

Fig. 17 .... Location of Vena Contracta in Relation to Ratio of Orifice to Pipe Diameter and to Rate of Flow

ready for installation. In such cases, the manufacturer's instructions should be followed with care in order to avoid serious errors. Further information on such systems is given in References 2, 3, and 5.

Pitot Tube

In certain cases, such as in rectangular ducts, it is impracticable to use standard orifices, and consequently, either a specially designed orifice must be calibrated, or an independent flow device must be used. In either case, the Pitot tube is useful. It consists essentially of an inner bent tube with its open end pointing upstream so as to measure total pressure, and an outer tube having small holes on the side for communicating static pressure to a manometer. (See Fig. 3, Chapter 44). The difference in liquid level in the manometer will be proportional to the square of the velocity, for incompressible flow, so that in general

$$V = \sqrt{2gh_f} \qquad (63)$$

For compressible flow, the differential head is to be divided by the correction F_c from Equation 64,

$$F_c = 1 + \tfrac{1}{4}M^2 + \tfrac{1}{40}M^4 \qquad (64)$$

where

$$M^2 = 2\frac{p_0 - p}{kp} \qquad (65)$$

In the use of a Pitot tube system, care is required in obtaining correct total and static pressures. The total pressure tube must be smoothly constructed, and should point directly upstream. The static pressure tap must be located so that local flow interferences will not reduce the value. In any case, it is better to obtain an independent calibration, or use a specially designed and manufactured probe. A number of such Pitot tube probes are available, and can be used without calibration.

In using Pitot tubes to obtain flow rates, it is necessary to make a traverse of the pipe and thereby to obtain one of the profiles of Fig. 5. In rectangular ducts or near valves or fittings, a disturbed flow pattern would be obtained, and therefore, in such cases, a fairly complete survey should be made. The flow in such cases will be computed from the average of the local velocities, as obtained by Equation 63.

Variable Area Flow Meters

For permanent installations where high precision, ruggedness, and ease of operation are important, the variable area flow meter has proved very satisfactory. Its most frequent use is in measurement of liquids or gases in small diameter pipes. For ducts or pipes over 6 in. in diameter, the expense of this meter may not be warranted. In large systems, however, the meter might be placed in a by-pass line and used in conjunction with an orifice.

In its most common form, the variable area meter, Fig. 18, consists essentially of a float which is free to move vertically in a transparent tapered tube. The fluid to be metered enters at the narrow bottom end of the tube and moves upward, passing at some point through the annulus formed between the float and inside wall of the tube. At any particular rate of flow, the float assumes a definite position in the tube, its

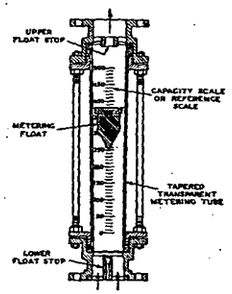


Fig. 18 .... Schematic Diagram of Variable Area Flow Meter

location being indicated by means of a calibrated scale on the tube.

The position of the float is established by a balance between the fluid pressure forces across the annulus and the weight of the float itself. The buoyant force which must support the float, $v_f(\rho_f - \rho)$, is balanced by the pressure difference acting on the cross-section area of the float, $A_f\Delta p$, where ρ_f, A_f, v_f, are, respectively, the float density, float cross-section area, and float volume. Accordingly, the difference in head across the annulus is given by

$$h_f = \frac{\Delta p}{\rho} = \frac{v_f(\rho_f - \rho)}{A_f\rho} \qquad (66)$$

The volume flow follows from Equation 53 as

$$Q = KA_2\sqrt{2gv_f(\rho_f - \rho)/\rho A_f} \qquad (67)$$

and the mass flow as

$$w = \rho Q = KA_2\sqrt{2gv_f(\rho_f - \rho)\cdot\rho/A_f} \qquad (68)$$

The flow for any selected fluid is, accordingly, very nearly proportional to the area, so that a convenient calibration of

the tube may be obtained. The behavior of the flow coefficient, K, has been investigated[6] and the action of the flow meter as just outlined, experimentally confirmed. The flow coefficient variation for any float must be known in order to use the meter for different fluids. Some developments have been carried on in the design of the float to reduce the variation of the flow coefficient with Reynolds number, and also with regard to float materials, to reduce the dependence of mass flow calibration on fluid density.

This type of flow meter is usually furnished in standard sizes calibrated for specific fluids by the manufacturer. The compactness, reliability, and ease of installation are particularly advantageous when many measurements of essentially the same type are to be made.

LETTER SYMBOLS USED IN CHAPTER 4

β = ratio, throat or orifice diameter to pipe diameter.
μ = absolute viscosity, pounds per foot second.
μ/ρ = kinematic viscosity, square feet per second.
ρ = density of flowing fluid, pounds per cubic foot.
ρ_m = proper mean density, pounds per cubic foot.
ρ_w = density of water at 60 F (62.37 lb per cubic foot).
ρ_f = density of float in variable area meters.
ϕ = expansion factor for nozzles.
a = velocity of sound, feet per second.
A = cross-sectional area of flow, square feet.
C = correction factor (coefficient of discharge) for flow through orifice, nozzle or Venturi.
c_p = specific heat of gas at constant pressure.
c_v = specific heat of gas at constant volume.
D = diameter of fluid stream, feet.
d = internal diameter of pipe, feet.
d_H = hydraulic diameter, feet.
e = absolute roughness of pipe surface, feet.
F_c = correction factor for differential head in compressible flow.
f = dimensionless friction coefficient.
g = gravitational acceleration, feet per (second) (second).
g_c = gravitational conversion factor = 32.174 (pounds mass per pound force) × feet per (second) (second).
h = enthalpy, Btu per pound of fluid.
h_f = loss of head, feet of fluid.
h_t = total head, feet of fluid.
J = mechanical equivalent of heat = 778 foot pounds per Btu.
K = flow coefficient (correction factor), including velocity of approach correction factor, for flow through orifice, nozzle or Venturi.
k = ratio of specific heat at constant pressure to specific heat at constant volume.
L = perpendicular distance from axis of pipe, feet.
l = length of pipe, feet.
M = Mach number.
N_{Re} = Reynolds number.
p = pressure, pounds per square foot.
p^0 = stagnation pressure, pounds per square foot.
p_c = critical pressure.
Q = discharge rate, cubic feet per second.
q = heat transferred to the fluid per pound of fluid flowing, Btu.
R = gas constant.
r = radius of pipe, feet.
s = entropy of fluid in Btu per (pound) (Fahrenheit degree).
T = temperature, absolute, Fahrenheit degrees.
u = internal energy, Btu per pound of fluid.
V = velocity, feet per second.
V_c = critical velocity, feet per second.
v = specific volume, cubic feet per pound.
W = mechanical work per pound of fluid flowing, foot pounds.
w = mass flow of gas, pounds per second.
Y = expansion factor (correcting for expansion of gas under reduced down-stream pressure).
z = elevation above some arbitrary datum, feet.

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