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INSTABILITY OF TWO-FLUID TAYLOR VORTEX FLOW IN THE CASE OF AN ASYMMETRIC SYSTEM

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Abstract

We report experimental results of the instability of the Taylor vortex flow in an asymmetric system with a small aspect ratio using two immiscible fluids, an aqueous solution of glycerin and silicon oil. Flow generations in the primary mode and secondary modes at the aspect ratio 7.0 are shown in sectional flow photographs. Flow development is clarified with the results for the variation of heights of cells with the Reynolds number and the critical Reynolds number for wavy Taylor vortex flow. Finally the relationship of bifurcation between the modes is discussed at the aspect ratio 6.0.

1. Introduction

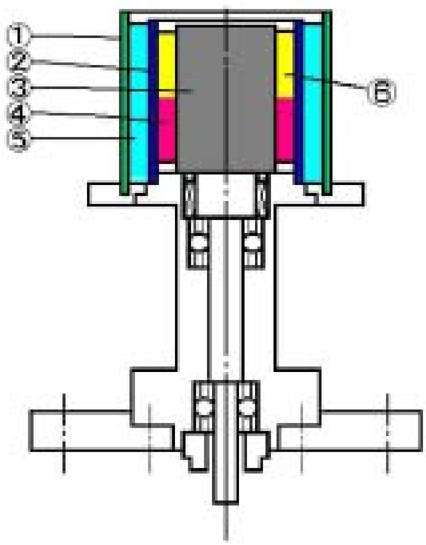
Concerning the instability of the Couette-Taylor vortex flow, many papers have been published using the theoretical, the experimental and the numerical methods of analysis. Considering the geometric condition of the concentric cylinders, the symmetric system, which has fixed end plates on the upper and the bottom sections of the cylinder has always been adopted [1]. And an asymmetric system that has a fixed plate on the bottom and a free surface on the top of the fluid has also been often used [2].

On the other hand, for the working fluid, only one fluid has usually been used, such as water, water and glycerin, some kinds of oil and so on. However, the instability of Couette-Taylor vortex flow using a combination of immiscible, insoluble fluids would also be of interest. This reason is that a boundary surface between two fluids could affect to the new features of the flow. Further, the geometrical condition of the upper liquid has a quasi-symmetric system with free surfaces on both end plates. Book concerning the two-fluid between concentric cylinders is published by D. D. Joseph and Y. Y. Renardy [3]. However, no papers with respect to a quasi-symmetric system with free surfaces have been presented.

In this study, two fluids with aqueous solution of glycerin and silicon oil were used as working fluids. Especially silicon oil being on the aqueous solution of glycerin is regarded to have a quasi-symmetric system. This work reports experimental results with the construction of cells, their development and instability, and the relationship of the bifurcation of the modes.

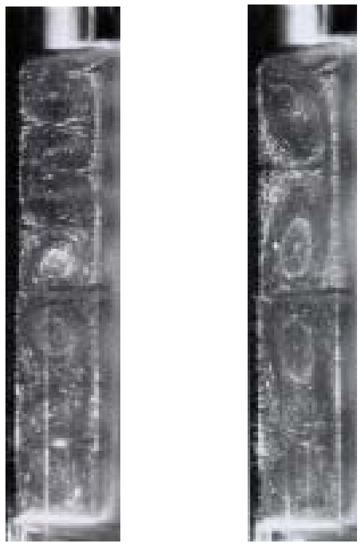
2. Experimental setup and procedures

Figure 1 shows an experimental setup. Inner cylinder (radius is 20mm) rotates and



1.Outer Bath 2.Outer Cylinder 3. Inner Cylinder
4.Glycerin and Water 5. Water 6. Silicon Oil

Fig. 1 Experimental Setup



Primary Mode Secondary Mode

Fig. 2 Sectional Flows

outer cylinder (radius is 40mm) is stationary. Aqueous solution of glycerin (hereafter, glycerin) and silicon oil (hereafter, oil) were used with the ratio of volume 1:1. Therefore, Γ_g (the ratio between the height of the glycerin and the clearance of cylinders) and Γ_o(the ratio between the height of the oil and the clearance of the cylinders) are same. Physical data for working fluids are as follows. Specific gravity of the oil was 0.93 ～ 0.94 (25 ℃) and that for 50% glycerin was 1.124 (20℃). Surface tension of the oil was 20.1 ～ 21.3 dyn/cm (25 ℃) by Shin-Etsu Chemical Corporation and that of glycerin was 70 dyn/cm (18℃). Therefore the ratio of specific gravity between two fluids was 1.2 and the ratio of surface tension was 3.5. When two fluids were introduced between the cylinders, the oil was positioned on the glycerin. To aid in flow visualization a small amount of aluminum powder was added into the fluids.

In the first experiments, the flow generations in the primary mode and secondary modes were examined. Secondary, heights of cells were measured with the Reynolds number (Ro and Rg are defined by the speed of the inner cylinder, the clearance of cylinders and the kinematic viscosity of each liquid). The critical Reynolds number of the wavy Taylor vortex flow was checked. Finally, the route of the bifurcation from one secondary mode to the other mode including the primary mode was investigated. In all experiment the Reynolds number was gradually increased and/or decreased every 4 minutes.

3. Results and consideration

3.1 Flow configuration

Figure 2 shows the flows in a meridian section at Γ=7.0 (Γg=3.5, Γo=3.5). The right sides of each photograph are the rotating inner cylinder and the left sides are the outer cylinders. And there is a boundary surface between two fluids in the centerline. The left hand photo shows the primary mode with 3 cells in the glycerin and with 4 cells in the oil (this mode is expressed as a primary 3-4 cell mode). The flow direction of the bottom cell in the glycerin is inward, that is, counter

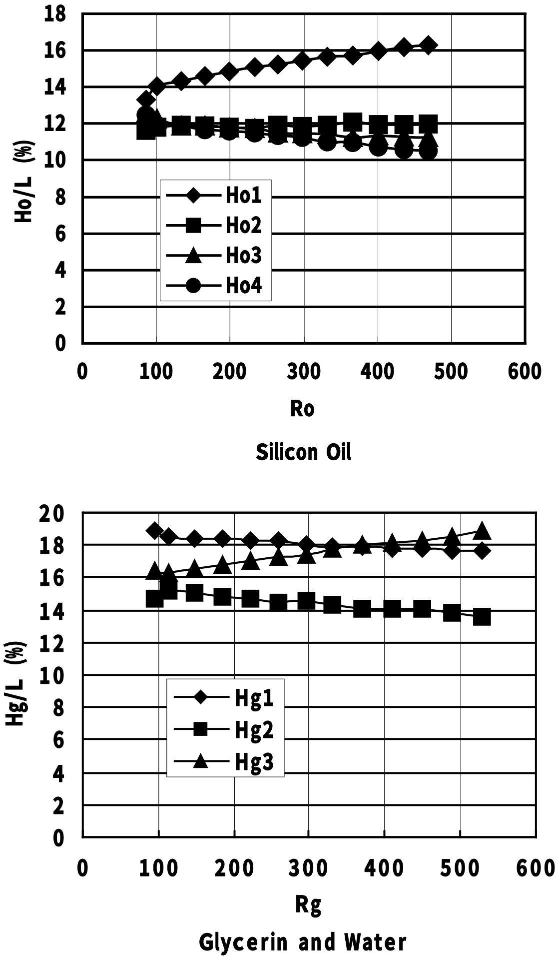


Fig. 3 Heights of cells at Γ=7.0

clockwise. The flow direction of the top cell in the oil is outward, that is, counter clockwise.

3.2 Variation of the heights of cells with the Reynolds number

Figure 3 shows the variation of the heights of cells with the Reynolds number for the primary 3-4 cell mode at Γ=7.0. The notation of heights is used as Hg1, Hg2, Hg3 for the glycerin and as Ho1, Ho2, Ho3, Ho4 for the oil from the bottom respectively. The graph of the glycerin shows that Hg1 and Hg2 decreased and Hg3 increased with the Rg. More experiments made clear that this qualitative character was same as those at the other values of Γ. What is more, it was similar to those of the

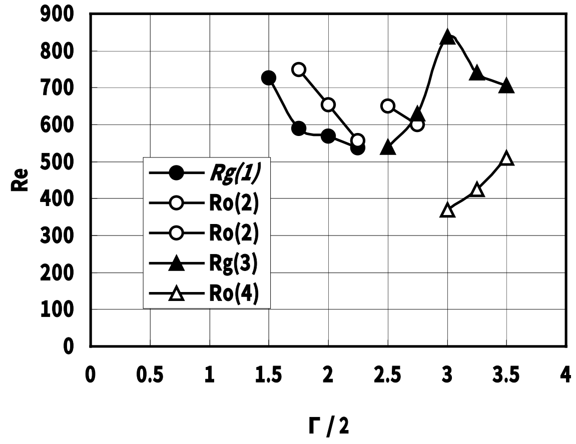


Fig. 4 Critical Reynolds Number

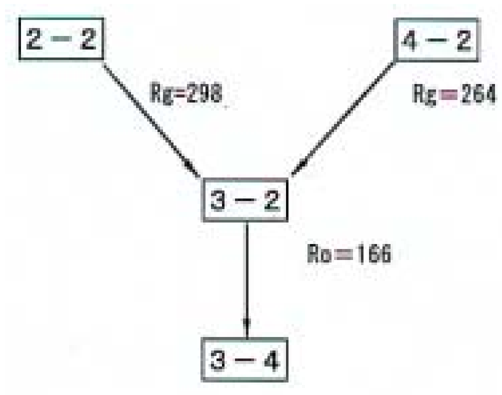


Fig. 5 Route of the Bifurcation at Γ=6.0

Taylor vortex flow in the case of the asymmetric system using just one fluid. For the variation of the cells of the oil, the Ho1 increased and Ho4 decreased with the Ro.

3.3 Critical Reynolds number of the wavy Taylor vortex flow

Figure 4 shows the critical Reynolds number at which the Taylor vortex flow bifurcates to the Wavy Taylor vortex. The abscissa is marked with the half of Γ to plot the critical Reynolds number for each fluid. The figures in the diagram, for example 4 in Ro(4), denote the cell number. From the result the quantitative and the qualitative characteristics of the glycerin would be similar to those in the asymmetric system with respect to one fluid. However the line of the critical number for the 2 cells in the oil was not connected. The reason is that the central boundary surface would be affected in the cell formation.

3.4 Flow bifurcation routes

Figure 5 shows the routes of the flow bifurcation between the primary mode and secondary modes at Γ=6.0. When the Reynolds number decreased gradually, the stable secondary 2-2 cell mode abruptly bifurcated to the stable 3-2 cell secondary mode at Rg=298. Further decrement of the Re made the stable 3-2 cell mode to bifurcate to the primary 3-4 cell mode at Ro=166. The stable secondary 4-2 cell mode bifurcated to the secondary 3-2 cell mode at Rg=264 as well.

4. Conclusion

The conclusions regarding the instability of the Taylor vortex flow using two immiscible fluids in an asymmetric system are as follows.

The characteristics of the aqueous solution of glycerin are similar to those in a single fluid asymmetric system.

The flow of the silicon oil exhibits a boundary condition with quasi-free surfaces on both end sides. New characteristics were found in the cell construction, the instabilities and the relationship of bifurcation because of the influence of the boundary surface between two fluids.

Reference

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