kPa (absolute).

(*3*) Free of water vapor or a condition of complete water-vapor saturation as specified per individual contract between interested parties.

2.3 *Standard Volume*:

TABLE 1 Apparatus for Measuring Gaseous Fuel Samples

Apparatus	Capacity and Range of Operating Conditions Covered in Section No.	Calibration Procedure Covered in Section No.
Containers		
Cubic-foot bottle, immersion type of moving-tank type	5	12
Portable cubic-foot standard (Stillman-type)	5	12
Fractional cubic-foot bottle	5	12
Burets, flasks, and so forth, for chemical and physical analysis	6	12
Calibrated gasometers (gas meter provers)	7	13-16
Gas meters, displacement type:		
Liquid-sealed relating-drum meters	8	17-22
Diaphragm- or bellows-type meters, equipped with observation index	9	23
Rotary displacement meters	10	24
Gas meters, rate-of-flow type:		
Porous plug and capillary flowmeters	11	25
Float (variable-area, constant-head) flowmeters	11	25
Orifice, flow nozzle, and venturi-type flowmeters	11	25

2.3.1 *Standard Cubic Foot of Gas* is that quantity of gas which will fill a space of 1.000 ft^3 when under the standard conditions (2.2.1).

2.3.2 *Standard Cubic Metre of Gas* is that quantity of gas which will fill a space of 1.000 m^3 when under the standard conditions (2.2.2).

2.4 *Temperature Term for Volume Reductions*—For the purpose of referring a volume of gaseous fuel from one temperature to another temperature (that is, in applying Charles' law), the temperature terms shall be obtained by adding 459.67 to each temperature in degrees Fahrenheit for the inch-pound units or 273.15 to each temperature in degrees Celsius for the SI units.

2.5 At the present state of the art, metric gas provers and meters are not routinely available in the United States. Throughout the remainder of this procedure, the inch-pound units are used. Those having access to metric metering equipment are encouraged to apply the standard conditions expressed in 2.2.2.

NOTE 1—The SI conditions given here represent a "hard" metrication,

[1] These test methods are under the jurisdiction of ASTM Committee D03 on Gaseous Fuels and are the direct responsibility of Subcommittee D03.01 on Collection and Measurement of Gaseous Samples.

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in that the reference temperature and the reference pressure have been changed. Thus, amounts of gas given in metric units should always be referred to the SI standard conditions and the amounts given in inch-pound units should always be referred to the inch-pound standard conditions.

3. Significance and Use

3.1 The knowledge of the volume of samples used in a test is necessary for meaningful results. Validity of the volume measurement equipment and procedures must be assured for accurate results.

4. Apparatus

4.1 The various types of apparatus used for the measurement of gaseous fuel samples may be grouped in three classes, as shown in Table 1. References to the portions of these methods covering the capacity and range of operating conditions, and the calibration, of each type are given in Table 1.

CAPACITY OF APPARATUS AND RANGE OF OPERATING CONDITIONS

5. Cubic-Foot Bottles, Standards, and So Forth

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

FIG. 1 Stillman-Type Portable Cubic-Foot Standard

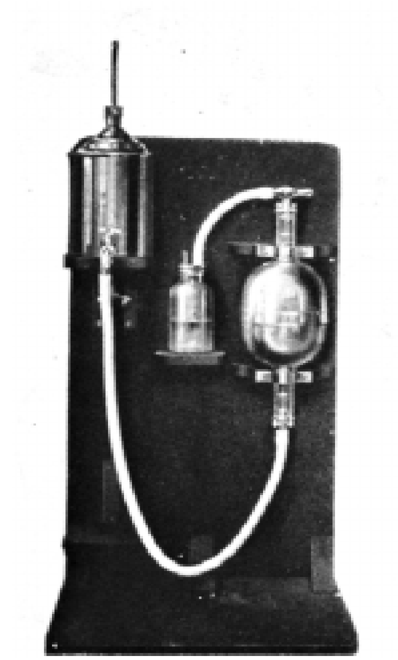


FIG. 2 One-Tenth Cubic Foot Bottle, Transfer Tank, and Bubble-Type Saturator for Testing Laboratory Wet Gas Meters

6. Burets, Flasks, and So Forth

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

7. Calibrated Gasometers

7.1 The stock capacities of calibrated gasometers (gas meter provers) are 2, 5, and 10 ft^3. The temperature and pressure at which they can be operated must be close to the ambient temperature and within a few inches of water column of atmospheric pressure. The equivalent rates of flow that may be attained, conveniently, are as follows:

Size, ft^3	Equivalent Rate, ft^3 of air/h
2	990
5	2250
10	5000

NOTE 2—Gasometers having volumetric capacities up to several thousand cubic feet have been made for special purposes. Their use is limited to temperatures close to the ambient temperature, although some may be operated as pressures slightly higher than mentioned above. These large gasometers can hardly be classed as equipment for measuring gaseous samples, and are mentioned only for the sake of completeness.

8. Liquid-Sealed Rotating-Drum Meters

8.1 The drum capacities of commercial stock sizes of liquid-sealed rotating-drum meters range from 1⁄20 (or litre) to

7.0 ft^3 per revolution. A 0.1-ft^3 per revolution meter is shown in Fig. 3. The operating capacities, defined as the volume of gas having a specific gravity of 0.64 that will pass through the meter in 1 h with a pressure drop of 0.3-in. water column across the meter, range from 5 to 1200 ft^3/h. Liquid-sealed rotating-drum meters may be calibrated for use at any rate for which the pressure drop across the meter does not blow the meter seal. However, if the meter is to be used for metering differing rates of flow, a calibration curve should be obtained, as described in Section 20, or the meter should be fitted with a rate compensating chamber (see Appendix X1).

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

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

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

9. Diaphragm-Type Test Meters

9.1 The displacement capacities of commercial stock sizes of diaphragm-type test meters range from about 0.05 to 2.5 ft^3 per revolution (of the tangent arm or operating cycle). The operating capacities, defined as the volume of gas having a specific gravity of 0.64 that a meter will pass with a pressure drop of 0.5 in. of water column across the meter, range from about 20 to 1800 ft^3/h. Usually these meters can be operated at rates in excess of their rated capacities, at least for short periods. A meter having a capacity of 1 ft^3 per revolution is shown in Fig. 4.

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

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

NOTE 3—The diaphragm-type test meter and the diaphragm-type consumers meter are similar in most respects. The principal difference is the type of index or counter. The test meter index has a main hand indicating 1 ft^3 per revolution over a 3-in. or larger dial, with additional smaller dials giving readings to 999 before repeating. On the index of consumers meters, aside from the test hand, the first dial indicates 1000 ft^3 per revolution of its hand so that the smallest volume read is 100 ft^3. The maximum reading for a consumers meter index may be 99 900 or 999 900. Another minor difference is that the maximum rated capacity for the larger consumers meters may be 17 000 ft^3/h.

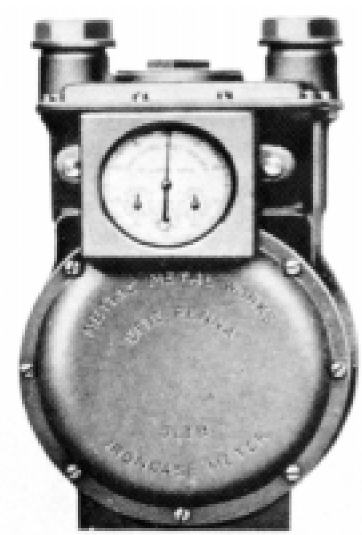


FIG. 4 Iron-Case Diaphragm-Type Gas Meter with Large Observation Index

10. Rotary Displacement Meters

10.1 Rotary displacement gas meters are mentioned here only to have a complete coverage of meters for gas, since meters of this type are of relatively large capacity, beyond that of sample measurement (Note 4). The rated capacities of stock sizes range from about 4000 to about 1 000 000 ft^3/h. They may be used at somewhat higher temperatures than other displacement meters, probably 400 to 500°F and are available for use under line pressures up to about 125 psi.

NOTE 4—It is of course possible to use a very small meter of this type as a test or "sample" meter. See Bean, H. S., Benesh, M. E., and Whiting, F. C., "Testing Large-Capacity Rotary Gas Meters," *Journal of Research*, Nat. Bureau Standards, JRNBA, Vol 37, No. 3, Sept. 1946, p. 183. (*Research Paper RP1741*).

11. Rate-of-Flow Meters

11.1 Rate-of-flow meters, as the name implies, indicate rates of flow, and volumes are obtained only for a definite time interval. They are especially useful in those situations where the flow is steady, but are not suited for use in the measurement of specified quantities nor on flows that are subject to wide or more or less rapid variations of either rate or pressure. In the smaller sizes, they may be particularly useful for both regulating and measuring continuous samples of a gaseous fuel.

11.2 No definite limits can be set to the range of rate of flow to which these meters may be applied, nor to the range of temperatures and pressures under which they may be operated. Where meters of this type are desired, it will usually be possible to design one to meet the particular service requirements. Of particular interest for continuous sampling and sample measurement are flowmeters of the capillary tube and porous plug (for example, sintered glass filter) type. The rates of flow that they can meter satisfactorily range upward from about 0.03 ft^3/min. The pressure drop across the metering element is not only low (a few inches of water column), but its relationship to the rate of flow is very nearly linear.

CALIBRATION OF APPARATUS

12. Calibration of Primary Standards

12.1 Cubic-foot bottles and fractional cubic-foot bottles are calibrated by weighing the quantity of distilled water that will be delivered between the gage marks (Note 5), correcting for the buoyancy of the air. At the standard conditions specified in 2.2, the weight of water contained between the gage marks of a correctly adjusted cubic-foot bottle should be 62.299 lb.

NOTE 5—It is now the practice at the National Bureau of Standards to calibrate or adjust these standards "to deliver" the specified quantity of water from a *wet* condition. To do this, the standard is filled with water, then emptied slowly over a period of 3 min and allowed to drain for an additional 3 min. Next, the quantity (weight) of distilled water contained between the two gage marks is determined. The corresponding volume of this quantity of water, adjusted to a temperature of 60°F, should be 1.000 ± 0.05 %.

12.2 A Stillman-type portable cubic-foot standard is calibrated by comparison with an immersion-type cubic-foot bottle. The calibration involves adjusting the stroke of the bell so that as 1 ft^3 of air is transferred from the bottle, or the reverse, the pressure within the system does not change, provided the temperature of the entire system is maintained constant. This requires that the test should be made in a room in which the temperature can be maintained constant and uniform within less than 0.5°F. Moreover, to diminish the cooling effects of evaporation from the surfaces of the bottle and bell, the sealing fluid should be a light, low-vapor pressure oil. Other observations forming a part of this calibration are those of the time intervals required for raising the bottle and bell from their respective tanks and the intervals they are held up for drainage to take place before pressure readings are made. From these times, corrections are determined for the volumes of undrained liquid.

12.3 Burets, flasks, and so forth, are considered a part of the analytical apparatus in which they are used, and methods of calibrating them therefore are not covered here.

NOTE 6—An outline of such methods is given in National Bureau of Standards *Circular C434* NBSCA, "Testing of Glass Volumetric Apparatus," by E. L. Peffer and Grace C. Mulligan.

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

13.1 Gas meter provers of 2-, 5-, and 10-ft^3 capacity customarily are calibrated by comparison with a cubic-foot bottle or standard as described in Sections 14 and 15. The procedure consists of measuring air out of or into the prover by means of the standard, 1 ft^3 at a time, noting the reading of the prover scale at the start and finish of each transfer. Some general considerations to be observed are given in 13.2 and 13.3.

13.2 Provers should be located in a well-lighted room provided with some degree of temperature regulation. It is desirable that this regulation should be adequate to maintain the temperature within ±2°F of the desired average temperature. The prover tank should be raised from the floor by legs or blocks as this not only reduces the lag between the prover and room temperatures but decreases the accumulation of moisture on the underside of the tank. If water is used as the sealing fluid in the provers, the relative humidity within the room should be maintained as high as possible. However, it is recommended that the sealing fluid used in provers (and in cubic-foot bottles and standards also) should be a light oil with a low vapor pressure of about 0.25-in. Hg at 70°F (Note 7). The use of oil as a sealing fluid will decrease the cooling effect caused by evaporation, when the prover bell is raised from the tank, and will also retard any tendency of the bell to corrode.

NOTE 7—This requirement for vapor pressure will probably be met if the open cup flash point is above 330°F, since the vapor pressure at the flash point is usually about 0.3- to 0.5-in. Hg.

13.3 Before starting a calibration, the bell should be examined to see that it is clean and free of dents. It should move freely throughout its entire travel with neither binding nor excessive play within its guides at any position. To facilitate reading the prover scale to one decimal place beyond that normally used when testing meters, the regular scale pointer may be replaced with a short auxiliary scale covering a 0.2-ft^3 interval of the main scale. This scale should be divided into 10 or 20 divisions, and mounted so that its mid-point will be at about the same elevation as the regular pointer.

14. Calibration of Provers by Means of an Immersion-Type Bottle

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

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

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

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

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

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

15.3 If so desired, several transfers each may be made for the same 1-ft^3 interval of the prover scale before going on to the next interval. In doing this, the prover scale reading should be readjusted to the even foot mark before a transfer in either direction is started being careful to have the connection between prover and standard open so that both are under the full prover pressure.

NOTE 8—*Example*—The observations and calculations involved in the calibration of a 5-ft^3 gas meter prover with a Stillman-type standard are shown in Table 2. The average delivery capacities of the 0- to 1- and 1- to 2-ft^3 intervals, from the five determinations on each interval, are 1.008 and 1.004, respectively. This means that if a correctly adjusted gas meter is tested against the 0- to 2-ft^3 interval, the final prover scale reading would be 1.99.

16. Calibration of Large Provers

16.1 The method to be used in calibrating gasometers of over 10-ft^3 capacity will depend upon the capacity, design, and mode of operation of the gasometer. If it is not too large (100 ft^3 or less), it may be most convenient to use a cubic-foot standard or a 5- or 10-ft^3 prover that has been calibrated. For other gasometers, it will probably be necessary to determine the capacity from a measurement of the dimensions. The procedure usually followed is to measure the outside circumference of the prover bell at several sections. From these measurements and the metal thickness, the average inside cross-sectional area and capacity per unit height are computed. In making this calculation, it may be necessary to take account of changes of the sealing fluid height produced by raising and lowering of the bell.

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

17.1 The objective of the calibration of a rotating-drum gas meter may be:

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

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

17.2 The two procedures described in Section 19 are intended for the routine calibration of a 0.1-ft^3 wet test meter that is to be used in conjunction with a water-flow calorimeter in the determination of the heating valve of a fuel gas. Furthermore, it is recommended that these calibrations be made with the meter in the position in which it will be used in the calorimetric determinations. When the conditions under which the meter will be used are such that the rate of flow through the meter will be less than 8 ft^3/h, the procedure described in 19.1-19.3, using a 0.1-ft^3 bottle, may be followed. If the rate of flow through the meter, when in use, will exceed 8 ft^3/h, the aspirator method of calibration described in Section 20 should be followed.

17.3 The average rate of flow at which the calibration is performed should be adjusted and maintained as nearly as possible the same as that at which the meter will operate when in use. In no event should the difference between the test rate and the use rate exceed 30 % of the use rate. This is because the volume of gas delivered per revolution of a liquid-sealed rotating-drum meter increases slightly with increasing rate of flow. In this connection, note that, by proper adjustment of the rate during calibration, the aspirator procedure may be followed when the meter is to be used at rates below 8 ft^3/h.

TABLE 2 Sample Data Sheet from Calibration of Bell Prover[A]

Prover Serial #272					Calibration Standard				Date: 4/30/47
S_i	R_b	R_s	ΔV_s	ΔV_c	ΔS_c	K	Temperatures, °F		
Major Scale Interval Calibrated	Prover Scale Readings, ft^3 Begin	Stop	Scale Indicated Vol, ft^3 (ΔR)	Standard Transferred Vol, ft^3	Calculated Transferred Vol, ft^3 (for Si)	Algebraic Correction of Proof N_s, %	Room Air	Standard Oil	Prover Oil
0 to 1	0.000	0.991	0.991	1.000	1.009	...	81.9	82.0	82.7
1 to 0	1.000	0.008	0.992	1.000	1.008	...	...	...	...
0 to 1	0.000	0.992	0.992	1.000	1.008	...	...	...	...
1 to 0	1.000	0.008	0.992	1.000	1.008	...	...	...	...
1 to 2	1.000	1.999	0.999	1.000	1.001	...	...	...	...
2 to 1	2.000	1.006	0.994	1.000	1.006	...	...	...	...
1 to 2	1.000	1.998	0.998	1.000	1.002	...	...	...	...
2 to 1	2.000	1.005	0.995	1.000	1.005	...	...	...	...
2 to 3	2.000	3.003	1.003	1.000	0.997	...	...	...	...
3 to 2	3.000	2.000	1.000	1.000	1.000	...	...	...	...
2 to 3	2.000	3.005	1.005	1.000	0.995	...	...	...	...
3 to 2	3.000	1.999	1.001	1.000	0.999	...	...	...	...
3 to 4	3.000	3.998	0.998	1.000	1.002	...	...	...	...
4 to 3	4.000	3.008	0.992	1.000	1.008	...	...	...	...
3 to 4	3.000	3.996	0.996	1.000	1.004	...	...	...	...
4 to 3	4.000	3.007	0.993	1.000	1.007	...	...	...	...
4 to 5	4.000	4.999	0.999	1.000	1.001	...	81.9	82.7	83.0
5 to 4	5.000	4.003	0.997	1.000	1.003	...	...	...	...
4 to 5	4.000	4.999	0.999	1.000	1.001	...	...	...	...
5 to 4	5.000	4.002	0.998	1.000	1.002	...	...	...	...
0 to 1	...	...	0.992	1.000	1.008	+ 0.8	...	...	...
1 to 2	...	...	0.996	1.000	1.004	+ 0.4	...	...	...
2 to 3	...	...	1.002	1.000	0.998	−0.2	...	...	...
3 to 4	...	...	0.995	1.000	1.005	+ 0.5	...	...	...
4 to 5	...	...	0.998	1.000	1.002	+ 0.2	...	...	...
0 to 2	0.000	1.988	1.988	2.000	2.012	+ 0.6	...	...	...
2 to 4	2.000	1.997	1.997	2.000	2.003	+ 0.2	...	...	...
0 to 5	0.000	4.983	4.983	5.000	5.017	+ 0.3	...	...	...

[A] The meanings and use of the identified columns in Table 2 are:

S_i This is the *major* scale interval calibrated *or* the "normal operating" scale interval used in a normal proving cycle. Ordinarily, a normal operating scale interval has appropriate *scale subdivisions* above and below the "upper" major graduation mark. Also, a normal operating scale interval may consist of one or more adjacent major scale intervals. Scale *subdivisions* normally are *not* directly calibrated. The suitability or "accuracy" of subdivisions are usually determined by visual inspection and measurement. Subdivisions must be *proper and uniform* proportions of the intended normal operating scale interval. (Note—S_i is a *designation* of a specific *portion* of the scale and is *not a numerical volume quantity*.)

R_b The scale reading at which the calibration *began*.

R_s The carefully *estimated or measured* scale reading *after* the bottle or Stillman standard has transferred 1 ft^3 or as many multiple cubic feet as is represented by the normal operating scale interval calibrated.

ΔV_s This is the scale *indicated* transferred volume and is the absolute difference between R_s and R_b such as $\Delta V_s = R_s - R_b$.

ΔV_c This is the "correct" transferred volume per the bottle or Stillman corresponding to the ΔV_s.

ΔS_c This is the "correct" or calculated delivery or displaced volume of the bell corresponding to bell movement over S_i. This is calculated thus:

$$\Delta S_c = \frac{(\Delta V_c)^2}{\Delta V_s}$$

K Correction to apply algebraically to the observed scale proof, N_s, to obtain the "correct" or calculated proof, N_c, thus:

$$N_c = N_s + K$$

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

17.5 When the purpose of the test is to determine the correct amount of sealing water for the meter (17.1.1), and this has been done by one of the test procedures described in Section 19, bring the metering drum to a position about midway between two of the seal-off positions, preferably with the long index hand nearly over the large dial zero and open both the inlet and outlet of the meter to atmosphere. Without altering the leveling adjustment of the meter, set the water level gage to the height of the bottom of the water meniscus in the gage glass. If the gage is the yoke type, the plane of the yoke top should coincide with that of the bottom of the meniscus. If the gage is the pointer type, start with the tip *below* the water surface and raise it until the tip appears to just meet its image in the water surface as viewed from below. Lock the gage in the position thus determined so that it may be used for checking the proper quantity of water in the meter before each subsequent use of the meter.

17.6 When the purpose of the test is to determine a calibration factor to be used in conjunction with a predetermined amount of sealing water (17.1.2), it is usually convenient to set the surface of the sealing water to the last position of the water-level gage. In this case, the position of the metering drum should be adjusted as prescribed in 17.5and add water to the meter until its surface is slightly above the gage. Then *very* slowly (a drop at a time) withdraw water until, with a yoke-type gage, the bottom of the water meniscus in the gage glass is in the plane of the top of the gage yoke. If the gage is the pointer type, withdraw water until the reflection of the point, as viewed from slightly below, appears to just touch the tip of the gage point.

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

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

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

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

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

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

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

18.5 When a water-sealed rotating-drum meter is in operation, the surface of the water in the gage glass rises and falls

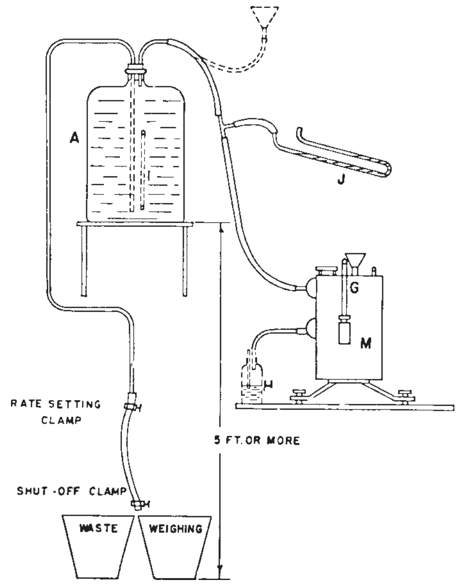
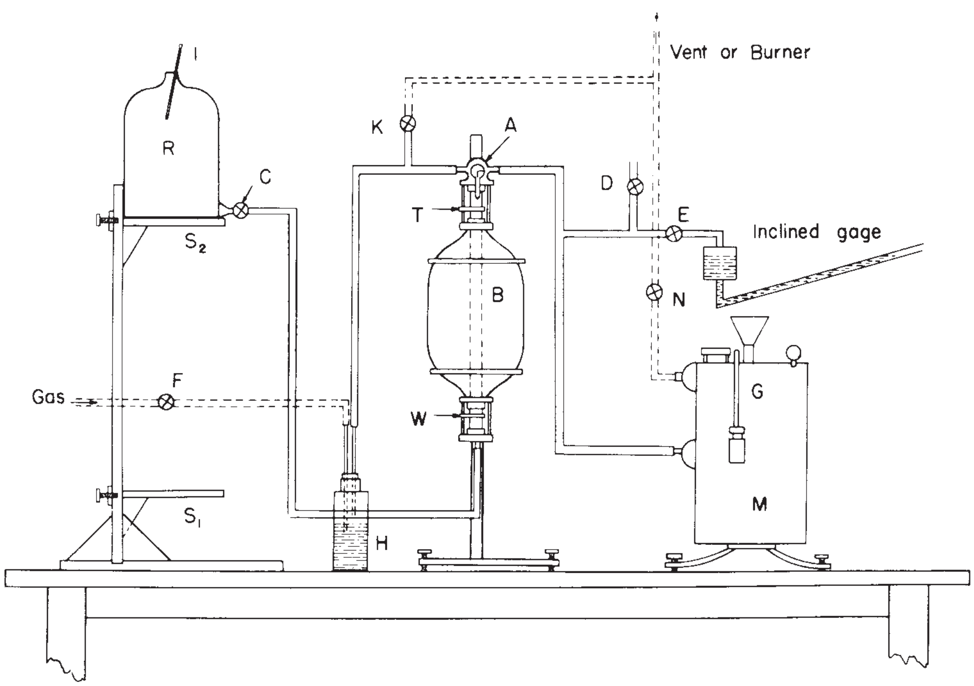


FIG. 6 Simple Equipment for Calibration by Aspirator Method



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

FIG. 5 Schematic Diagram of Equipment and Connections for Calibration of a 0.1-ft^3 Wet Test Meter with a 0.1-ft^3 Bottle

noticeably four times during each revolution of the drum (and of the large hand of the meter index). These fluctuations occur as one drum compartment seals off and another unseals to the outlet. With many of these meters, particularly the 0.1 ft^3 per revolution size, the large index hand is mounted directly on the drum shaft. With other sizes, this hand is geared to make an even multiple or submultiple of turns with respect to the drum. The position (azimuth) of the hand on its shaft should be such that the hand will pass the zero of its dial nearly midway between two fluctuations of the water surface in the gage glass. If it does not do this, loosen the lock nut by which the hand is secured and shift the position of the hand as may be needed; then tighten the lock nut. If possible, the relative position of the hand on the shaft should be marked so that it may be reset in the same position in case it becomes loose or displaced during subsequent handling of the meter.

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

18.7 A check for leaks in the connections may be made as follows: Refering to Fig. 5, turn cock *A* to connect bottle *B* to meter *M*. Close cocks *D, E, C,* and *N*, and place reservoir *R* on shelf S_2 (Note 9). Open cock *C* slowly while observing the water in the manometer of the meter. When the pressure in the system forces the water in the manometer to its limit, close cock *C* and read the manometer. If after 5 min the manometer reading has not changed, the system is free of leaks.

NOTE 9—If the test is to be made with air, the meter outlet may be closed with a stopper.

18.8 Occasionally, when leakage is indicated that cannot be located externally, it may be necessary to check for leaks in the meter drum, and this may be done in the following manner. First calibrate the meter at the normal rate as described in Section 19. Then repeat the calibration with cock *C* partly closed so that it requires 10 to 12 min for the transfer to be made. If the slow calibration does not differ from the first by more than 0.001 ft^3, there is probably no leak in the drum.

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

19. Calibration of Small Water-Sealed Rotating-Drum Meters by Means of a 0.1-ft^3 Bottle

19.1 *Adjusting Water Level*—Adjust the water level in the reservoir and bottle system as follows:

19.1.1 Vent the bottle to atmosphere by setting cocks *A* and *D*.

19.1.2 Place reservoir *R* on shelf S_2 and observe the water level at gage *T*. Add or remove water to bring the level exactly to the gage mark.

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

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

19.2 *Adjusting for Rate of Test*:

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

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

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

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

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

19.3.1 For starting, the reservoir should be on shelf S_2, cocks *C* and *E* open, cock *D* closed, and cock *A* set to connect the bottle *B* with saturator *H*. The meter hand should be at approximately zero,

19.3.2 Read and record the room temperature, saturator temperature, meter temperature, and barometric pressure,

19.3.3 Close cock *C* and move reservoir *R* to shelf S_1.

19.3.4 Open cock *C*, reading and recording the time.

19.3.5 Read and record the reservoir water temperature,

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

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

19.3.8 Quickly transfer reservoir *R* to shelf S_2.

19.3.9 Note and record the meter water temperature.

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

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

19.3.12 Close cock *C* while moving the reservoir to shelf S_1 and then open cock *C*.

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

19.3.14 Thirty seconds after the water was approximately at the lower gage marker, turn cock *A* so that the bottle *B* is isolated from both saturator and meter. Close cock *C* and replace reservoir *R* and shelf S_2. The meter hand should be at the same reading as in 19.3.11.

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

19.3.16 Repeat 19.3.9-19.3.15 until the meter has completed four or more revolutions.

19.3.17 Divide the difference between the final and initial meter reading by the number of revolutions. The result is the indication of the meter for 0.1 ft^3 of air (or gas) as delivered by the bottle.

NOTE 10—*Example*—Let us assume that the bottle temperature was 71.0°F, the meter temperature 70.2°F, and the meter indication 0.0999. Taking the pressure at the meter outlet as the "metering pressure" gives, in this case, $\rho_m = \rho_b = 29.70$-in. Hg. Then the indication of the meter adjusted to the bottle temperature would be as follows:

$$0.0999 \times [(459.7 + 71.0)/(459.7 + 70.2)] \times [(29.70 - 0.74)/(29.70 - 0.76)] = 0.1001 \quad (1)$$

NOTE 11—The effect of using 460 in place of 459.7 in this relation will be less than 1 part in 20 000 in most cases.

NOTE 12—As provided by the instructions, the observed temperatures should not differ by more than 1°F. On the other hand, if the difference is 0.3°F or less, no adjustment need be made because the effect will be less than the smallest amount to which the meter reading can be estimated.

19.3.18 If the objective of the calibration is to make the meter indication per revolution correspond as nearly as possible to the delivery capacity of the standard bottle, that is as nearly 0.1000 as possible, then if the value obtained by 19.3.17 differs from 0.1000 by more than 0.0002 adjustment should be made to the quantity of sealing water in the meter. Changing the quantity of sealing water in the meter by 10 mL (⅓ oz) changes the capacity of the meter per revolution by about 0.0002 ft^3.

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

NOTE 13—*Example*—Assume that the meter indication, after adjustment, as shown above, for any temperature difference between bottle and meter is 0.0991. Then the meter correction factor is

$$0.1 \times (1/0.0991) = 1.0091 \quad (2)$$

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

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

19.4.2 Read and record room temperature, saturator temperature, meter temperature, and barometric pressure.

19.4.3 Close cock *C* and place the reservoir on shelf S_1.

19.4.4 Open cocks *C* and *F* as nearly simultaneously as possible.

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

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

19.4.7 Proceed as directed in 19.3.7-19.3.11.

19.4.8 Close cock *C* while moving reservoir to shelf S_2, then open cocks *C* and *F* as nearly together as possible.

19.4.9 Same as 19.4.5.

19.4.10 Continue in accordance with 19.3.13-19.3.19.

20. Calibration by the Aspirator or Weighed-Water Method

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

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

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

NOTE 14—*Example*—An example of the observations and calculations involved in such a test is shown in Table 3.

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

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

21.1 The smallest division of the main dial of a wet test meter such as is shown in Fig. 3 represents 0.001 ft^3. It is customary practice to estimate the meter reading to ⅒ of these

TABLE 3 Sample Data Sheet for Calibration of Meter with an Aspirator Bottle

	Start	End
Time	2:54:38	2:59:17
Meter reading, ft^3	26.6000	26.9000
Room temperature, °F		77.7
Meter temperature, °F		78.4
Bottle temperature,° F		77.4
Gas pressure at meter inlet, in. of water		1.42
Gas pressure in bottle, in. of water		1.10
Weight of water, lb		18.6974
Calculations:		
Weight of water at 77.4°F, lb		18.6974
Correction for buoyancy = 18.6974 × 0.001 06		+0.0198
Correction for density of water at 77.3°F to density at 39.2°F $= 18.6974 \times \left[\frac{1.000\,00}{0.997\,03} - 1\right]$		+0.0557
Correction for temperature difference = $18.6974 \times \left[\frac{459.7 + 78.4}{459.7 + 77.4} - 1\right]$		+0.0348
Correction for pressure difference[A] = 18.6974 × $\left[\frac{(29.92 + ((0.0737) \times 1.10) - 0.948)}{(29.92 + ((0.0737) \times 1.42) - 0.980)} - 1\right]$		+0.0051
Corresponding weight of water at maximum density		18.8128
Equivalent volume, ft^3		0.3014
One revolution of index		0.1005

[A] 0.0737 = conversion factor, in. of water to in. Hg.

$$\frac{(0.948)}{0.980} = \frac{\text{vapor pressure, in. Hg. bottle}}{\text{vapor pressure, in. Hg. meter}}$$

divisions, or 0.0001 ft^3. However, one can hardly claim an accuracy of this last estimated figure better than ±1, which is equivalent to an uncertainty of ±0.1 % of the volume represented by a single revolution of the large hand.

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

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

22. Calibration of Large Water-Sealed Rotating-Drum Meters

22.1 Water-sealed rotating-drum gas meters, registering 1 ft^3 or more per revolution of the main index hand, may be tested with a cubic-foot bottle of the moving-tank type. The procedure will be similar to that described in Section 19 for the calibration of the 0.1-ft^3 meter. The aspirator method may be used also, provided the aspirator tank has sufficient capacity, at least 1.5 ft^3, to allow for starting and stopping. Finally, if the accuracy requirements of the meter are not too high, the test may be made with a gas meter prover. However, to keep the rate of flow within the meters operating range and to avoid blowing the seal, it will be necessary to increase the counterweights of the prover bell, or to regulate the rate by a valve placed on the meter outlet.

23. Calibration of Small Dry Diaphragm Meters

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

23.2 Place the proper cap on the meter outlet to allow air (or gas) to pass at about one fifth the rated capacity of the meter. By manipulation of the prover valve, bring the meter test hand in line with one of the divisions of its dial (preferably on its upward swing) and close the valve. Fill the prover with air (or gas) and set to zero scale reading. Open the prover valve allowing air (or gas) to pass through the meter until the test hand makes exactly one revolution, closing the valve quickly. Note and record the prover scale reading to the nearest 0.01 ft^3.

23.3 Calculate the meter correction as follows:

$$\text{Correction to meter reading, \%} = [(A - B)/B] \times 100 \quad (3)$$

where:

A = prover reading and
B = meter reading.

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

NOTE 15—More detailed discussions of gas meter testing are given in the report of the 1920 Consumers' Meters Committee of the American Gas Association, Proceedings of the Second Annual Convention, and the report of the 1930 Subcommittee on Meters, Distribution Committee, American Gas Associations.

24. Calibration of Rotary Displacement Meters

24.1 For the testing of rotary displacement meters, it is desirable to use a method by which the meter correction may be determined over operating rates from about 5 or 10 % of rated capacity up to the full capacity or at least the normal maximum operating rate. Such a method would be the use of a large volume prover.

NOTE 16—Other methods of calibrating rotary displacement meters, applicable to both shop and field use, are described in the paper by Bean, H. S., Benesh, M. E., and Whiting, F. C., "Testing Large-Capacity Rotary Gas Meters," *Journal of Research*, National Bureau of Standards, JRNBA, Vol 37, No. 3, Sept. 1946, p. 183. (*Research Paper RP1741*.)

25. Calibration of Rate-of-Flow Meters

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

25.2 A small orifice meter or a flowmeter of the capillary tube type may be calibrated in much the same way as described in 25.1. In this case, it will be necessary to measure the static pressure of the gas on the inlet side of the orifice or capillary tube and the pressure drop across it. From the pressure and temperature (and humidity), the density of the air entering the orifices and the "flow coefficient" of the orifice may be calculated as follows:

$$\rho_1 = 1.3273\,([p_1 - 0.378e]/(459.7 + t)) \quad (4)$$

$$Q_1 = 0.0997\,KD_2^{\,2}\sqrt{h/\rho_1}$$

$$w = 0.0997\,KD_2^{\,2}\sqrt{h\rho_1}$$

where:
D_2 = diameter of the orifice;
e = pressure of water vapor at the temperature and relative humidity of the air;
h = pressure drop across orifice, inches of water;
K = orifice flow coefficient (a ratio);
p_1 = absolute pressure at the orifice inlet, inches of water;
t = temperature of the air (usually at the orifice inlet), °F;
Q_1 = actual volume rate of flow at orifice inlet conditions as calculated from the prover observations, ft^3/s;
w = actual mass rate of flow as calculated from the prover observations lb/s; and
ρ_1 = density of the air at the orifice inlet, lb/ft^3.

25.3 If the rate of flow is subject to variations such that the differential pressure, h, will vary by more than 3 in. of water from the value at which K was determined, several values of K corresponding to different values of h should be determined. These may be plotted against h, or better against h/ρ_1.

NOTE 17—For a more complete treatment of the calibration and use of rate-of-flow meters, reference should be made to such texts and reports as the following:

"Experimental Mechanical Engineering," H. Diederichs and W. C. Andrae, Vol 1, Chap. X, Part II.

"Fluid Meters, Their Theory and Application," Report of A.S.M.E. Special Research Committee on Fluid Meters.

NOTE 18—For the application of rate-of-flow meters, particularly orifice meters, to the commercial metering of fuel gases, Report No. 2, 1945 reprint, of the Gas Measurement Committee, American Gas Association, Natural Gas Department, or any later revisions thereof should be used.

26. Keywords

26.1 gaseous fuels; natural gas

APPENDIXES

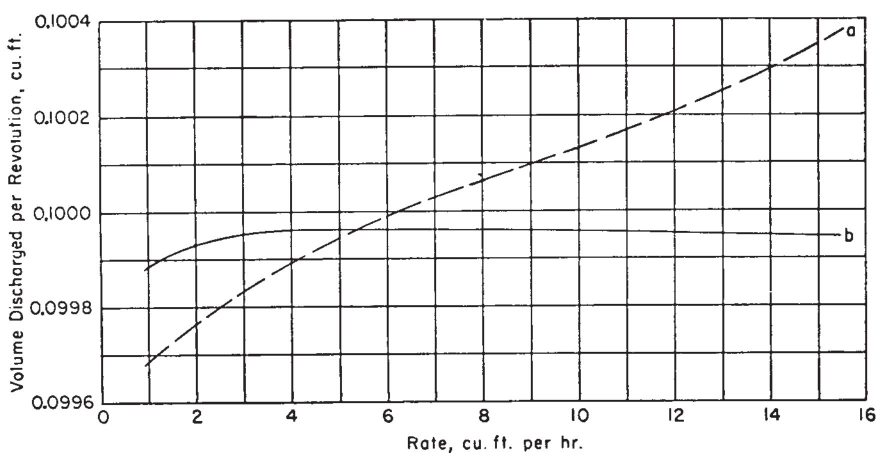
(Nonmandatory Information)

X1. RATE COMPENSATING CHAMBERS FOR LIQUID-SEALED ROTATING-DRUM METERS

X1.1 From the curve in Fig. X1.1, it is seen that the volume discharged per revolution by a wet gas meter increases as the rate of flow increases. This change with rate may amount to as much as 1 % over the operating range of the meter. The explanation for it is that the increase in the rate of flow through the meter is accompanied by (or is caused by) an increase in the pressure drop through the metering drum. This increase in the pressure drop through the meter drum depresses the surface of the water within the measuring compartments as they are filled with gas, thereby increasing the volume of gas that the drum will contain per revolution.

X1.2 This change in the elevation of the water surface within the metering compartment with change in rate of flow may be diminished or completely compensated for by attaching to or incorporating within the meter case an auxiliary water compartment of a special cross-sectional shape. There is also a restricting orifice or tube placed in the inlet of the meter and so situated that the gas pressure within the auxiliary water compartment is greater than within the metering drum. This pressure difference increases as the rate of flow increases and causes water from the auxiliary compartment to be displaced into the main body of the meter in such amount as will maintain the surface of the water in the metering compartments at a constant elevation. In this way, the volume of gas discharged per revolution of the drum remains practically constant over the full operating range of the meter, as shown by Fig. X1.1. Note that, in general, the pressure drop across the metering drum is less than half the total pressure drop across the meter, since the drop in the inlet tube was the larger part of the total. For this reason, the inclusion of the regulating orifice or tube does not increase the overall pressure drop to any significant extent.

X1.3 A complete description of this method of rate compensation is given in U.S. Patent No. 2321038, assigned to the U.S. Government.



a = Rate without rate-compensating chamber.
b = Rate with rate-compensating chamber.

FIG. X1.1 Calibration Curves of a Wet Test Meter Without and With a Rate-Compensating Chamber

X2. DERIVATION OF EQUATIONS RELATING THE VALUES IN Table 2

X2.1 The equations relating the tabular values are derived thus:

let:

N_s = uncorrected proof observied on scale, %;
N_c = corrected proof (corrected for scale error), %; and
K = correction in percent to apply algebraically to N_s to obtain N_c.

$$K = N_c - N_s \text{ or } N_c = N_s + K \quad \text{(X2.1)}$$

$$N_s = \Delta V_s / V_m \times 100 \quad \text{(X2.2)}$$

$$N_c = \Delta V_c / V_m \times 100 \quad \text{(X2.3)}$$

Dividing Eq X2.3 by Eq X2.2: $(N_c/N_s = \Delta V_c/V_s)$ (X2.4)

or solving for $N_c = N_s\ (\Delta V_c/\Delta V_s) = N_s + K$ (X2.5)

$$N_s\ (\Delta V_c/V_s) = N_s\ [1 + (K/N_s)]$$

Canceling and solving for $K = N_s\ [(\Delta V_c/\Delta V_s) - 1]$ (X2.6)

but since N_s is usually nearly 100,

$$K = 100\ [(\Delta V_c/\Delta V_s) - 1] \quad \text{(X2.7)}$$