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Experimental study on radial temperature gradient effect of a Taylor–Couette flow with axial wall slits

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ABSTRACT

The flow between two concentric cylinders with the inner cylinder rotating and an imposed radial temperature gradient was studied using a digital particle image velocimetry method. The flow transition process under both a positive and negative temperature gradient with four different models of a stationary outer cylinder without and with differing numbers of slits (6, 9 and 18) was studied. The results showed that the buoyant force due to the temperature gradient clearly generated a helical flow when the rotating Reynolds number was small. For the plain and 6-slit models, the transition to a turbulent Taylor vortex flow was not affected by the temperature gradient considered in this study. In addition, the transition process of a larger number of slits (9-, 18-slit models) was accelerated due to the slit wall. As the temperature gradient became larger, the critical Reynolds number of the transition process decreased.

1. Introduction

The flow between two concentric cylinders with the inner cylinder rotating or both rotating is known as the Taylor–Couette flow. As the inner cylinder rotation speed increases, a series of transitions occurs, starting with stable Taylor vortices and leading to a fully developed turbulent flow. This was first studied by Taylor [1]. Since then, many researchers have studied the instability that causes Taylor vortices [2–5].

The stability of the Taylor–Couette flow in concentric cylinders with a radial temperature gradient has been the subject of large number of studies during the last few decades. Under this condition, two governing forces affect the flow between two cylinders. The first is the centrifugal force caused by the rotation of the inner cylinder, and the second is the buoyancy force caused by the presence of a radial temperature gradient. Various numerical and experimental studies have been conducted to solve this type problem with numerous practical devices, such as electrical motors [6] and high-speed pumps [7]. Among the many studies in this area, Snyder and Karlsson [8] investigated the radial temperature gradient effect on the stability of a Taylor–Couette flow and observed that relatively small temperature gradients had a considerable effect on the critical Taylor number. Sorour and Coney [9] found that the imposed radial temperature gradient destabilized the base flow. The flow pattern obtained in their experiment was composed of stationary axisymmetric toroidal vortices. Lepiller et al. [10] studied the influence of radial heating on the stability of a circular Couette flow. They found that a radial temperature gradient destabilized the Couette flow; moreover, a pattern of traveling helical vortices was found near the bottom of the system. They observed that the size of the pattern increased as the rotation frequency of the cylinder increased when varying the Grashof number from −1000 to 1000.

Most of these studies were performed under plain wall conditions. That is, the annular surface had a smooth plane. However, in engineering applications, the walls of cylinders generally have complex geometries. Therefore, studies of a Taylor–Couette flow with a temperature gradient considering the effect of the cylinder wall shape were necessary.

Lee and Minkowycz [11] studied heat transfer characteristics using a naphthalene sublimation technique in the annular gap between two short concentric cylinders which had either two smooth walls or one smooth and one axially slit wall. This study yielded qualitative information regarding the heat transfer but did not address the flow phenomena inside the annular gap. Hayase et al. [12] studied the flow and heat transfer in the space between two coaxial cylinders using numerical calculations. Three different models were considered in their study: a plain model along with two models in which one or the other cylinders had an axially

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