ASME/ANSI MFC-9M-1988

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Measurement of Liquid Flow in Closed Conduits by Weighing Method

The American Society of Mechanical Engineers

AN AMERICAN NATIONAL STANDARD

Measurement of Liquid Flow in Closed Conduits by Weighing Method

ASME/ANSI MFC-9M–1988

The American Society of Mechanical Engineers

345 East 47th Street, New York, N.Y. 10017

Date of Issuance: February 28, 1989

This Standard will be revised when the Society approves the issuance of a new edition. There will be no addenda or written interpretations of the requirements of this Standard issued to this edition.

FOREWORD

(This Foreword is not part of ASME/ANSI MFC-9M-1988.)

This Standard was prepared by the ASME Committee on Measurement of Fluid Flow in Closed Conduits (MFC). It is based on and closely parallels the International Organization for Standardization (ISO) International Standard ISO 4185-1980, incorporating U.S. practices and terminology where they differ.

This Standard was approved by the American National Standards Institute (ANSI) as an American National Standard on December 15, 1988.

ASME STANDARDS COMMITTEE MFC
Measurement of Fluid Flow in Closed Conduits

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PERSONNEL OF SUBCOMMITTEE 14 — FLOW MEASUREMENT BY WEIGHING AND VOLUMETRIC MEASUREMENTS

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MEASUREMENT OF LIQUID FLOW IN CLOSED CONDUITS BY WEIGHING METHOD

1 GENERAL

1.1 Scope and Field of Application

This Standard specifies a method of liquid flow rate measurement in closed conduits by measuring the mass of liquid delivered into a weighing tank in a known time interval. It deals in particular with the measuring apparatus, procedure, and method for calculating the flow rate and the uncertainties associated with the measurement.

The method described may be applied to any liquid, provided that its vapor pressure is such that any escape of liquid from the weighing tank by vaporization is not sufficient to affect the required measurement accuracy. Closed weighing tanks and their application to the flow measurement of liquids of high vapor pressure are not considered in this Standard.

This Standard considers only the measurement techniques and does not address any possible hazards involved in handling the liquid involved.

Theoretically, there is no limit to the application of this method, which is used generally in fixed laboratory installations only. However, for economic reasons, typical hydraulic laboratories using this method can produce accurate flow rates of 500 kg/s (3300 lbm/sec) or less.

Owing to its high potential accuracy, this method is often used as a primary method for calibration of other methods or devices for mass flow rate measurement or volumetric flow rate measurement, provided that the density of the liquid is known accurately. It must be ensured that the pipeline is running full with no air or vapor pockets present in the measuring section.

1.2 References

The American Society of Mechanical Engineers

ANSI/ASME MFC-1M (latest edition), Glossary of Terms Used in the Measurement of Fluid Flow in Pipes

ANSI/ASME MFC-2M (latest edition), Measurement Uncertainty for Fluid Flow in Closed Conduits

International Organization of Legal Metrology[1]

Recommendation No. 1, Cylindrical Weights From 1 Gram to 10 Kilograms of Medium Accuracy Class

Recommendation No. 2, Rectangular Bar Weights From 5 Kilograms to 50 Kilograms of Medium Accuracy Class

Recommendation No. 3, Metrological Regulations for Non-Automatic Weighing Machines

Recommendation No. 20, Weights of Accuracy Classes E_1 E_2 F_1 F_2 M_1 From 50 Kilograms to 1 Milligram

Recommendation No. 28, Technical Regulations for Non-Automatic Weighing Machines

Recommendation No. 33, Conventional Value of the Result of Weighing in Air

1.3 Definitions

The following definitions are given for terms used in some special sense or for terms, the meaning of which seems useful to emphasize. A more comprehensive list of definitions and symbols applicable to the measurement of fluid flow in closed conduits can be found in ANSI/ASME MFC-1M and ANSI/ASME MFC-2M.

buoyancy correction — correction made to the readings of a weighing device to compensate for the upward thrust exerted by the atmosphere on the liquid being weighed and on the reference weights used during the calibration of the weighing machine

diverter — device which diverts the flow either to the weighing tank or its bypass without changing the flow rate during the measurement interval

dynamic weighing — method in which the net mass of liquid collected is deduced from weighing made while fluid flow is being delivered into the weighing tank (a diverter is not required with this method)

flow stabilizer — structure forming part of the hydraulic system, ensuring a stable flow rate in the

[1]Available from the International Bureau of Legal Metrology, 11 rue Turgot, 75009, Paris, France.

conduit being supplied with liquid; for example, a constant level head tank, the level of liquid which is controlled by a weir of sufficient capacity

static weighing — method in which the net mass of liquid collected is deduced from tare and gross weighings made before and after the liquid has been diverted for a measured time interval into the weighing tank

1.4 Symbols

Table 1 reproduces the symbols that are used in this Standard.

2 PRINCIPLES

2.1 Statement of the Principles

2.1.1 Static Weighing. The principle of the flow rate measurement method by static weighing (for schematic diagrams of typical installation, see Figs. 1A, 1B, and 1C) is:

(*a*) to determine the initial mass of the tank plus any residual liquid;

(*b*) to divert the flow into the weighing tank (until it is considered to contain a sufficient quantity to attain the desired accuracy) by operation of the diverter, which actuates a timer to measure the filling time;

(*c*) to determine the final mass of the tank plus the liquid collected in it.

The flow rate is then derived from the mass collected, the collection time, and other data as discussed in Section 5 and Appendix A.

2.1.2 Dynamic Weighing. The principle of the flow rate measurement method by dynamic weighing (see Fig. 1D for a schematic diagram of a typical installation) is:

(*a*) to let the liquid collect in the tank to a predetermined initial mass, when the timer is then started;

(*b*) to stop the timer when a predetermined final mass of collected liquid is reached.

The flow rate is then derived from the mass collected, the collection time, and other data as discussed in Section 5 and Appendix A.

2.1.3 Comparison of Instantaneous and Mean Flow Rate. It should, however, be emphasized that only the mean value of flow rate for the filling is given by the weighing method. Instantaneous values of flow rate as obtained on another instrument or meter in the flow circuit can be compared with the mean rate only if the flow is maintained stable during the measurement interval by a flow-stabilizing system, or if the instantaneous values are properly time-averaged during the whole filling period.

2.2 Accuracy of the Method

2.2.1 Overall Uncertainty on the Weighing Measurement. The weighing method gives an absolute measurement of flow which, in principle, requires only mass and time measurements. Provided that the precautions listed in para. 2.2.2 are taken, this method may be considered as one of the most accurate of all flow rate measuring methods, and for this reason it is often used as a calibration method. When the installation is carefully constructed, maintained, and used, an uncertainty of $\pm 0.1\%$ (with 95% confidence limits for the random part of that uncertainty) can be achieved.

2.2.2 Requirements for Accurate Measurements. The weighing method gives an accurate measurement of flow rate provided:

(*a*) there is no leak in the flow circuit and there is no unmetered leakage flow across the diverter:

(*b*) there is no accumulation (or depletion) of liquid in a part of the circuit by thermal contraction (or expansion), and there is no accumulation (or depletion) by change of vapor or gas volume contained unknowingly in the flow circuit;

(*c*) necessary corrections for the influence of atmospheric buoyancy are made (this correction may be made when calibrating the weighing apparatus);

(*d*) the weighing device, the timer, and means for starting and stopping it achieve the necessary accuracy;

(*e*) the time required by the diverter for traversing is small with respect to the filling time, the timer being started and stopped while the diverter is crossing the hydraulic center line;

(*f*) in the case of the dynamic weighing method, the effects of the dynamic phenomena are sufficiently small.

3 APPARATUS

3.1 Diverter

The diverter is a moving device used to direct flow alternately along its normal course or toward the weighing tank. It can be made up of a conduit or moving gutter, or, better, by a baffle plate pivoting around a horizontal or vertical axis (see Fig. 2).

The motion of the diverter should be sufficiently fast (less than 0.1 s, for example) to reduce the

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(1) *In* Table 1 *for* Symbol ϱ_a, *change* Quantity *from* Density of air (at 20°C and 1 bar*) *to read*:

Density of air

(2) *Delete asterisked footnote.*

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TABLE 1 SYMBOLS

Symbol	Quantity	Dimension [Note (1)]	SI (Metric) Units	U.S. (Customary) Units
B	Bias	...	...	...
m	Mass	M	kg	lbm
q_m	Mass flow rate	MT^{-1}	kg/s	lbm/sec
q_V	Volume flow rate	L^3T^{-1}	m^3/s	ft^3/sec
t	Time	T	s	sec
t_{95}	Two-tailed Student's t	...	...	...
V	Volume	L^3	m^3	ft^3
U_{RSS} U_{95}	Uncertainty at the 95% confidence level	...	...	...
U_{ADD} U_{99}	Uncertainty at the 99% confidence level	...	...	...
ϱ	Density of liquid	ML^{-3}	kg/m^3	lbm/ft^3
ϱ_a	Density of air (at 20°C and 1 bar*)	ML^{-3}	kg/m^3	lbm/ft^3
ϱ_p	Density of standard weights	ML^{-3}	kg/m^3	lbm/ft^3
σ	Standard deviation of the sample	...	...	...

*1 bar = 10^6 Pa

NOTE:
(1) Fundamental dimensions: M = mass, L = length, T = time.

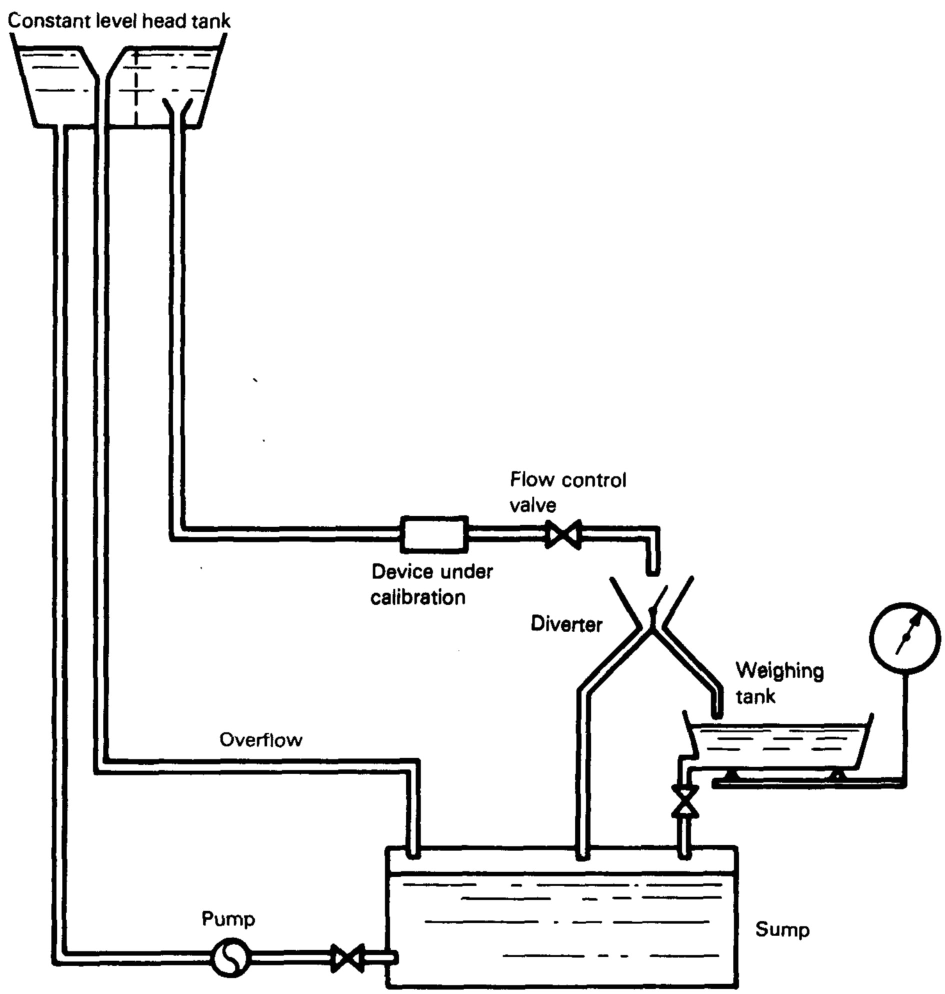

FIG. 1A DIAGRAM OF AN INSTALLATION FOR CALIBRATION BY WEIGHING (Static Method, Supply by a Constant Level Head Tank)

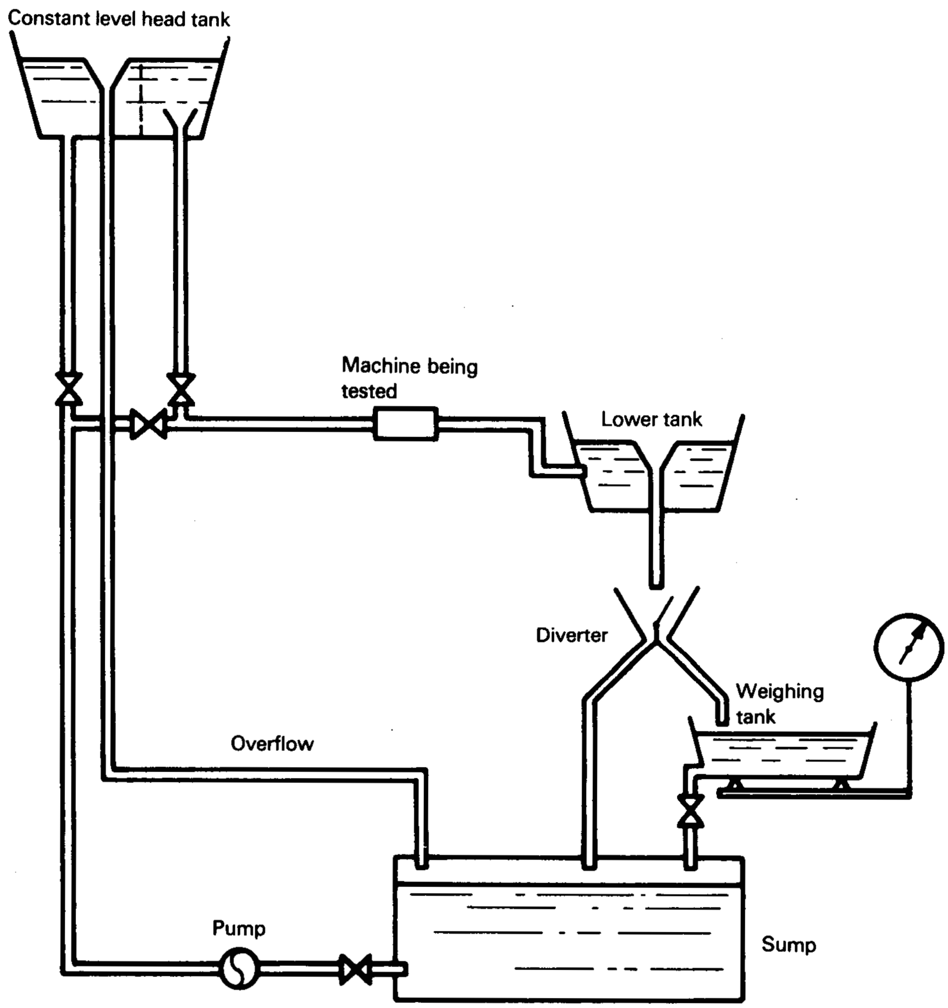

FIG. 1B DIAGRAM OF AN INSTALLATION FOR FLOW RATE MEASURE BY WEIGHING
(Used for Hydraulic Machine Test; Static Method, Supply by a Constant Level Head Tank)

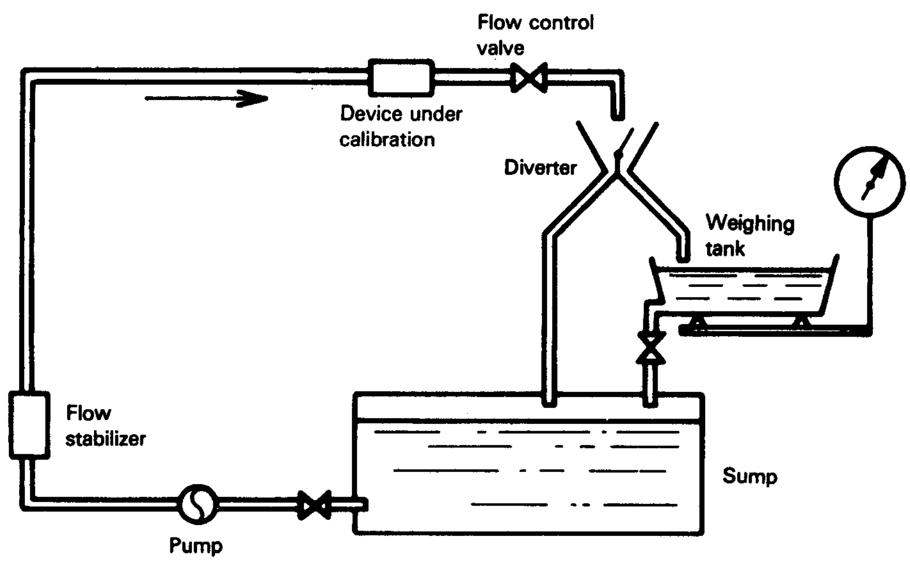

FIG. 1C DIAGRAM OF AN INSTALLATION FOR CALIBRATION BY WEIGHING (Static Method, Direct Pumping Supply)

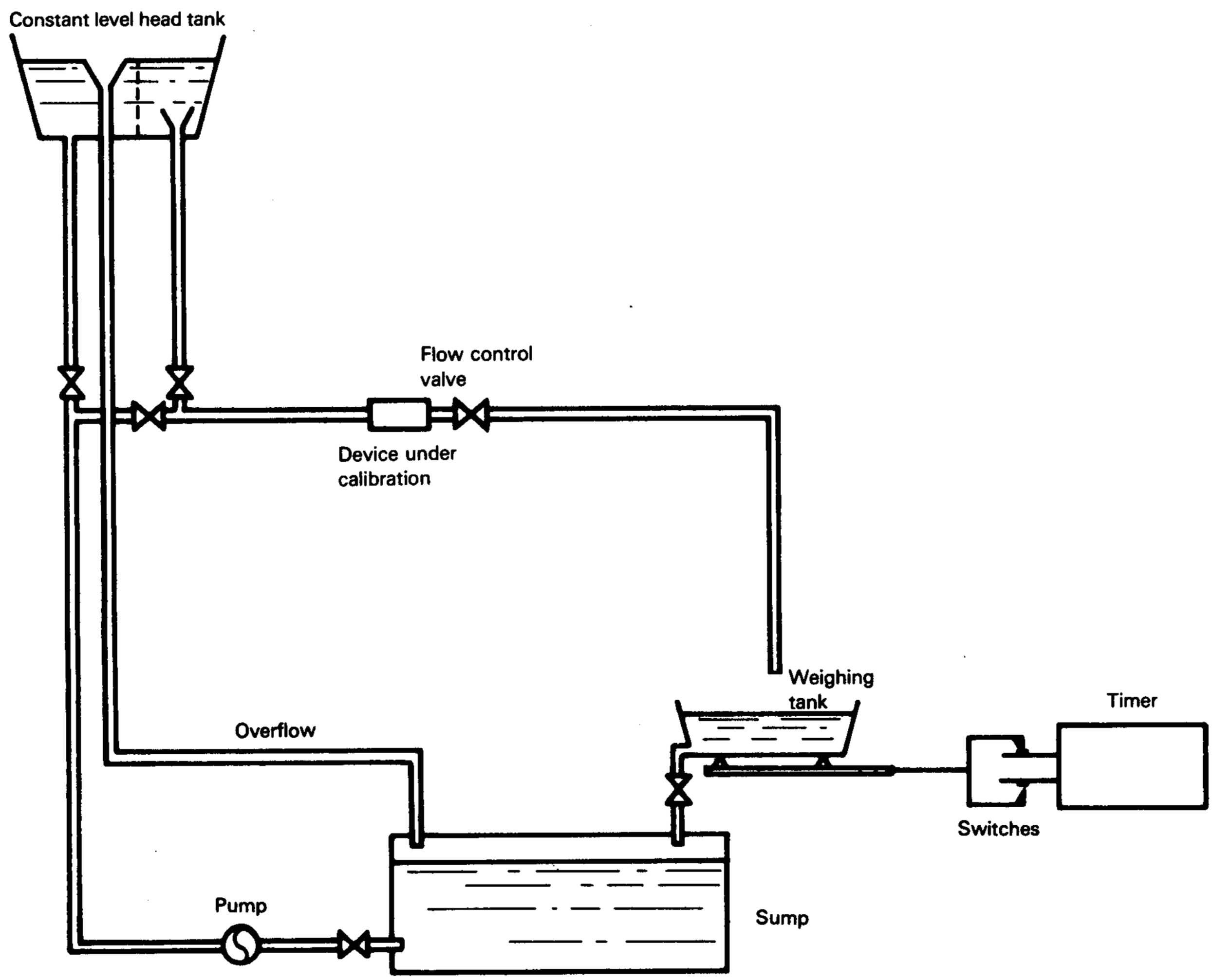

FIG. 1D DIAGRAM OF AN INSTALLATION FOR CALIBRATION BY WEIGHING (Dynamic Method, Supply by a Constant Level Head Tank)

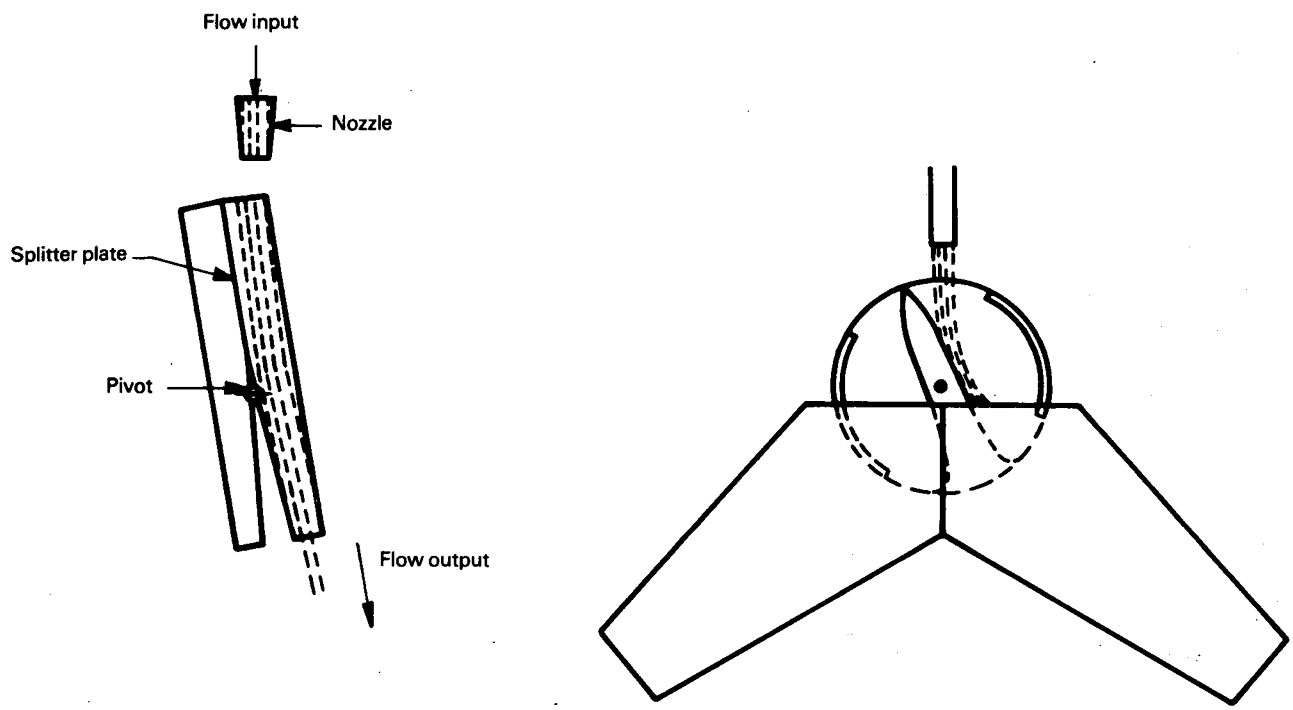

FIG. 2 EXAMPLES OF DIVERTER DESIGN

possibility of a significant error occurring in the measurement of the filling time. This is accomplished by rapid diverter travel through a thin liquid sheet as formed by a nozzle slot. Generally, this liquid sheet has a length 15 to 50 times its width in the direction of diverter travel. The pressure drop across the nozzle slot should not exceed about 20 kPa (3 psi) to avoid splashing, air entrainment,[2] and flow across the diverter and turbulence in the weighing tank. This motion of the diverter can be generated by various electrical or mechanical devices — for example, by a spring or torsion bar or by electrical or pneumatic actuators. The diverter should in no way influence the flow in the circuit during any phase of the measuring procedure.

For large flow rates which could involve excessive stresses, however, a diverter with a proportionately slow performance rate (1 s to 2 s, for example) can be used, provided the operating law is constant (see para. 3.2 and Fig. 3) and the variation of the flow rate distribution as a function of the diverter stroke is preferably linear and is in any case known and can be verified.

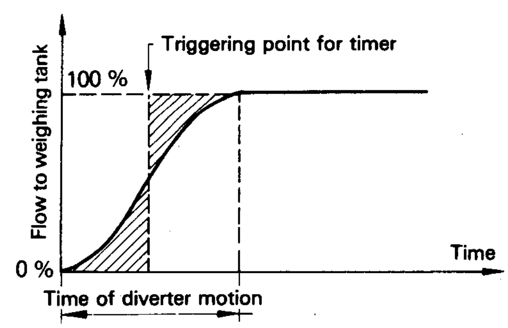

FIG. 3 OPERATIONAL LAW OF DIVERTER

Care shall be taken when designing the mechanical parts of the device and the diverter, as well as during frequent checks in service, that no leak or splash of liquid occurs either toward the outside or from one diverter channel to the other.

Besides a thin flat liquid stream, other shapes of liquid stream are permissible in the diverter duct, if the necessary corrections for the diverting time are applied as indicated in Appendix A.

[2]In certain designs of nozzle slot, however, special vents to allow air ingress to the fluid jet may be necessary to ensure stable flow within the test circuit.

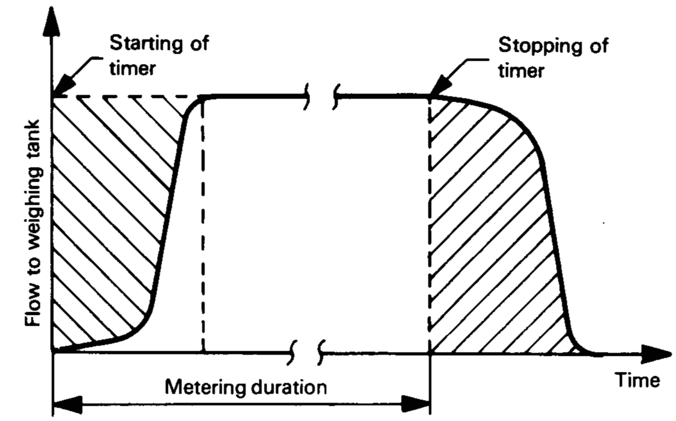

FIG. 4 TIME METERING FOR A DIVERTER, THE OPERATION LAW OF WHICH IS IDENTICAL IN BOTH DIRECTIONS

3.2 Time-Measuring Apparatus

The time of discharge into the weighing tank is normally measured by an electronic counter with a built-in accurate time reference — for example, a quartz crystal. The diversion period can thus be read to 0.01 s or better. The error arising from this source can be regarded as negligible, provided the resolution of the timer display is sufficiently high and the equipment is checked periodically against a national time standard — for example, the frequency signals transmitted by certain radio stations.

The timer shall be actuated by the motion of the diverter itself through a switch fitted on the diverter — for example, optical or magnetic. Strictly speaking, the time measurement shall be started (or stopped) at the instant when the hatched areas in Fig. 3, which represent flow variation with time, are equal. In practice, however, it is generally accepted that this point corresponds to the mid-travel position of the diverter in the fluid jet. The error will be negligible, provided the time of passage of the diverter through the stream is negligible in comparison with the period of diversion to the tank.

If a diverter is used, then the operating law of the diverter should be identical in both directions (see Fig. 4), and the timer may be started and stopped at the instant when the motion of the diverter is started in each direction; this is the case particularly when the time–flow rate law is linear.

If the error in the filling time measurement arising from the operation of the diverter and starting and stopping of the timer is not negligible, then a correction should be made in accordance with the directions of Appendix A.

3.3 Weighing Tank

The weighing tank shall be of sufficient capacity so that the error in timing is negligible. Taking account of what is stated in paras. 3.1 and 3.2, the filling time for the highest expected flow rate shall be at least 30 s. Nevertheless, this time may be reduced provided that it is possible to determine experimentally, according to procedures such as described in Appendix A, that the required accuracy is achieved.

The tank may be of any shape but it is essential that it is perfectly leak-tight, and care should be taken to avoid liquid spillage. Internal walls or baffles may be required to reduce oscillations of the liquid in the tank and to improve structural rigidity.

The tank may be suspended from the weighing device or may constitute the platform of the latter, or may be placed on one of the platforms. To prevent sudden overloads detrimental to the weighing apparatus, it may be necessary to lock the tank in position on the scale during filling.

The tank may be drained by different means:

(*a*) by a valve at the base, the leak-tightness of which shall be capable of being verified (free discharge, transparent hose, or leak detection circuit); or

(*b*) by a siphon fitted with an efficient and checkable siphon break; or

(*c*) by a self-priming or submersible pump.

The rate of draining shall be sufficiently high so that test runs can follow each other at short intervals.

In all cases it shall be carefully checked that no pipe connections or electric wire links exist which are likely to transmit stresses between the weighing tank and the fixed parts of the installation; indispensable links shall therefore be extremely flexible and their flexibility verified during the calibration of the weighing device.

3.4 Weighing Device

The weighing machine may be of any type — for example, mechanical or with strain-gage load cells — provided that it offers the required sensitivity, accuracy, and reliability. When the weighing method of measuring flow rate is applied for the purposes of legal metrology, it is advisable to employ the weighing machine according to OIML Recommendation Nos. 3 and 28.

After its installation in the test facility, the weighing device shall be calibrated over the whole measuring range using standard weights. Here it is advisable to follow OIML Recommendation Nos. 1, 2, 20, and 23.

The weighing device shall be regularly maintained and its calibration shall be periodically checked. If the weights available are not sufficient in number or size to cover the whole measuring range, a calibration shall be made in steps by replacing the weights by liquid and by using standard weights to verify intervals accurately. Uncertainties in calibration may increase, depending on the techniques used.

It should be noted that in view of the difference in buoyancy when calibrating the weighing device with weights and when weighing an equivalent mass of liquid, a correction to the readings is necessary (see the calculation in para. 5.1).

3.5 Auxiliary Measurements

To obtain the volume flow rate from mass measurement, it is essential to know the density of the liquid through the flowmeter with the required accuracy at the time of weighing.

If the liquid to be measured is reasonably pure and clean, it is acceptable to measure its temperature and to derive its density from a table of physical properties (see Appendix B for the case of water). Temperature may be measured with a simple mercury-in-glass thermometer or, better, by any device such as a resistance probe or thermocouple, which is installed to measure the temperature of the fluid as it passes through the meter(s). Devices should be placed downstream of the device under calibration. For water, taking into account the small variation of density with temperature about ambient temperature, an accuracy of 0.5°C (1°F) is enough to ensure less than 10^{-4} error on density evaluation.

If, however, the purity of the liquid is in doubt, it is essential to measure its density. To this end, a sample can be collected and its density measured either by a direct method, by weighing in a graduated cylinder on an analytical balance, or by an indirect method — for example, by measuring the hydrostatic force exerted on a calibrated float (hydrostatic balance). Whatever the method used, the liquid temperature must be measured when measuring the density; in many cases it may be assumed that the relative variation of density with respect to temperature is the same as for the pure liquid.

4 PROCEDURE

4.1 Static Weighing Method

In order to eliminate the effect of residual liquid likely to have remained in the bottom of the tank or adhering to the walls, a sufficient quantity of liquid shall first be discharged into the tank (or left at the end of draining after the preceding measurement) to reach the operational threshold of the weighing device. This initial mass m_0 will be recorded while the diverter directs the flow to storage, and while the flow rate is being stabilized. After steady flow has been achieved, the diverter is operated to direct the liquid into the weighing tank, this operation automatically starting the timer. After collection of an appropriate quantity of liquid, the diverter is operated in the opposite direction to return the liquid to storage, automatically stopping the timer and thus allowing the filling time t to be determined. When the oscillations in the tank have subsided, the apparent final mass m_1 of the weighing tank is recorded. The tank shall then be drained.

4.2 Dynamic Weighing Method

After steady flow has been achieved, the drain valve of the weighing tank is closed. As the mass of liquid in the tank increases, it overcomes the force due to counterpoise mass M_1 on the end of the balance beam, which then rises and starts the timer. An additional mass Δm is used as $(m_1 - m_0)$ in the subsequent calculation of the flow rate.

There exist other possible methods of measurement — for example, automatic reading of the weighing device indication.

In all cases it shall be carefully checked that no pipe connections or electric wire links exist which are likely to transmit stresses between the weighing tank and the fixed parts of the installation; indispensable links shall therefore be extremely flexible and their flexibility verified during the calibration of the weighing device.

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It should be noted that in view of the difference in buoyancy when calibrating the weighing device with weights and when weighing an equivalent mass of liquid, a correction to the readings is necessary (see the calculation in para. 5.1).

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There exist other possible methods of measurement — for example, automatic reading of the weighing device indication.

4.3 Common Provisions

It is recommended that at least two (2) measurements be carried out for each of a series of flow rate measurements if a subsequent analysis of random uncertainties is to be carried out.

The various quantities to be measured may be noted manually by an operator or transmitted by an automatic data acquisition system to be recorded in numerical form on a printer or provide direct entry into a computer.

5 CALCULATION OF FLOW RATE

5.1 Calculation of Mass Flow Rate

The mean mass flow rate during the filling time is obtained by dividing the real mass m of the liquid collected by the filling time t:

$$q_m = \frac{m}{t} = \frac{m_1 - m_0}{t} \times \frac{1 - \dfrac{\varrho_a}{\varrho_p}}{1 - \dfrac{\varrho_a}{\varrho}}$$

If necessary, t is corrected in concordance with one of the procedures described in Appendix A to take into account the diverter timing error or the dynamic weighing timing error. The final term in this equation is a correction term introduced to take into account the difference in buoyancy exerted by the atmosphere on a given mass of liquid and on the equivalent mass in the form of weights made — for example, of cast iron, used when calibrating the weighing machine.

NOTE: In view of the relative magnitudes of the quantities, this equation can be written as follows with satisfactory approximation:

$$q_m = \frac{m_1 - m_0}{t} (1 + \epsilon)$$

where

$$\epsilon = \varrho_a \left(\frac{1}{\varrho} - \frac{1}{\varrho_p} \right)$$

In the case where the liquid is water, it is sufficient to calculate the correction factor ϵ from mean approximate values:

$$\varrho = 1\ 000 \text{ kg/m}^3$$

$$\varrho_a = 1.21 \text{ kg/m}^3 \text{ (at 20°C and 1 bar)}$$

$$\varrho_p = 8\ 000 \text{ kg/m}^3 \text{ (conventional mean value according to OIML Recommendation No. 33)}$$

Hence,

$$\epsilon = 1.06 \times 10^{-3}$$

and

$$q_m = 1.001\ 06 \frac{m_1 - m_0}{t}$$

5.2 Calculation of Volume Flow Rate

The volume flow rate is calculated from the mass flow rate as computed in para. 5.1, and from the density of the liquid at the temperature of operation, as read from standard tables — for example, as given in Appendix B for water in the range of ambient temperatures. (In exceptional cases, it may be necessary to measure the density directly.)

$$q_V = \frac{q_m}{\varrho} = \frac{m_1 - m_0}{\varrho t} (1 + \epsilon)$$

6 UNCERTAINTIES IN THE MEASUREMENT OF FLOW RATE

Uncertainty calculations shall be performed in accordance with ANSI/ASME MFC-2M.

For the purpose of this Standard, as in ANSI/ASME MFC-2M, the *uncertainty interval* is defined as an estimate of the error band, centered about the measurement within which the true value must fall with high probability.

The uncertainty U can be expressed in absolute or relative terms. The uncertainty interval is centered about the results of the flow measurement and is defined as $q_m \pm U$. The uncertainty U may be either

$$U_{\text{ADD}} = U_{99} = (B + t_{95}\sigma)$$

or

$$U_{\text{RSS}} = U_{95} = \sqrt{B^2 + (t_{95}\,\sigma)^2}$$

The bias B is an estimate of the upper limit of the true bias error, and the precision σ is the sample standard deviation.

The statistical parameter t_{95} is defined and tabled in ANSI/ASME MFC-2M. When σ is based on a large sample, greater than 30, t_{95} is set equal to 2.0.

NOTE: For a comprehensive presentation of bias, precision, and uncertainty, see ANSI/ASME MFC-2M. ANSI/ASME MFC-2M also includes several flow measurement uncertainty examples.

APPENDIX A
CORRECTIONS ON THE MEASUREMENT OF FILLING TIME

(This Appendix contains supplementary information for the convenience of the reader. It is not part of ASME/ANSI MFC-9M-1988.)

Experience has shown that, for a well-designed system, the error occuring due to switching the timer on and off for one start-stop cycle of the diverter may correspond to a value of 0 ms to 25 ms. This error is dependent upon the flow rate, the velocity of traverse in each direction of the diverter tip through the liquid flow, the exact location of the diverter tip through the liquid flow, and the exact location of the timer actuator with respect to the liquid flow emerging from the nozzle slot. This error should not be assumed to be insignificant, but should be evaluated by experimental tests, using the procedure described in this Appendix.

A1 STATIC WEIGHING METHOD

A1.1 Method 1

When steady flow is established at the flow control valve, a standard test is run to determine the flow rate. Then a series of short flows or bursts of flow (as many as 25 bursts) are deflected into the weighing tank without resetting the timer or the scales; the flow is then determined from the totalized mass and totalized time. To complete the run, a second standard determination is made on the steady flow, and the two standard determinations are averaged. Results obtained are then compared with the totalized flow determination.

If the totalized mass for n bursts is about equal to that of the standard run, it can be shown that the average timing error Δt due to chronograph control for one cycle is closely equal to:

$$\Delta t = \frac{t}{n-1}\left(\frac{q}{q'} \times \frac{\Sigma_1^n \Delta m_i \,/\, \Sigma_1^n t_i}{(m_1 - m_0)/t} - 1\right)$$

where

q and q' = flow rates during the standard run and during the n bursts, respectively, as measured by a self-contained meter in the flow circuit. The corrective term q/q' takes into account the flow rate variations, if any, between both measuring runs.

$\Sigma_1^n \Delta m_i \,/\, \Sigma_1^n t_i$ = flow rate determined from the totalized mass and totalized time for n bursts

$(m_1 - m_0)/t$ = flow rate determined by the standard procedure

After this procedure has been repeated over a wide range of flow rates, it will be possible, on any further measurement, to correct the measured filling time by the value Δt so determined.

A1.2 Method 2

The following alternative method of setting the diverter timer actuator may also be employed.

The normal flow rate control mechanism of the hydraulic circuit should first be set to give a flow rate close to the maximum flow rate capability of the system, with a good quality flow rate meter in the circuit. The system is run at this condition for several hours, during which many successive measurements of flow rate are made using different diversion times. Suggested times are normal, and 0.2, 0.1, and 0.05 of normal. The highest number of tests will be required at the 0.05 of normal (or long), with the lowest number of tests at the normal diversion time. During each of these times the average reading on the flow rate meter should be taken as accurately as possible.

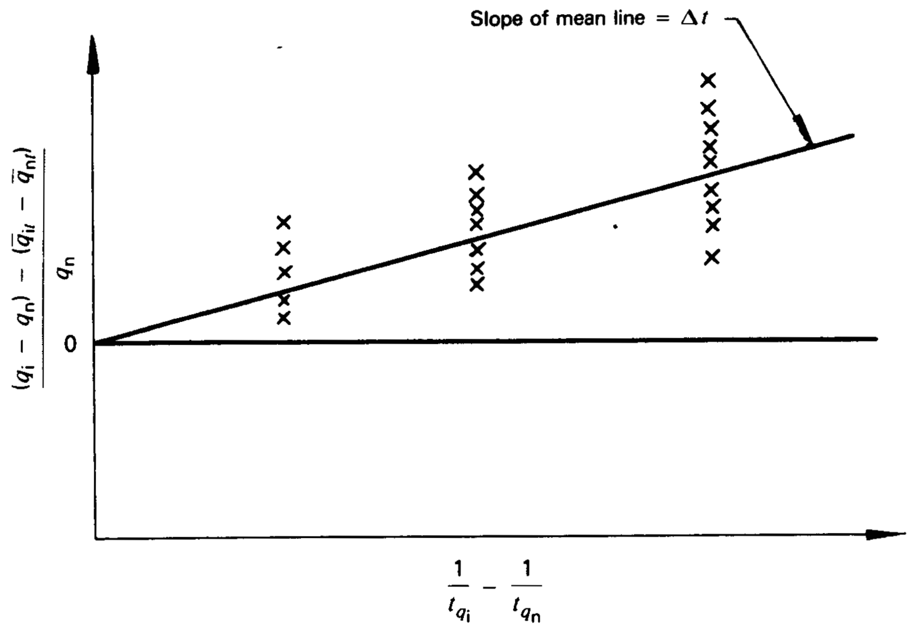

FIG. A1 PLOTTING OF RESULTS OF DIVERTER TIMER ACTUATOR

The results obtained should be fitted into the following equation, in which Δt is the required timing error of the diverter system:

$$\Delta t \left(\frac{1}{t_{qi}} - \frac{1}{t_{qn}} \right) = \frac{(q_i - q_n) - (\bar{q}_{it} - \bar{q}_{nt})}{q_n}$$

where

t_{qi} = diversion time for a particular short test
t_{qn} = diversion time for the normal length test occurring nearest in diurnal time in the testing sequence
q_i = flow rate calculated for the particular diversion time t_{qi}
q_n = flow rate calculated for the normal diversion time t_{qn} occurring nearest in diurnal time in the testing sequence
$\bar{q}_{it}$ = average flow rate meter reading time t_{qi}
$\bar{q}_{nt}$ = average flow rate meter reading during time t_{qn}

The values obtained for the right-hand side of this equation should be plotted against $(1/t_{qi} - 1/t_{qn})$ as shown in Fig. A1. The points should define a straight line passing through the origin, the slope of which is equal to Δt.

If a significant value of Δt is obtained, the diverter timer actuator should be adjusted to minimize the value of the error as shown by repeated testing.

The procedure should be repeated at a few lower flow rates to examine whether or not the value of Δt obtained is significantly flow rate dependent. If significant changes in the Δt value are obtained, it will be necessary to improve the operation of the diverter system or to introduce a variable correction time Δt to be applied to the diversion time.

A2 DYNAMIC WEIGHING METHOD

This procedure involves movement of the beam of the weighing device just prior to both start and stop actuations of the timer.

Four important dynamic phenomena take place during the dynamic weighing cycle, namely:

(*a*) a change in the impact force of the falling liquid between the initial and final weighing points;

(*b*) collection of an extra amount of liquid from the falling column by the rising level in the tank;

(*c*) forces due to waves in the tank;

(*d*) a change in the inertia of the weighing device and liquid in the weighing tank, with a resultant change of time required to accelerate the balance beam to the timer actuation point.

Generally, the decrease in impact force is equal and opposite to the additional weight of liquid collected so that these two effects cancel each other.

Oscillation of liquid within the weighing tank may have a serious influence on the precision of the method. Devices prescribed in para. 3.3 can reduce, but not eliminate completely, this undesirable phenomenon, which is always most pronounced at higher rates of flow.

Changes in inertia between the initial and final weighing points can affect indicated flow rate by up to 0.5% if the error Δt in measured time t is not accounted for. This error is approximately:[1]

$$\frac{\Delta t}{t} = \left[\frac{6L\alpha}{g}\right]^{1/3} \left[\frac{\Delta m}{t}\right]^{2/3} \frac{(M_1 + \Delta m)^{1/3} - M_1^{1/3}}{\Delta m}$$

[1]Shafer, M. R., and F. W. Ruegg "Liquid Flowmeter Calibration Techniques," *Transactions*, ASME, Vol. 80, No. 7, October 1958.

where

$L\alpha$ = distance travelled by the end of a balance beam of length L deflected through an angle α from rest to the timing point

M_1 ordinarily will include the masses of the weighing tank and initial liquid therein, and possibly other masses depending on the weighing device used.

The corrected collection time in this case is $(t - \Delta t)$.

This error Δt can be reduced in conventional weighing applications by limiting the deflection α. Alternatively, static weighing experiments can be compared with those using the dynamic technique to determine Δt; the results can then be used to test the above equation for applicability and to evaluate the constants therein. On smaller dynamic weighing systems, the inertia effect can be practically eliminated by using a substitute weighing technique.

APPENDIX B
DENSITY OF PURE WATER

(This Appendix contains supplementary information for the convenience of the reader. It is not part of ASME/ANSI MFC-9M-1988.)

°C	Density kg/m^3	°F	Density lbm/ft^3
0.00	999.839	32	62.41796
2.22	999.947	36	62.42465
4.44	999.970	40	62.42611
6.67	999.916	44	62.42271
8.89	999.788	48	62.41476
11.11	999.592	52	62.40254
13.33	999.333	56	62.38631
15.56	999.012	60	62.36630
17.78	998.634	64	62.34271
20.00	998.202	68	62.31572
22.22	997.718	72	62.28549
24.44	997.184	76	62.25216
26.67	996.602	80	62.21587
28.89	995.975	84	62.17673
31.11	995.304	88	62.13484
33.33	994.591	92	62.09032

STANDARDS FOR MEASUREMENT OF FLUID IN CLOSED CONDUITS

(Published by the American Society of Mechanical Engineers)

TITLE OF STANDARD

Glossary of Terms Used in the Measurement of Fluid Flow in Pipes	MFC-1M–1979(R1986)
Measurement Uncertainty for Fluid Flow in Closed Conduits	MFC-2M–1983(R1988)
Measurement of Fluid Flow in Pipes Using Orifice, Nozzle, and Venturi	MFC-3M–1985
Measurement of Gas by Turbine Meters	MFC-4M–1986
Measurement of Liquid Flow in Closed Conduits Using Transit-Time Ultrasonic Flowmeters	MFC-5M–1985
Measurement of Fluid Flow in Pipes Using Vortex Flow Meters	MFC-6M–1987
Measurement of Gas Flow by Means of Critical Flow Venturi Nozzles	MFC-7M–1987
Fluid Flow in Closed Conduits — Connections for Pressure Signal Transmissions Between Primary and Secondary Devices	MFC-8M–1988
Measurement of Liquid Flow in Closed Conduits by Weighing Method	MFC-9M–1988
Method for Establishing Installation Effects on Flowmeters	MFC-10M–1988

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