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Research on Backflow Region Length of Sudden-Enlarge Oil Tube Flows

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Abstract: Sudden-enlarge tube has important applications in reality lives. The backflow region length in sudden-enlarge tube flows is closely related with its energy loss. In this paper, the characteristics of backflow region length in sudden-enlarge oil tube flows are researched. The results show that backflow region length decreases with the increase of the contraction ratio; when Reynolds number is more than 105, Reynolds number have little impacts on backflow region length. Empirical expression about backflow region length is also obtained by fitting curve in this paper.

Keywords: Backflow region, Contraction ratio, Reynolds number, Simulations, Transportation in tube.

1. INTRODUCTION

Sudden-enlarge tube has important applications in reality lives. The most common application of it is used to measure the fluid. In recent years, with the development of hydropower projects, Sudden-enlarge tube and sudden-reduction tube are used to dissipate the energy in discharge tunnel [1]. During 1960s, by taking advantage of sudden-enlarge flows and sudden-reduction flows, the plug energy dissipater, with the energy dissipation ratio of over 50% [2], was used in the flood discharge tunnel of the Mica dam in Canada. While the orifice plate energy dissipater, similar as plug, was used in flood discharge tunnel of the Xiaolangdi hydropower project in China, and the energy dissipation ratio of about 44% was obtained [3-4].

The flow through sudden-enlarge oil tube is shown in Fig. (**1**). There exists the backflow region after the sudden-enlarge oil tube. Many researches were conducted about the energy dissipaters with sudden reduction and sudden enlargement forms [5-7]. The interesting areas have been focused on the effects of the geometric parameters on energy loss coefficient. Many researchers deemed that the energy losses of both sudden reduction flows and sudden enlargement flows increased with the decrease of the contraction ratio [8-9]. As a matter of fact, the backflow region L_b defined in Fig. (**1**), is the original region of the energy dissipation [10-11]. However, the characteristics of backflow region are neglected by many researchers. The purpose of the present work, therefore, is to investigate the effects of the geometric and hydraulic parameters on the backflow region length; and to present an empirical expression of the backflow region length by means of the numerical simulations.

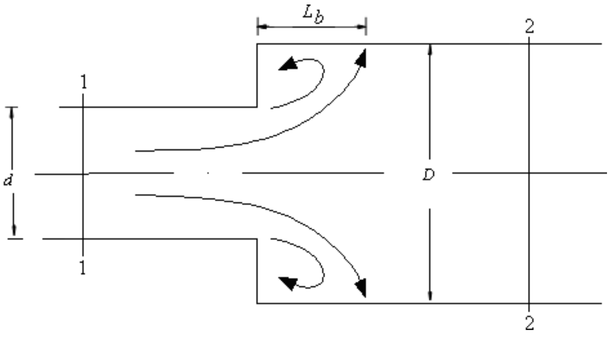

Fig. (1). The flows in sudden-enlarge tube.

2. METHODOLOGY AND PHASES OF RESEARCH

The RNG k～ε model was used to calculate the hydraulic parameters of the flow through the orifice plate, due to its suitability for simulating the flow inside large change boundary forms as well as its high precision and calculation stability. For the steady and incompressible flows, the governing equations of this model can be written as [12, 13]:

Continuity equation:

$$\frac{\partial u_i}{\partial x_i} = 0 \quad i = 1, 2 \tag{1}$$

Momentum equation:

$$u_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}[(\nu+\nu_t)(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i})] \quad i = 1, 2 \tag{2}$$

k-equation:

$$u_i \frac{\partial k}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\alpha_k\left(\nu+\nu_t\right)\frac{\partial k}{\partial x_j}\right] + \frac{1}{\rho}G_k - \varepsilon \quad i{=}1{,}2 \tag{3}$$

ε-equation:

$$u_i \frac{\partial \varepsilon}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\alpha_\varepsilon\left(\nu+\nu_t\right)\frac{\partial \varepsilon}{\partial x_j}\right] + \frac{1}{\rho}C_1^* G_k \frac{\varepsilon}{k} - C_2\frac{\varepsilon^2}{k} \quad i{=}1{,}2 \tag{4}$$

where x_i (= x, y) are the coordinates in longitudinal and transverse directions, respectively; u_i (= u_x, u_y) are the

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velocity components in x and y directions, respectively; ρ is the density of oil; p is the pressure; v is the kinematics viscosity; v_t is the eddy viscosity and can be given by $v_t = C_\mu(k^2/\varepsilon)$, in which k is the turbulence kinetic energy, ε is the dissipation rate of k and C_μ=0.085. The other parameters are:

$$C_1^* = C_1 - \frac{\eta(1-\eta/\eta_0)}{1+\lambda\eta^3},\ \eta = Sk/\varepsilon,\ S = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right),$$

C_1 =1.42, η_o = 4.377, λ = 0.012, $G_k = \rho v_t \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\frac{\partial u_i}{\partial x_j}$, C_2 =1.68 and $\alpha_k = \alpha_\varepsilon$ = 1.39. The calculation boundary conditions are treated as follows: in the inflow boundary the turbulent kinetic energy k_{in} and the turbulent dissipation rate ε_{in} can be defined as respectively [13]:

$$k_{in} = 0.0144u_{in}^2,\ \varepsilon_{in} = k_{in}^{1.5}/(0.25D) \tag{5}$$

where u_{in} is the average velocity in the inflow boundary. In the outflow boundary, the flow is considered as fully developed. The wall boundary is controlled by the wall functions. And the symmetric boundary condition is adopted, that is, the radial velocity on symmetry axis is zero.

Two kinds of calculation phases were simulated and these phases are: Phase No.1, to calculate the dimensionless backflow region length $l_b(l_b=L_b/D)$ at the range of Reynolds number $Re = 9.00\times10^4$ - 2.76×10^6 when d/D = 0.50, in order to analyze the effects of Re on lb. Phase No. 2, to calculate dimensionless backflow region length lb at the different d/D when $Re = 1.80\times10^5$, to discuss the variations of the dimensionless backflow region length l_b with d/D, and to establish the relationship expression of them. The method to determine backflow region length is as follows: taking a section along tube direction, which is very close to the tube's wall; viewing the flow's horizontal velocity at this section; regarding the distance between contraction section rear and the point, where flow's horizontal velocity is 0, is backflow region length.

3. DISCUSSION

3.1. Numerical Simulation Results

The simulation results of Phase No.1 and Phase No.2 are shown in Tables **1** and **2** respectively.

Table 1. Variations of l_b with Re (d/D = 0.50).

Re (×10^5)	0.90	1.80	9.20	18.40	27.60
l_b	2.2	2.3	2.3	2.3	2.3

3.2. Considerations

It could be seen from Table **1** that the dimensionless backflow region length l_b has hardly changed with Reynolds number Re approximately. And they changed from 2.2 to 2.3 respectively with regard to the change of Reynolds number Re from 9.00×10^4 to 2.76×10^6. Therefore, it could be concluded that the effects of Reynolds number Re could be neglected on the dimensionless backflow region length l_b in the considered range of Re.

Fig. (**2**), which was drawn by using the data in Table **2**, shows the effects of contraction ratio d/D on the relative backflow region length l_b. It can be concluded that the larger the contraction ratio d/D is, the smaller the relative backflow region length l_b will be. The longer the length of backflow region is, the greater the scope of flow's intensive shear stress and intensive friction will be [14]. So energy losses of sudden enlargement flows increased with the decrease of the contraction ratio. The empirical expression, by means of the numerical simulation results from Fig. (**2**), could be obtained:

$$l_b = -3.57(d/D)^2 - 0.6(d/D) + 3.5 \tag{6}$$

Table 2. Variations of l_b with d/D (Re = 1.8×10^5).

d/D	0.4	0.5	0.6	0.7	0.8
l_b	2.6	2.3	1.8	1.2	0.7

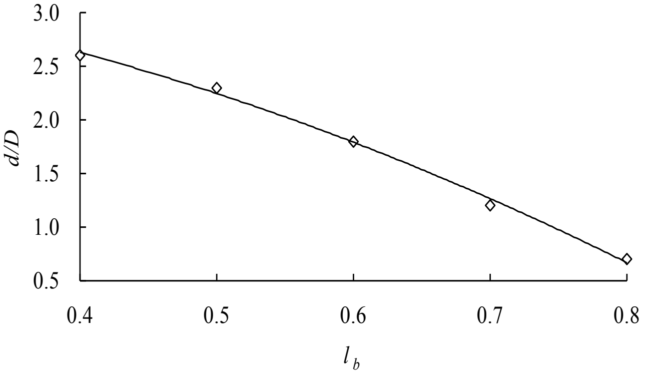

Fig. (2). The relationship between l_b and d/D.

CONCLUSION

For Sudden-enlarge tube oil flow, its dimensionless backflow region length l_b is the function of the contraction ratio d/D. And the effects of Re could be neglected on the l_b when this number is larger than 10^5. The contraction ratio d/D is the key factor that dominates the dimensionless backflow region length lb. The lower the contraction ratio d/D is, the longer the dimensionless backflow region length l_b will be. The relationship of lb and d/D could be expressed as Eq. (6).

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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