Flow Simulation (on a tuning flow into an inner pipe from annulus)

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Flow Simulation (on a tuning flow into an inner pipe from annulus)

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This paper presents the studies aimed to predict a flow pattern at the bottom of the outer pipe in a concentric double pipe. Author find that the formation of the vortex ring are closely related to the geometrical feature of the flow path and Reynolds number R_e. If the ratio of clearance length L/d_i (the ratio of clearance length, which is the distance between the outlet of the annulus and the bottom of the outer pipe, to the inner pipe diameter) and R_e increased up to be L/d_i=0.500 and to be R_e=200, respectively, the vortex ring appear at the bottom of the outer pipe.

1. Introduction

The turning flow into an inner pipe from annulus in a concentric double pipe is very complicated. This kind of flow can be very often found in engineering designs as bayonet heat exchanger. Hence, it is very important to know flow patterns in the turning-flow region. In the existing report[1], the Navier-Stokes equation describing the laminar flow field in a concentric double pipe was solved numerically by the finite difference relaxation method. It[1] was reported flow patterns in the turning flow into the annulus from the inner pipe in a concentric pipe

This report deals with a fluid flow issuing from annulus and turning back into an inner pipe of a concentric double pipe. The flow pattern at the bottom of the outer pipe in a concentric double pipe was studied for laminar flow. The distance from the outlet of the annulus to the inlet of the inner one was 2~3 d_i. The influence of the ratio of the clearance length L_r (L_r is the ratio of the distance between the inlet of the inner pipe and the bottom of the outer one, to the inner pipe diameter) upon the flow through the concentric double pipe was investigated. The computations were made under the conditions from L_r=0.25 to 1.00. The ratio of the cross-sectional area A_r (A_r is the ratio of the area of the annulus to that of the inner pipe) were chosen to be equal to 0.480. The Reynolds number R_e ($R_e = v_1 r_1/\nu$, where v_1 is the representative velocity, r_1 is the representative length and ν is the kinematic viscosity) was taken to be less than or equal to 1000. If a fluid starts flowing with a uniform velocity distribution at the distance of 2~3 d_i before the outlet of the annulus, the occurrence of separations and vortexes can be observed by mean of the graphics of velocity vector and stream function.

2. Fundamental Equations

The concentric double pipe having a circular section is illustrated in Fig. 1. The ratio of the clearance length ($L_r = L/d_i$) is defined L between the inlet of the inner pipe and the bottom of the outer one, to the inner pipe diameter. Assume that the flow is steady, laminar and two-dimensional, and the fluid is incompressible,

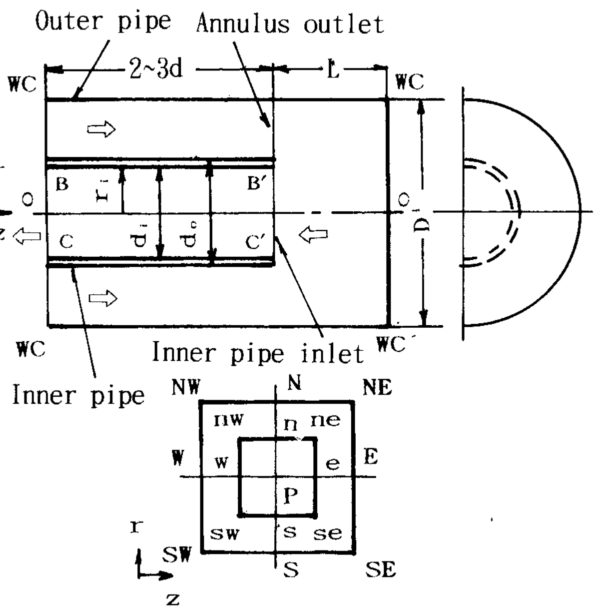

Fig. 1 Concentric double pipe and coordinate system

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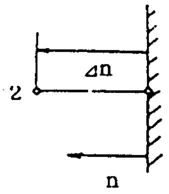

Fig. 2 Linearly-varying vorticity

and the body force is negligible. The symbols r, z, u, v, ω and ψ are expressed non-dimensional, the representative length and velocity being the inner pipe radius r_1 and the mean velocity in the section of the inner pipe u_1. p denotes the non-dimensional pressure divided by $\rho\ u^2$, where ρ denotes the fluid density.

The fundamental for the problem are the Navier-Stokes equations

$$v\frac{\partial v}{\partial r}+u\frac{\partial v}{\partial z}=-\frac{\partial p}{\partial r}+\frac{1}{R_e}$$

$$\left(\frac{\partial^2 v}{\partial r^2}+\frac{\partial v}{r\partial r}+\frac{\partial^2 v}{\partial z^2}-\frac{v}{r^2}\right) \tag{1}$$

$$v\frac{\partial u}{\partial r}+u\frac{\partial u}{\partial z}=-\frac{\partial p}{\partial z}+\frac{1}{R^e}$$

$$\left(\frac{\partial^2 u}{\partial r^2}+\frac{\partial u}{r\partial r}+\frac{\partial^2 u}{\partial z^2}\right) \tag{2}$$

as expressed for in cylindrical coordinates r and z, and the equation of continuity

$$\frac{\partial u}{\partial z}+\frac{\partial}{r\partial r}(rv)=0 \tag{3}$$

Navier-Stokes equation (1) and (2) can be formed by mean of the stream function ψ and vorticity ω by eliminating the pressure term. It can be written as,

$$r^2\left(-\frac{\partial}{\partial r}\frac{\omega}{r}\frac{\partial\phi}{\partial z}+\frac{\partial}{\partial z}\frac{\omega}{r}\frac{\partial\phi}{\partial r}\right)=$$

$$\frac{1}{\mathrm{R}_e}\left(\frac{\partial}{\partial z}\left(r^3\frac{\partial}{\partial z}\frac{\omega}{r}\right)+\frac{\partial}{\partial r}\right.$$

$$\left.\left(r^3\frac{\partial}{\partial r}\frac{\omega}{r}\right)\right) \tag{4}$$

By using the stream function ψ, vorticity ω expressed as follow,

$$\omega=-\frac{1}{r}\left(\frac{\partial^2\psi}{\partial z^2}+\frac{\partial^2\psi}{\partial r^2}-\frac{\partial\psi}{r\partial r}\right) \tag{5}$$

The r and z components of the velocity can be written as by

$$v=\frac{\partial\psi}{r\partial z}\qquad u=\frac{\partial\psi}{r\partial r} \tag{6}$$

By using Eq. (6), the vorticity ω can be expressed as

$$\omega=\frac{1}{r}\left(\frac{\partial v}{\partial z}+\frac{\partial u}{\partial r}\right) \tag{7}$$

In these equation, u and v denote the velocity components along the z and r coordinates.

The values of ψ and ω/r[1] can be obtained by changing Eqs. (4) and (5) to a finite difference form which is solved by the iterative relaxation method over mesh points covering the flow field.

The velocity components, u and v, are derived from Eqs. (8) and the velocity is derived from the formula, $w=\sqrt{u^2+v^2}$. The symbols ψ, r with the subscripts denote the values on the infinitesimal area, NWSE, shown in Fig 1.

$$\left.\begin{aligned} u&=-(\psi_N-\psi_S)/r\ (r_N-r_S)\\ v&=(\psi_E-\psi_W)/r\ (r_E-r_W)\end{aligned}\right\} \tag{8}$$

The calculation is repeated until the function, ϕ, meets the convergent condition shown in the following formula:

$$max\ |\ \phi^n-\phi^{(n-1)}\ |\ /\phi^n<0.005 \tag{9}$$

2.1 Boundary condition

A general boundary condition on the fixed wall surface is described. Assume that a stream on the fixed wall surface does not slide. Here, the vorticity ω_1 in the n direction perpendicular to the wall surface shown in Fig. 2 is given by the following equation.

$$\omega_1=-3\ (\psi_2-\psi_1)/r_1\,\Delta\,n^2-\omega_2/2 \tag{10}$$

3. Computed Results and Discussion

The computation were made for various values of R_e in the range from 30 to 1000 and for various values of L/d_i in the range from 0.125 to 1.00, and under the

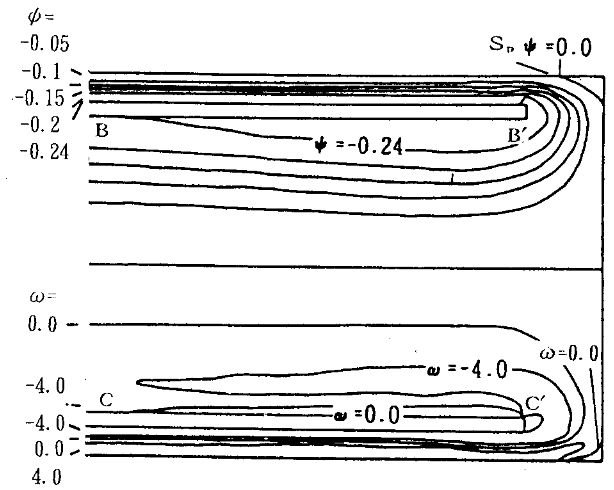

Fig. 3 (a) (b) Stream line contours and vorticity contours (A_r=0.480 L/d_i=0.250 R_e=1000) (a): upper (b): lower

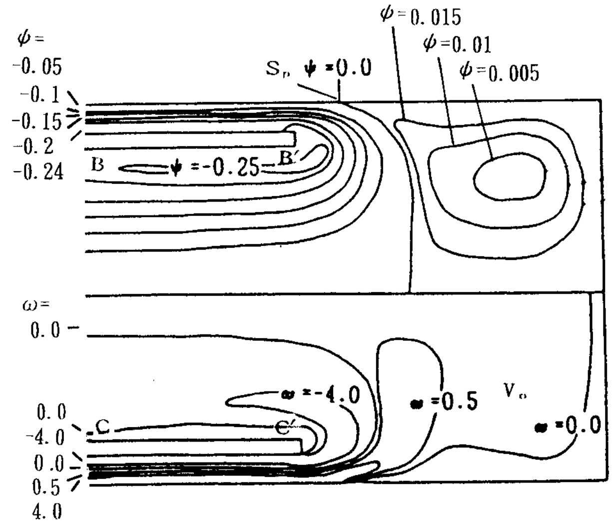

Fig. 4 (a) (b) Stream line contours and vorticity contours (A_r=0.480 L/d_i=1.00 R_e=1000) (a): upper (b): lower

condition A_r=0.48.

Figures 3 (a) and (b) show the computed results for the case of L/d_i=0.250, and Figs. 4 (a) and (b) show the computed results for the case of L/d_i=1.00. The flow from the annulus outlet into the inner pipe separates from the upstream corner of the inlet of the inner pipe, as shown in Figs. 3 (a) and 4 (a). But it reattaches itself at a point on the wall BB′ just downstream from the point B′. One side, the flow from the annulus to the bottom of the outer pipe separates from the downstream of the outlet of the annulus, namely, the point s_p. The magnitude of the vorticity ω increase substantially near the point C′, as shown in Figs 3 (b) and 4 (b). Its aspect of variation in these is complex and abrupt. One side, the magnitude of the vorticity ω increases near the point v_o, as shown in Fig. 4 (b).

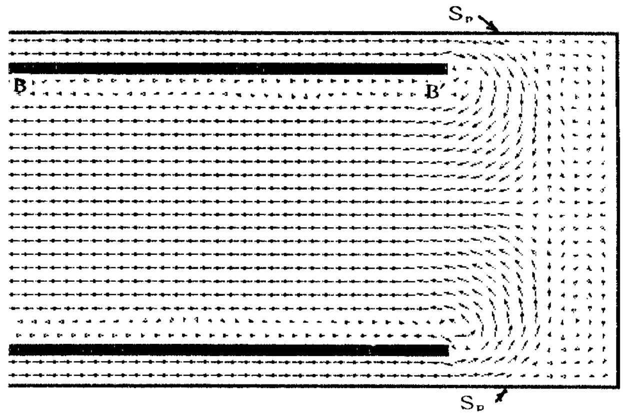

Fig. 5 Velocity vectors (A_r=0.480 L/d_i=0.500 R_e=1000)

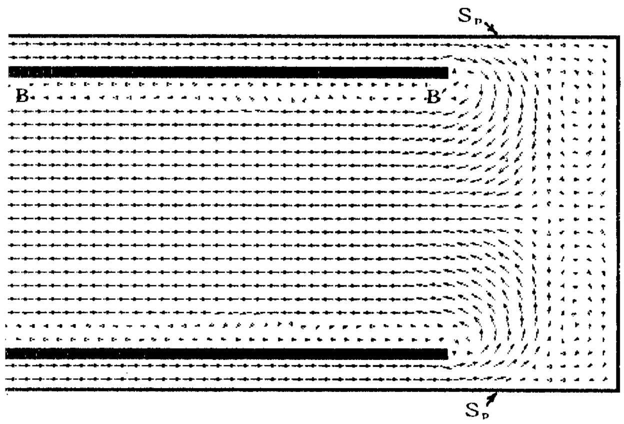

Fig. 6 Velocity vectors (A_r=0.480 L/d_i=0.625 R_e=1000)

Figures 5 and 6 show the the computed results for the case of the L/d_i=0.50 and L/d_i=0.625, respectively. Figures 5 and 6 indicated by graphing the velocity vector, respectively. The flow from the annulus outlet into the inner pipe separates from the upstream corner of the inlet of the inner pipe, as shown in Figs. 5 and 6. The flow from the annulus to the bottom of the outer pipe separates from downstream of the outlet of the annulus, namely, points s_p. Therefore, the vortex appears at the bottom of the outer pipe, as shown in Figs 5 and 6.

4. Conclusion

In order to examine the pattern of a fluid flow issuing from annulus and turning back into an inner pipe of a concentric double pipe, the two dimensional laminar flow fields of a concentric double pipe were investigated by numerical calculation.

The results obtained can be summarized as follows

1) A fluid flow is symmetrical flow for the clearance length ratio up to $L/d_i \fallingdotseq 0.375$.

2) The vortex ring appear at the outlet of the outer pipe when L/d_i and R_e increase up to be $L/d_i = 0.50$ and $R_e = 300$, respectively.

3) It was made clear that distance from separation at the upstream corner of the inlet of the inner pipe to reattachment is about 2.5 d_i.

Reference

1) Y. Okudaira, M. Maeda: Proc. 6th ICECGDG, No. 3, 624 (1994)