Laboratory work No 2: Calibration of Orifice Flow Meter

1. Objective

Calibrate the orifice flow meter and draw the graphs $\Delta p = f_1(Q)$ and $C_d = f_2(Re_D)$.

2. Necessary equipment

1. Orifice flow meter
2. Measuring tank with gauge glass, scale arrangement and drain valve
3. Differential manometer
4. Thermometer
5. Pump
6. Valves to regulate flow rate
7. Drain tank
8. Tubes and valves to connect the parts

3. The experimental apparatus and basics

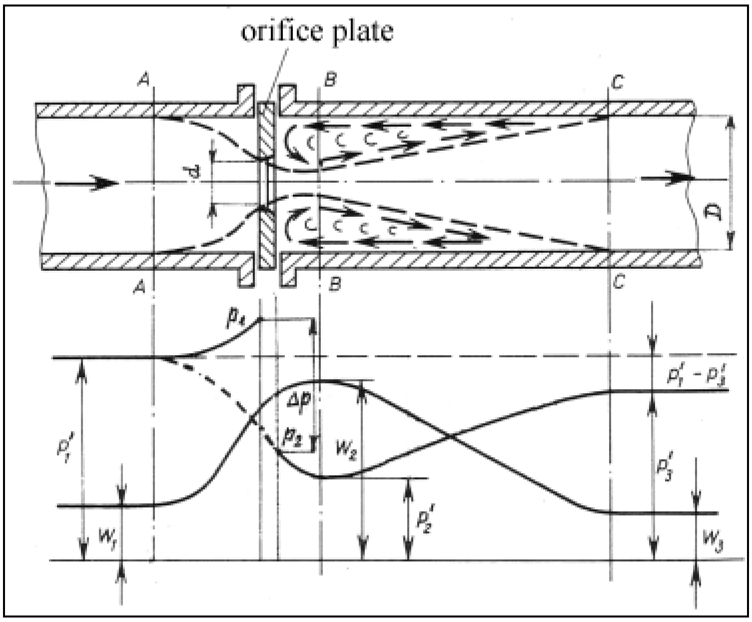

Figure 2.1. Decrease of the stream cross section area and acceleration of the flow.

When liquid flows through the orifice inside the tube the cross section area of the stream decreases and the velocity increases. Kinetic energy of the liquid increases and the potential energy and therefore the static pressure also decreases. Velocity decreases and achieves the original velocity at some distance from the orifice and the static pressure also increases. Due to hydrodynamic resistance of the orifice the pressure would be lower than before the orifice ($p'_1 - p'_3$).

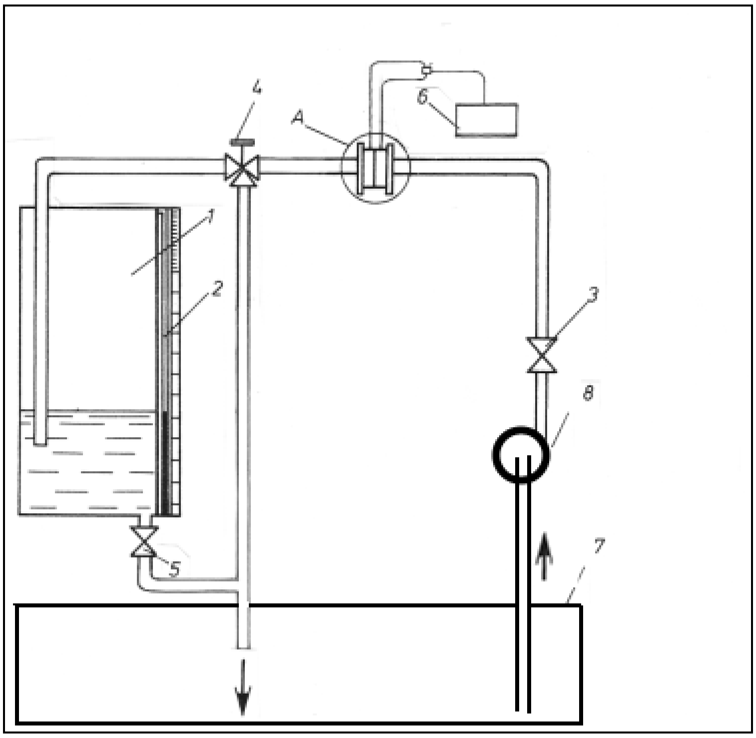

Figure 2.2.Calbration rig scheme. 1 - measuring tank; 2- gauge glass with scale; 3 – flow rate regulating valve, 4 – valve to switch water flow to bypass or measuring tank; 5 – drain valve; 6 – manometer consist of pressure transducer with piezo resistor and indicating meter; 7 – drain tank; 8 – pump; A – orifice plate assembly.

Orifice plate flow meter consists of orifice plate unit and the manometer. Static pressure drop over the orifice plate $\Delta p = p_1 - p_2$ depends from the flow rate of the liquid. Finding that relation experimentally is called calibration. Orifice plate assembly (A on Figure 2.2) is mounted on the steel pipe. Orifice plate has annular slot with corner taps for pressure measurements. The valve 4 switches the water to measuring tank 1 or bypass which goes directly to drain tank 7. Bypass is used during the flow rate setting. Pressure drop is measured by meter 6 connected to pressure transducer with piezo resistor connected with tubes to pressure taps. Volume of the water in measuring tank is measured with scaled gauge glass 2. Water flow is generated with pump 8 and the flow rate is set with the valve 3. Measuring tank can be emptied with drain valve 5. The measuring tank has thermometer to measure water temperature inside the tank. The cross-sectional view of the orifice plate assembly is on Figure 2.3.

The flow of uncompressible liquid (constant density) through the orifice can be described with Bernoulli's equation

$$\frac{\rho w_2^2}{2} - \frac{\rho w_1^2}{2} = p'_1 - p'_2 \qquad (2.1)$$

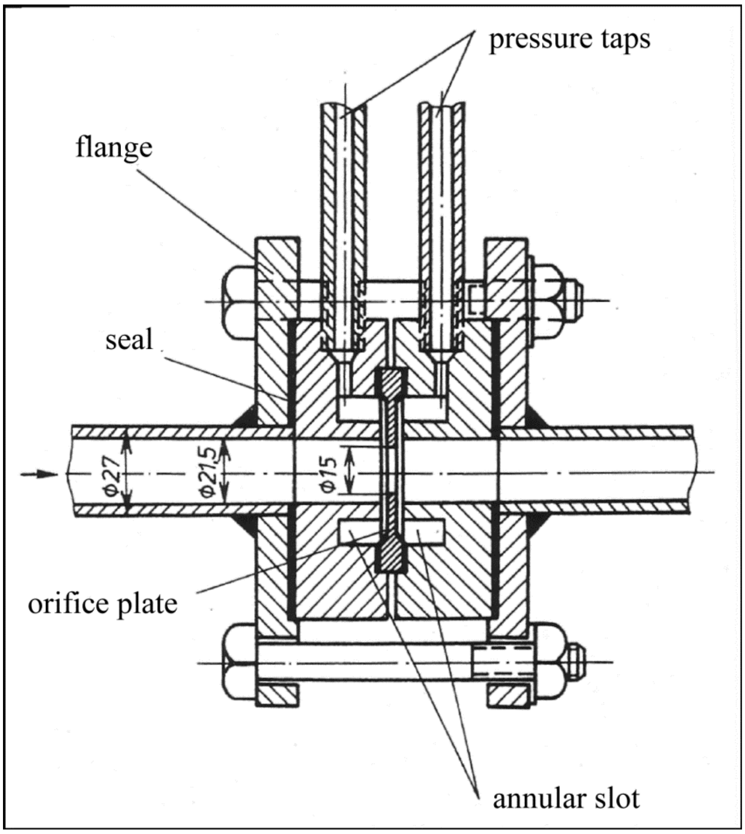

Figure 2.3. Orifice plate assembly.

Same time the equation of continuity can be applied

$$A_1 w_1 = A_2 w_2 = A w_2 \qquad (2.2)$$

where A_1 – cross-section are of the pipe, m^2;

A – orifice plate cross-section area, m^2;

A_2 – cross-section areaof the stream at it's narrowest place, (cross-section B - B, Figure 2.1), Based onm^2;

ρ – density of the liquid kg/m^3;

w_1 – average liquid velocity before orifice, m/s;

w_2 – average liquid velocity at it's narrowest cross-section, m/s;

p'_1 – pressure of the liquid before orifice (cross-section A – A, Figure 2.1) Pa;

p'_2 – pressure of the liquid at it's narrowest cross-section (cross-section B - B, Figure 2.1), Pa;

p_1 – pressure of the liquid straight before orifice, Pa;

p_2 – pressure of the liquid straight after orifice, Pa;

Based on formulas 2.1 and 2.2 the ISO 5167 declares that the relation between the liquid flow rate and pressure drop of the flow through orifice $\Delta p = p_1 - p_2$ can be calculated as

$$Q = C_d\ A\sqrt{\frac{2(p_1 - p_2)}{\rho(1-\beta^4)}} = C_d\ A\sqrt{\frac{2\ \Delta p}{\rho(1-\beta^4)}} \quad \frac{m^3}{s} \tag{2.3}$$

where C_d - discharge coefficient;

β - the ratio of orifice diameter d to pipe diameter D.

$$\beta = \frac{d}{D} \tag{2.4}$$

Dischrge coefficient can be calculated for orifice flow meters with coner taps and diameter less than 71,2mm with Reader-Harris/Gallagher equation set as standard for calculation by ISO 5167

$$\begin{aligned} C_d &= 0{,}5961 + 0{,}0261\beta^2 - 0{,}216\beta^8 + 0{,}000521\left(\frac{10^6\beta}{Re_D}\right)^{0{,}7} + \\ &+ \left[0{,}0188 + 0{,}0063\left(\frac{19000\beta}{Re_D}\right)^{0{,}8}\right]\beta^{3{,}5}\left(\frac{10^6}{Re_D}\right)^{0{,}3} + \\ &+ 0{,}011(0{,}75-\beta)\left(2{,}8 - \frac{D}{0{,}0254}\right) \end{aligned} \tag{2.5}$$

The Reynolds number Re_D is defined as the ratio of inertial forces to viscous forces and is dimensionless quantity

$$Re_D = \frac{w\,D}{\nu} = \frac{4\,Q\,D}{\pi\,D^2\nu} = \frac{4Q}{\pi D\,\nu} \tag{2.6}$$

where w – velocity of the liquid, m/s;

Q – flow rate of the liquid, m^3/s;

ν – kinematic viscosity of the fluid, m^2/s.

4. Procedure of experiment

Procedure of experiment will be given by supervisor prior the experiment.

5. Processing of the Experimental Data

Calculate the water flow rate Q using the volume of water V collected into measuring tank and time τ it took to collect it. Calculate the Re_D with formula 2.6 using this flow rate. Find the disscharge coefficient $C_{d.exp.}$ from formula 2.3 using experimental data. Calculate the theoretical value of discharge coefficient $C_{d.theor.}$ for each measured flow rate with formula 2.5. The experimental data and results should be presented in form of table 2.2.

Draw graphs $Q=f_1(\Delta p)$. On to second graph put $C_{d.exp.} = f_2(Re_D)$ and $C_{d.theor.}=f_3(Re_D)$ abcissa axis must be in logaritmic scale.

Compare the both discharge coefficients $C_{d.exp.}$ and $C_{d.theor}$ and draw conclusions.

Table 2.1 Propertis of water

Temperature °C	Density kg/m^3	Dynamic Viscosity Pa·s	Kinematic Viscosity m^2/s
0	1000	$175{,}6 \cdot 10^{-5}$	$1{,}783 \cdot 10^{-6}$
10	1000	$130{,}5 \cdot 10^{-5}$	$1{,}304 \cdot 10^{-6}$
20	998	$100{,}1 \cdot 10^{-5}$	$1{,}000 \cdot 10^{-6}$
30	996	$79{,}6 \cdot 10^{-5}$	$0{,}801 \cdot 10^{-6}$

Table 2.2 Table for experimental data and results

No.	Δp	V	τ	Q	Re_D	$C_{d.exp.}$	$C_{d.theor.}$
	kPa	dm^3	s	m^3/s	-	-	