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VISCOSITY INFLUENCE ON THE FLOW COEFFICIENT TO SMALL ORIFICES

BY

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Abstract. In a laboratory facility with small orifices (d = 1.15...2.55 mm) there was found a maximum value for the flow coefficient (μ = 0.7) and the Re numbers which were obtained were determined by varying the viscosity of the liquid used, at which these values are reached: Re = 1,200 for alcohol, Re = = 3,700 for water.

Key words: small orifices; flow coefficient; the influence of viscosity.

1. Introduction

The fluid flow with ρ density through a small A_g section orifice is calculated with the eq.:

$$Q = \varphi_v \varphi_c A_g \sqrt{\frac{2\Delta p}{\rho}} = \mu A_g \sqrt{\frac{2\Delta p}{\rho}}, \tag{1}$$

where: φ_v is the velocity coefficient, φ_c – the contraction coefficient, $\mu = \varphi_v\varphi_c$ – the flow coefficient, $\Delta p/\rho g$ – the hole head and Q – the flow. Basically μ

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depends on the physical properties of the liquid (viscosity, surface tension), on head $H = \Delta p/\rho g$ and on the size of the A_g (the diameter of the orifice). For example (Mateescu, 1963) for the orifices with diameters of d = 0.25...2" and H = 24.4...308.4 cm, μ at H = const. decreases with the increasing diameter of the orifice and at d = const. decreases with increasing of H, noting that at large diameters the variation is very small (μ = 0.605...0.596).

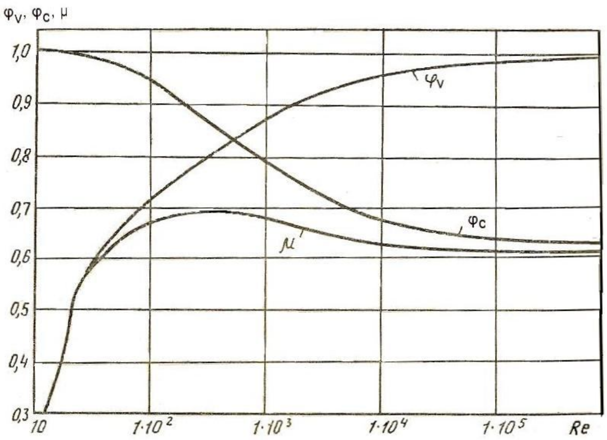

Fig. 1 – Dependence of the φ_v, φ_c and μ coefficients according to $\Re e$ number.

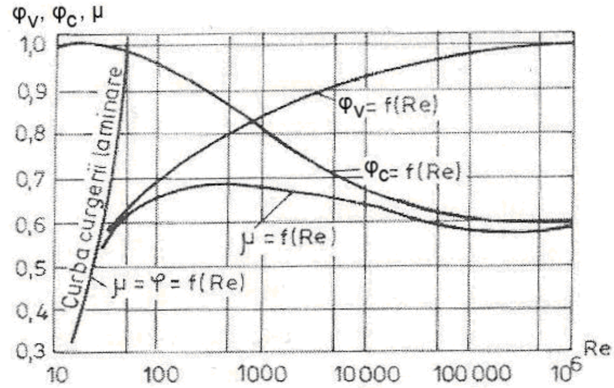

Fig. 2 – The φ_v, φ_c and μ coefficients dependence *vs.* the $\Re e$ number.

The influence of viscosity is shown empirically in charts φ_v, φ_c, μ according to the $\Re e = d\sqrt{2gH}/\nu$ (Figs.1 and 2). Idelcik, (1984), has considered that μ depends on the Froude and Weber numbers $Fr = 2\Delta p/\rho dg$, $We = 2\Delta pg/\sigma$, with σ – the surface tension coefficient, but for the $Fr \geq 10$ and $We \geq 200$ their influence is negligible.

Regarding the flow regime, laminar or turbulent, for orifices specific to hydraulic drives (Vasiliu & Vasiliu, 2005) the flow is laminar for $\Re e$ < 10 and μ depends on $\Re e$ as it follows:

$$\mu = \delta \sqrt{\Re e} \tag{2}$$

with δ = 0.2 – the laminar flow coefficient.

In this paper there are analysed the results others as those previously published. There are presented experimental results on the influence of viscosity on the μ coefficient, obtained in a specially designed experimental facility.

2. Theoretical Research

2.1. Perfect Fluids

In this case φ_v = 1 and $\mu = \varphi_c$ applying the theory of the plane potential movement with

$$F(f(z)) = \mathrm{e}^{-(\varphi + \mathrm{i}\psi)} \tag{3}$$

and the $f(z) = \varphi + \mathrm{i}\psi$ as the movement potential is obtained for infinite tanks and slit type orifices having the width of 2*a* (Lotianski, 1970)

$$\phi_c = \frac{\pi}{\pi + 2} = 0.611. \tag{4}$$

For tanks with width of 2*b* and the same slit with

$$\frac{z}{a} = \cos\frac{i\pi f}{Q}, \tag{5}$$

one obtains an implicit dependence solved by successive approximations and presented in tabular form (Carafoli, 1950). Thus for: a/b = 0.1; μ = 0.630; a/b = = 0.5; μ = 0.653.

By the numerical integration of the Euler equations to the flow through a circular orifice of r_0 radius in a tank with the height H (Iancu, 1970), an average speed is obtained in the contracted section namely

$$V_m = \left(0.6 + 0.7\frac{r_0}{H}\right)\sqrt{2gH}. \tag{6}$$

In this case:

$$\mu = 0.6 + 0.7\frac{r_0}{H}, \tag{7}$$

and it depends only on the ratio r_0/H.

2.2. Viscous Liquids

Introducing the velocity coefficient and applying the momentum theorem (Mateescu, 1963) there results the eq.:

$$\frac{4}{\pi^2}\varphi_c^2 - 2\varphi_c + \frac{1}{\varphi_v^2} = 0. \tag{8}$$

If $\varphi_v = 1$, then $\varphi_c = 0.564$, a lower value than the above submitted.
If $\varphi_v = 0.9$, there results $\varphi_c = 0.723$.

3. Experimental Research

Defining the $\mathrm{R}e$ number of the flow through circular orifices with the diameter d

$$\Re e = \frac{d\sqrt{2gH}}{\nu} \tag{9}$$

with H – the orifice head and synthesizing the experimental results there is obtained the dependence of the φ_v, $\varphi_{c,}$ and μ coefficients according to the $\mathrm{R}e$ number presented in Fig. 1 (Kalitun & Drozdov, 1980).

Subsequently the diagram was completed with their variation in laminar flow regime (Idelcik, 1984; Hâncu & Marin, 2007) (Fig. 2).

The μ coefficient dependence *vs*. H head orifice is expressed implicitly by the Reynolds number.

4. The Experimental Installation

It comprises a tank (*1*) in which it is poured the liquid, pumped by the WILO type centrifugal pump (*2*), of variable power between 27…72 W, to the containers (*4*) with H = 178 mm, provided with one bottom orifice with the diameters d = 1.15…2.55 mm (Fig. 3). The constant level maintenance is achieved by the valves (*3*), and in order not to have level errors, each tank was provided with one overflow. As the level of the cylinders is constant, the speed at which the liquid exits through the lower orifice is maintained constant and the flow rate is determined by the volumetric method.

One maintained a steady flow by keeping a constant level in the circular tanks. The flow was determined by means of the volumetric method, by measuring the volume in time, the fluid temperature values varying between 22.8°…23.5°C. The liquids which were used for the measurements were water and alcohol.

The density and viscosity of the alcohol were determined in the laboratory and have the following values: $\rho = 878$ kg/m^3, $\eta = 2.309\times10^{-3}$ Pa·s.

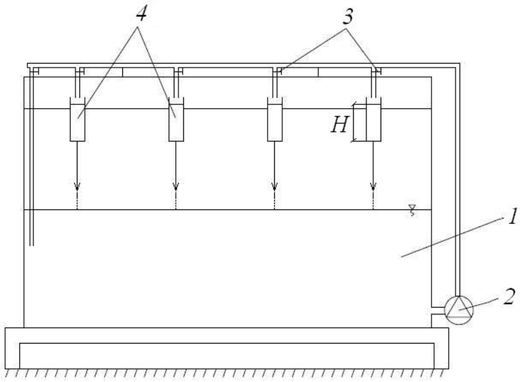

Fig. 3 – The experimental installation.

The temperature was measured before and after each set of measurements with a Comet digital thermometer and the time with a digital timer.

We performed measurements and calculation; both water and the alcohol results were shown in Table 1 and the graphic representation in Fig. 4.

Table 1
Variation of Q, μ and $\Re e_t$ According to the d Diameter

d, [mm]	Q, [cm^3/s]	μ	$\mathrm{R}e_{t\ \mathrm{water}}$	$\mathrm{R}e_{t\ \mathrm{alcohol}}$
1.15	1.18	0.608	2,268	810
1.65	2.76	0.688	3,255	1,162
2.25	5.08	0.679	4,438	1,444
2.55	6.09	0.638	5,030	1,796

To determine the flow coefficient and theoretical Re number, there were used eqs.

$$\mu = \frac{4Q}{\pi d^2 \sqrt{2gH}}, \tag{10}$$

$$\Re e_t = \frac{d\sqrt{2gH}}{\nu}, \tag{11}$$

where: Q is the measured flow, d – the orifice diameter, H – the head tank and ν – the kinematic viscosity.

There is a maximum value of the μ coefficient (μ = 0.7) and is performed at $\Re e$ numbers depending on the orifice diameter and viscosity namely, $\Re e = 500$ (Figs. 1 and 2), regardless of the d and υ, the Reynolds number, $\Re e = 3{,}700$ for water and $\Re e = 1{,}200$ for alcohol having orifices with $d = 1.15\ldots 2.55$ mm.

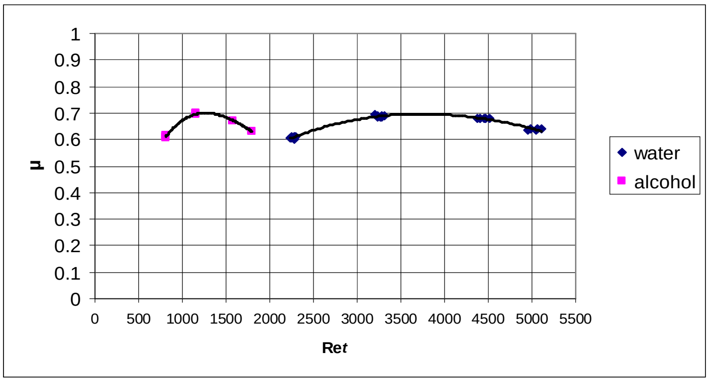

Fig. 4 – μ coefficient variation *vs*. the $\Re e$ theoretical number.

From the graphs that express the dependence of the flow coefficient *vs*. the theoretical $\Re e$ number for both water and alcohol there is shown that the influence of viscosity on the flow coefficient is insignificant in this range of viscosity. This is very favourable for the hydraulic throttle valves functionality from the hydraulic drive systems because the volumetric flow passing through the throttle remains constant, even if there are important variations of the temperature or if there is used a liquid with a different viscosity. Thus the hydraulic throttle valves that perform the inert-elastic damping of the oscillation systems can also function properly in the very small flow area (Vasiliu & Vasiliu, 2005).

5. Conclusions

The published theoretical researches, based on the hypotheses adopted (potential movements or the Euler eqs. numerical integration) these obtained relatively large variations of the flow coefficient which is identified with the contraction coefficient $\mu = 0.611...0.653$, for the hypothesis of the viscous liquid, pertaining to the impulse theorem; this variation is maintained and there results $\mu = 0.654$ for $\varphi_v = 1$ and $\mu = 0.723$ for $\varphi_v = 0.9$.

The experimental researches show that for relatively large circular orifices (0.25”...2”) μ decreases monotonously either for H = const. and d increases, or for d = const. and the H increases, a fact which suggests a more complicate dependence $\mu(H,d)$ for ν = const. In other researches $\mu(\Re e)$ has a maximum of $\mu = 0.7$ for $\Re e \approx 500$ and it remains constant, that is $\mu \approx 0.61$ for $\Re e > 10^4$ (Figs. 1 and 2).

The results obtained for the diameters of 1.15...2.55 mm and H = const., show the existence of a maximum value for the flow coefficient ($\mu \approx 0.7$) for $\Re e \approx$ 3,500...4,000 and $\Re e \approx$ 1,200...1,300, depending on the liquid viscosity (Fig. 4).

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INFLUENŢA VISCOZITĂŢII ASUPRA COEFICIENTULUI DE CURGERE PRIN ORIFICII MICI

(Rezumat)

Într-o instalaţie de laborator cu orificii mici (d = 1,15…2,55 mm) a fost găsită valoarea maximă pentru coeficientul de curgere (μ = 0,7). Numerele $\Re e$ au fost determinate prin variaţia viscozităţii lichidul utilizat, la care sunt atinse aceste valori: $\Re e$ = 1 200 pentru alcool, $\Re e$ = 3 700 pentru apă.