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INFLUENCE OF ACCELERATION TIME OF INNER CYLINDER ON TAYLOR VORTEX FLOW

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ABSTRACT: In concentrically rotating double cylinders consisting of a stationary outer cylinder a rotating inner cylinder, Taylor vortex flow appears. Taylor vortex flow occurs in journal bearings, various fluid machineries, containers for chemical reaction, and other rotating components. Therefore, the analysis of the flow structure of Taylor vortex flow is highly effective for its control. The main parameters that determine the modes of Taylor vortex flow of a finite length are the aspect ratio, Reynolds number Re. Aspect ratio is defined as the ratio of the cylinder length to the gap length between cylinders, and Re is determined on the basis of the angular speed of the inner cylinder. Aspect ratio was set to be 4.0, and Re to be values in the range from 100 to 1000 at intervals of 100. Thus far, a large number of studies on Taylor vortex flow have been carried out; however, the effects of the differences in initial conditions have not yet been sufficiently clarified. In this study, we changed the acceleration time of the inner cylinder in a numerical analysis, and examined the resulting changes in the mode formation and bifurcation processes. In this study, the acceleration time was changed from 1.0s to 10.0s. As a result, a difference was observed in the final mode depending on the difference in the acceleration time. From this finding, non-uniqueness, which is a major characteristic of Taylor vortex flow, was confirmed. However, no regularities regarding the difference in mode formation were found and the tendency of the mode formation process was not specified. Moreover, the processes of developing the vortex resulting in different final modes were monitored over time by visual observation. Similar flow behaviors were initially observed after the start of the calculation. Then, a bifurcation point, at which the flow changed to a mode depending on the acceleration time was observed, and finally the flow became steady. In addition, there was also a difference in the time taken for the flow to reach the steady state. Both EFD and CFD results show good agreement qualitatively.

1 Introduction
Taylor vortex flow has been studied as an important vortex flow since the classical studies of G.I.Taylor in 1923. When the circumferential velocity of the inner cylinder of two concentric cylinders is gradually increased from zero, Couette flow occurs between the inner and outer cylinders. As the circumferential velocity is accelerated further, the flow transitions to Taylor vortex flow, characterized by multiple stacks of toroidal flow called “cells”, then to wavy Taylor vortex flow, and thereafter to turbulent flow. Taylor vortex flow occurs in journal bearings, hydraulic machines, chemical reaction vessels, etc., and elucidation of its mechanism is beneficial from an engineering perspective. Taylor vortex flow between two concentric cylinders of finite length is primarily governed by two parameters: the aspect ratio, defined as the ratio of the height of the cylinders to the width of the gap between the inner and outer cylinders, and the Reynolds number, based on the circumferential velocity...
of the inner cylinder. Depending on these parameters, Taylor vortex flow can form various types of flow.

Taylor vortex flow can be broadly categorized into two modes: normal mode and anomalous mode. When the upper and lower edges of the double cylinder are fixed, the normal mode is the mode having the flow direction from the outer cylinder to the inner cylinder at both the upper and lower end walls. On the other hand, the anomalous mode is the mode having the flow direction from the inner cylinder to the outer cylinder at either one or both of the upper and lower end walls. In this study, we examined Taylor vortex flow in non-Newtonian fluids at low aspect ratios.

2 Results

2.1 Experimental Results

In this experiment, we observed steady-state vortex flows upon varying the acceleration time and Reynolds number under four experimental conditions: \( \Gamma = 4, 5 \) for free ends and fixed ends. In general, in the case of a Newtonian fluid, an odd number of cells are generated under free-end boundary conditions. However, in this experiment, we also observed the generation of even numbers of cells. Odd numbers and even numbers of cells were also observed under fixed-end boundary conditions.

The Taylor vortices that were generated in the experiment are shown schematically in Fig.1 and Fig.2. In each figure, (1) shows three-cell Taylor vortices, (2) shows four-cell Taylor vortices, (3) shows five-cell Taylor vortices, and (4) shows six-cell Taylor vortices.

![Fig. 1. Formation of lower right vortex flow (\( \Gamma = 4, 5 \) free edge)](image1.png)

![Fig. 2. Formation of lower right vortex flow (\( \Gamma = 4, 5 \) fixed edge)](image2.png)
2.2 Numerical results
Figure 3 shows all cells obtained in the present analysis. From the left, two-cell, four-cell, six-cell, and anomalous four-cell vortices are shown.

![Fig.3. Formation of the fixed end wall vortex flow](image)

First, when the aspect ratio was 4, four types of vortices occurred: two-cell, four-cell, six-cell, and anomalous four-cell. We observed that the vortices tended to form four cells when the Reynolds number was between 100 and 300, six cells when it was between 400 and 500, and four cells when it was between 700 and 1000. In addition, when the Reynolds number was between 900 and 1000, anomalous cells occurred when the acceleration time was 1 second.

Next, when the aspect ratio was 5, two types of vortices occurred: four-cell and six-cell. When the Reynolds number was 100, four-cell vortices tended to occur as the acceleration time became slower; otherwise, six-cell vortices were mostly observed. Figure 4 shows a graph where the horizontal and vertical axes show the Reynolds number and acceleration time, respectively.

![Fig.4. Graph of the Reynolds number and acceleration time (Fixed end wall)](image)

3 Conclusion
Non-uniqueness of Taylor vortex flow is investigated both experimentally and numerically. Both results show good agreement qualitatively.