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Standard Method of

FLOW MEASUREMENT OF WATER BY THE VENTURI METER TUBE[1]

This Standard is issued under the fixed designation D 2458; 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.

1. Scope

1.1 This method covers the measurement of the rate of flow of water in pipelines using the Herschel Standard Venturi meter tube.

1.2 Venturi[2] meter tubes are applicable for the measurement of industrial water flow and particularly for slurries or similar nonhomogeneous liquids containing large concentrations of suspended solids. Individually calibrated, the Venturi tube is used as a standard of measurement for acceptance tests on pumping and similar equipment. Pressure losses through Venturi tubes are less than for other primary flow measuring devices installed in pipelines. Thus, substantial savings in pumping power consumption can be realized by its use.

2. Definitions

2.1 *head, H*—the energy (capacity to do work) possessed by a liquid because of its elevation, velocity, pressure, or any combination of these. Each source of energy may be expressed in terms of equivalent head in feet, inches of water, or pounds per square inch, and each can be converted into the other two.

2.2 *differential head,* H_D—the difference in pressure head H_D in Fig. 2 between the inlet and the throat of the Venturi tube.

2.3 *loss of head*—the difference in line pressure at the inlet end and just downstream from the Venturi tube. It is also termed "nonrecoverable head."

2.4 *hydraulic gradient*—a line in any selected plane, connecting all points representing pressure head in any system.

2.5 *beta ratio*—the ratio of throat diameter, *d*, to the inlet diameter, *D*. The quantity *d*/*D* is expressed as a decimal and represented by the Greek letter Beta.

3. General Principles

3.1 The standard (long-type) Herschel[3] Venturi meter tube is a specially constructed primary differential producer and flow-measuring device which is installed between two flanges in a pipeline to form a constricted section (Fig. 1). The device operates on the principle that when a fluid passes through a reduced cross sectional area, an increase in velocity and a corresponding decrease in pressure (head) will occur (Fig. 2). This reduction in pressure is a simple function of the rate of flow. Two pressure measurements are made, one each at the high-pressure inlet point and at the low-pressure throat section. The difference in head, H_D (h_{v2}), expressed either as inches of water column or feet of water, is a measure of velocity, which is a measure of rate of flow, with the flow varying as the square root of the differential.

3.1.1 The increase in velocity is given as follows:

$$V = C(2gh_{v2})^{0.5}$$

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[1] This method is under the jurisdiction of ASTM Committee D-19 on Water.

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[2] The principle of the Venturi meter was first stated in 1797 by J. B. Venturi, an Italian, and was first applied by Clemens Herschel to the measurement of flow in pipes in 1887.

[3] Herschel, Clemens, "Fluid Meters: Their Theory and Application," Report of Special Research Committee on Fluid Meters, ASME, 1924.

where:

V = velocity, theoretical, ft/s,

C = discharge coefficient (average value = 0.98),

g = acceleration constant of gravity = 32.16 ft/s^2, and

h_{v2} = velocity head, theoretical, ft of water.

3.1.2 The fluid flow formulas for the Venturi tube are derived from this basic relationship. The flow formula then becomes the following:

$$Q = AC(2gh_{v2})^{0.5}$$

where:

Q = ft^3/unit time, and

A = area of pipe, ft^2.

3.2 In addition to the simple determination of the differential head, H_D, there are two factors to be considered in measurement with a Venturi tube. These are the velocity of approach and friction. Flowing fluid in a pipeline as it reaches the inlet section of the Venturi tube has a certain velocity of approach. At the throat section, the fluid has a velocity due to the constriction plus the original velocity. Observed differential head must be corrected for this velocity of approach factor. This correction is made through a table of values related to the Beta ratio d/D. The factor is expressed as $1/[(1 - B^4)^{0.5}]$.

3.2.1 When the throat-to-inlet ratio, B, is less than 0.3, the velocity of approach factor correction amounts to less than 1 percent and may be disregarded in other than exact calculations.

3.2.2 Values of the velocity of approach factor $1/[(1 - B^4)^{0.5}]$ for B ratios greater than 0.350 are as follows:

B or d/D	$1/(1 - B^4)^{0.5}$	B or d/D	$1/(1 - B^4)^{0.5}$
0.350	1.008	0.600	1.072
0.400	1.013	0.650	1.103
0.500	1.033	0.750	1.209
0.550	1.049	...	...

3.2.3 The friction factor causes the apparent value of the flow to be lower than the theoretical value indicated by the observed differential. Each Venturi tube, therefore, has a discharge coefficient, C, to correct the observed differential value to the actual value. Depending on throat velocity and measuring range, the value of C for various sizes of Venturi tubes will be between 0.96 and 0.99 with an average value of 0.98 generally used.

3.3 The formula for Venturi tube measurement evolved from consideration of the concept of flow, pressure, velocity, and the necessary correction factors becomes:

$$Q = AC\left(\frac{1}{(1 - B^4)^{0.5}}\right) \times (2gH_D)^{0.5}$$

where Q = ft^3/unit of time. By the use of proper additional numerical factors, this equation can be converted into gallons per unit of time.

4. Apparatus

4.1 *Venturi Meter Tube* (*Primary Device*) —The apparatus shall consist of the Venturi meter tube referred to as the primary measuring device suitably constructed in accordance with standard dimensions selected to give accurately measurable differential pressures over the entire required variation of quantity flow. At no time should the throat pressure drop below atmospheric. The Venturi tube should consist of inlet, throat, and outlet sections (Fig. 1). The inlet section shall consist of a short cylinder, A, and a truncated cone, B, of about 20 deg total angle equipped with piezometer ring or annular chamber which circumscribes the section and serves as a means of obtaining the average pressure of fluid at the upstream point.

4.1.1 The fluid pressure enters the annular chamber through equally spaced vent holes drilled through the inner wall of the chamber. The outside wall of the annular chamber contains one or more tapped holes, to one of which is connected the "high-pressure" line to the metering instrument.

4.1.2 The throat section, the most constricted part, follows the inlet section and is surrounded by an annular chamber to serve as a means of obtaining the average pressure at that point. Reamed holes through the liner admit fluid pressure to the annular chamber. The outside wall is tapped for the "low-pressure" line to the metering instrument (Note 1). The diameter of the throat is usually between one-third and three-fourths of the entrance of pipeline diameter.

NOTE 1—When a Venturi tube is to be used for metering liquids containing large concentrations of suspended solids or sludge, the annular ring is eliminated and replaced by single hole taps at the inlet and throat and these are flushed continuously with clean water.

4.1.3 The outlet section follows the throat section and is essentially a long truncated cone of about 5 to 7-deg angle which gradually returns to the original pipeline size. Construction is generally of high-tensile cast iron, tar-coated on the outer and inner surfaces, except for the throat liner of bronze or other corrosion material as conditions require. The liner is carefully finished to specified diameter and profile, since accuracy of metering depends largely upon the shape, dimensions, and surface finish of this tube section. Complete linings of bronze, rubber, vitreous enamel, or glass are frequently used for extremely corrosive conditions.

5. Instrumentation

5.1 Two small pressure lines should connect at either side on the horizontal axis of the annular chambers of a Venturi tube with the metering instrument employed. In laying out the pressure lines, it is important that air locks or accumulations of sediment be avoided. The lines should slope in one direction only with a minimum pitch of 1:24 or be vertical as shown in Fig. 3.

5.2 When metering liquids carrying solids in suspension, it is important that the suspended material be prevented from entering the annular chambers and pressure connections to the instrument. Continuous flushing is recommended and is achieved by attaching a clear water supply to each instrument pressure pipe and maintaining a small but continuous flow of water into the annular chambers of the Venturi tube. The flushing water pressure should exceed the maximum line pressure by at least 70 kPa (10 psi). Flows should be equal, continuous, and held to a small quantity to prevent any measurable pressure differential which would be reflected in the metering instrument.

5.3 Mercury-well instruments must be located so that air vents on the wells are at least the maximum differential of instruments, plus 305 mm (12 in.) below the minimum hydraulic grade of the pipeline at the inlet of the Venturi tube. Referring to Fig. 3, "*E*", the elevation of the air vents above the center line of the tube equals the elevation "*A*" of the hydraulic grade of the tube minus "*B*" minus 305 mm.

5.4 Since the minimum elevation of the hydraulic grade in a pipeline varies widely under differing conditions of flow, a careful study should be made whenever an instrument is to be installed under "borderline" conditions. Special applications of standard devices and instrument layouts have been developed to meet the problems imposed by low hydraulic grade as follows:

5.4.1 *Electrical Transmission*—The measuring instrument may include an electrical transmitter connected by a simple two-wire circuit or by means of leased telephone wires with a remotely located recording, indicating or totalizing instrument, or both, as shown in Fig. 4.

5.4.2 *Pneumatic Transmission*—In installations where air-operated instruments are desired and where the distance from the Venturi tube to the meter instrument does not exceed 304.8 m (1000 ft), an air transmitter, located at the Venturi tube, may be employed as shown in Fig. 5. This air transmitter is a differential unit with pressure connections to the Venturi tube as described in 5.1 and 5.2. The rate of flow is indicated or recorded on an air-operated receiver connected to the transmitter by one pneumatic pressure tube. Changes in the pressure output signal, which vary from 21 to 103 kPa (3 to 15 psi) are proportioned to changes on the measured variable, rate of flow.

5.4.3 *Water Columns*—With a low hydraulic grade and only moderate fluctuation in head, a float-operated instrument with water columns (float wells) can be used as shown in Fig. 6. In this case, differential pressure is represented by the difference in water level in the two columns.

6. Calibration

6.1 To meet accuracy standards, it is recommended that each Venturi be calibrated in place if the discharge can be directly measured by other methods.

NOTE 2—For calibration purposes, the application of the volumetric method or comparative salt dilution method of flow measurement is recommended.

6.2 The volumetric method is applicable only when there is available a reservoir of regular form, the volume of which, up to var-