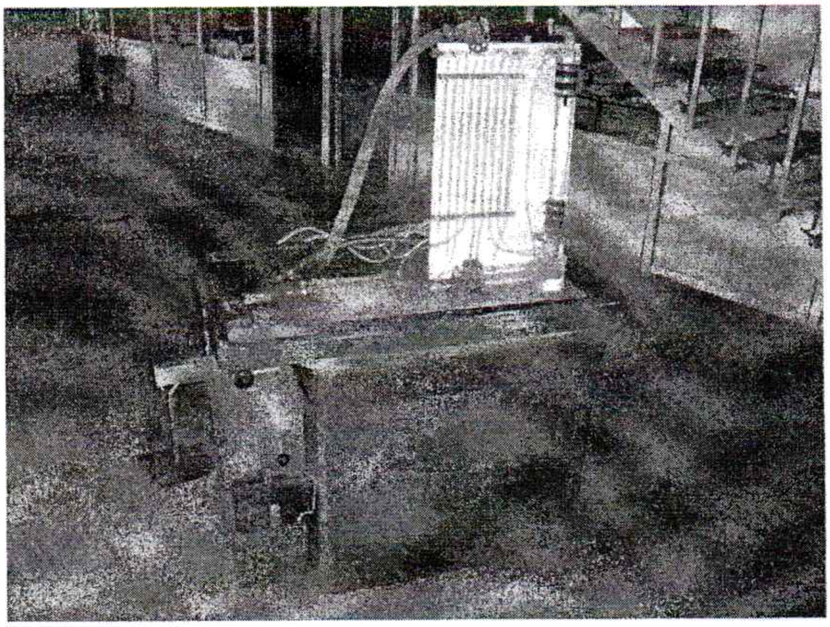
FLOW MEASUREMENT EXPERIMENT



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OBJECTIVE

This experiment is designed to accustom students to typical methods measuring the discharge of an essentially incompressible fluid, while at the same time giving applications of the steady-flow energy equation (Bernoulli's Equation). In addition to weigh-tank evaluation, the discharge is determined using a Venturi Meter, an orifice plate meter and a rotameter. Head losses associated with each meter are determined and compared. The head losses arising in a rapid enlargement and a 90-degree elbow can also be evaluated.

THEORY

Consider a tube through which an incompressible fluid such as water flows steadily and adiabatically. Changes of energy through the system to be used, other than internal energy, kinetic energy and potential energy are considered negligible and no shaft work done by the fluid in its motion. Assume the velocity to be uniform across the section. Then from the continuity law, mass of flow entering and leaving is given by

$$Q = V_1A_1 = V_2A_2 = CONSTANT \quad (1)$$

Suffixes 1 and 2 denote cross-sections of the system. On the other hand, Bernoulli's Equation is given below which was derived by establishment of both energy and momentum principles.

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2 + \Delta H_{12} \quad (2)$$

- $\frac{P}{\rho g}$ *is called the fluid's hydrostatic head*
- $\frac{V^2}{2g}$ *is called the fluid's kinetic head*
- Z *is called the fluid's potential head*
- $\left(\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1\right)$ *represents the fluid's total head*

Thus ΔH_{12} is the loss in total head between sections 1 and 2

MEASUREMENT OF DISCHARGE

The Venturi meter, the orifice plate meter and the rotameter are all dependent upon Bernoulli's equation for their principle of operation.

Venturi Meter

Since ΔH_{12} is negligibly small between the ends of a contracting duct application of equation (1) between pressure tappings (A) and (B) gives

$$\frac{P_A}{\rho g}+\frac{V_A^2}{2g}=\frac{P_B}{\rho g}+\frac{V_B^2}{2g}$$

And since, by continuity

$$m_A=\rho V_A A_A=\dot{m}_B=\rho V_B A_B\,,$$

$$V_B=\left[\frac{2g}{1-(A_B-A_A)^2}\left(\frac{P_A}{\rho g}-\frac{P_B}{\rho g}\right)\right]^{1/2} \qquad (3)$$

Thus the discharge,

$$Q=A_B V_B$$

$$=A_B\left[\frac{2g}{1-(A_B/A_A)^2}\left(\frac{P_A}{\rho g}-\frac{P_B}{\rho g}\right)\right]^{1/2} \qquad (4)$$

Orifice Meter

Between tapping's (E) and (F) ΔH_{12} in equation (1) is by no means negligible. Rewriting the equation with the appropriate symbols,

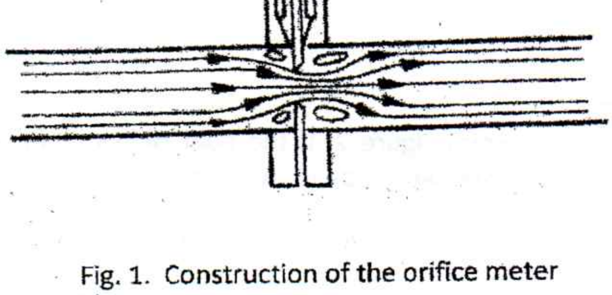


Fig. 1. Construction of the orifice meter

$$\frac{V_F^2}{2g} - \frac{V_E^2}{2g} = \left(\frac{P_E}{\rho g} - \frac{P_F}{\rho g}\right) - \Delta H_{12} \qquad (6)$$

i.e. the effect of the head loss is to make the difference in manometric height $(h_E - h_F)$ less than it would otherwise be.

An alternative expression is

$$\frac{V_F^2}{2g} - \frac{V_E^2}{2g} = K^2\left(\frac{P_E}{\rho g} - \frac{P_F}{\rho g}\right) \qquad (6)$$

where the coefficient of discharge K is given by previous experience in B.S. 1042 for the particular geometry of the Orifice Meter. For the apparatus provided K is given as 0.601.

Reducing the expression in exactly the same way as for Venturi Meter,

$$Q = A_F V_F$$

$$= KA_F\left[\frac{2g}{1-(A_F/A_E)^2}\left(\frac{P_E}{\rho g} - \frac{P_F}{\rho g}\right)\right]^{1/2} \qquad (7)$$

Rotameter

Observation of recordings for the pressure drop across the rotameter, (H) - (I), shows that this difference is large and virtually independent of discharge. Though there is a term which arises because of wall shear stresses and which is therefore velocity dependent, since the rotameter is of large bore this term is small. Most of the observed pressure difference is required to maintain the float in equilibrium and as the float is of constant weight, this pressure difference is independent of discharge.

The cause of this pressure difference is the head loss associated with the high velocity of water around the float periphery. Since this head loss is constant then the peripheral velocity is constant. To maintain a constant velocity with a varying discharge rate, the cross sectional area through which this high velocity occurs must vary. This variation of cross sectional area will arise as the float moves up and down the tapered rotameter tube.

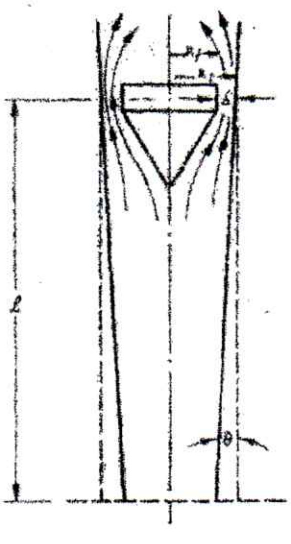


Fig. 2. Principle of the rotameter

From Figure 2, if the float radius is R_f and the local bore of the rotameter tube is $2R_t$, then

$$\pi(R_t^2 - R_f^2) = 2\pi R_f \delta = Cross\ sectional\ area$$

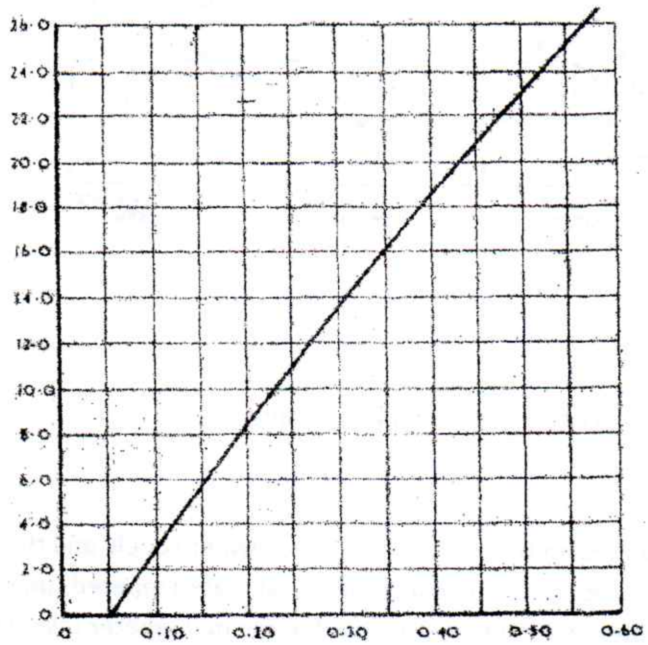
$$= Discharge/constant\ velocity$$

Now $\delta = l\theta$ where l is the distance from datum to the cross-section at which the local bore is R_t and θ is the semi-angle of tube taper.

Hence l is proportional to discharge.

An approximately linear calibration characteristic would be anticipated for the rotameter.

$\Delta H(cm)$



The calibration characteristic for the rotameter provided is given in Figure 3.

e.g. if the rotameter scale reading is 22.5, from Fig.6 the discharge = 0.49 kg/s.

(The corresponding weigh tank assessment was 0.47kg/s)

Mass flow of water (kg/s)

Fig. 3. rotameter calibration curve

DESCRIPTION OF APPARATUS

Water enters the flow measuring through a perspex Venturi meter, which consists of a long gradually-converging section followed by a throat, then by a long gradually-diverging section. Pressure measurements in the stream are made at the entry to the meter (A),at the throat (B) and at exit (C).After a change in cross-section through a rapidly diverging section and another pressure measuring station(D),the flow continues down a settling length and through an orifice plate meter.

This meter, manufactured from brass plate with a hole of reduced diameter through which the fluid flows, is mounted between two pressure-tapped perspex flanges (E) and (F).

Following a further settling length and a right angled bend which is also pressure-tapped (G) and (H) so that the bends loss coefficient may be derived, the flow enters the rotameter. This consists of a transparent tapered tube in which a float takes up an equilibrium position. The position of the flask, assessed from the scale on the wall of the rotameter, is measure of the flow rate. The pressure drop across the rotameter is given from the manometer levels (H) and (I).

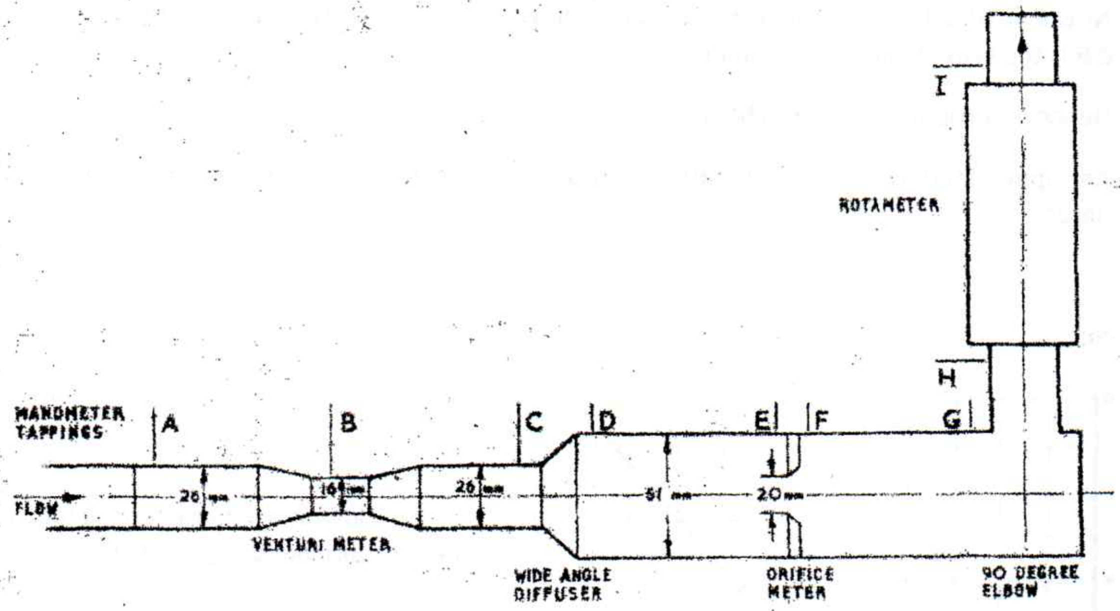


Fig.4. Explanatory diagram of flow measuring apparatus

PROCEDURE

The flow measuring apparatus is connected to the hydraulic bench water supply and the control valve is adjusted until the rotameter is about at mid-position in its calibrated tapered tube. Air is removed from the manometric tube by flexing it. The pressure within the manometer reservoir is now varied and the flow rate decreased until, with no flow,the manometric height in all tube is about 280mm.the apparatus can be levelled and the level checked by comparing the manometric heights when no water flows. A set of experimental readings can now be obtained. Take the data and fill the table 1 at various speeds by filling the water tank with 15 kg water at each run. Do not rise above 0.37 kg/s mass flow rate.

CALCULATIONS

1. Calculate the mass flow rates and head losses for each element and fill in table 2.
2. Plot calibration curves of elements on the same graph.(ΔH_{meter} vs $\dot{m}_{meter}$)
3. Plot the mass flow rate of element , $\dot{m}_m$, versus mass flow rate, $\dot{m}_t$, which is found from weight tank on the same graph and assuming the least square method fit an equation for each plot.
4. Calculate the head loss ,ΔH, and the inlet kinetic head ,KE, of each section then fill the table 3.
5. Plot the curves

$\Delta H_{AC}/KE_A \quad vs \quad KE_A$

$\Delta H_{CD}/KE_C \quad vs \quad KE_C$

$\Delta H_{HI}/KE_H \quad vs \quad KE_H$

On the same graph,

$\Delta H_{EF}/KE_E \quad vs \quad KE_E$

$\Delta H_{GH}/KE_G \quad vs \quad KE_G$

6. Estimate the appropriate error in the Venturi-meter, orifice meter and rotameter which can be calculated as

$$e(\%) = \frac{\dot{m}_m - \dot{m}_t}{\dot{m}_t} * 100$$

(Use equations in calculation 3)

7. Discuss the results and write conclusion.

HINTS

-the manometric level indicates the hydrostatic heads.$(P/\rho\, g)$

-For Venturi meter,

ΔH_{AB} *is negligible*

-For orifice meter,

$$\frac{V_F^2}{2g} - \frac{V_E^2}{2g} = K^2(h_E - h_F)$$

Where K=0.601 for this apparatus (K: discharge coefficient)

-For rotameter ,

Use calibration curve

-If the diameter of pipe increases two times , mean velocity is one quarter of that in the upstream section and kinetic head is 1/16 of that in the upstream section or vice versa.

e.g.

$$KE_2 = \frac{V_2^2}{2g}$$

REFERENCES

1. Fluid Flow, Sabersky & Acosta.
2. Fluid Mechanics and Hydraulics, Giles Company Notes.
3. Experimental Methods for Engineers, Holman.

	MANOMETRIC LEVELS(mm)											
Run no	A	B	C	D	E	F	G	H	I	Rotameter (cm)	Water (kg)	Time (seconds)
1												
2												
3												
4												
5												
6												
7												
8												
9												

TABLE.1

	$\dot{m}$(kg/s)			
RUN NO	Venturi	Orifice	Rotameter	Weight tank
1				
2				
3				
4				
5				
6				

TABLE.2

RUN NO	Inlet Kinetic Head , KE					$\Delta H / KE$				
1										
2										
3										
4										
5										
6										

TABLE.3