FLOW REGIMES AND VORTEX COMPETITION IN MODIFIED TAYLOR COUETTE SYSTEM: INNER ROTATING WAVY CYLINDER COAXIAL WITH A SMOOTH STATIONARY OUTER CYLINDER

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Abstract

The hydrodynamic instability of a viscous fluid flow in an annular space between a rotating inner cylinder having axi-symmetric wavy (cosinusoidal) surface, coaxial with an outer fixed smooth cylinder is studied both numerically and experimentally. The basic flow is two-dimensional, axi-symmetric with two counter-rotating vortices per wavelength. On one hand, a CFD code based on a finite volume technique (FLUENT) is used for flow simulations and on the other hand, the Particle Image Velocimetry (PIV) and wall shear probe measurement techniques are used, to localise the transitions and to understand the competition between Taylor's vortices and those imposed by the wavy surface. In this flow system, different flow regimes (steady and transient states) appear which are not characteristics of the flow in right circular cylinders geometry. The Taylor vortices appearing in the modified system have to compete with the vortices forced by the geometry.

Introduction

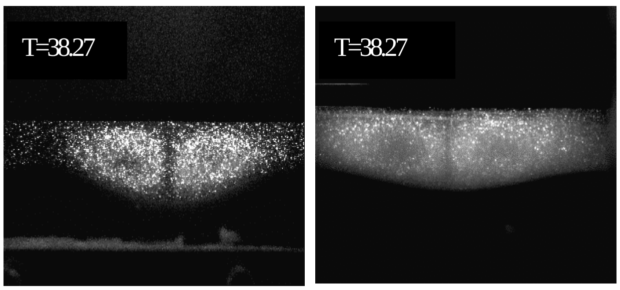
The flow between concentric cylinders, as described by Taylor [1], is one of the most investigated problems of the motion near rotating bodies. These vortices may also appear in geometries other than right circular cylinders. In this connection, Wimmer [2], among others, has studied the flow between two rotating spheres. The flow between two-coaxial cones and a variety of cone-cylinder combinations have been studied by Wimmer [3-4]. In past, a number of modifications to the right cylindrical Taylor-Couette system have been the subject of investigations [5, 6, 7, 8].

This study considers a geometry consisting of two coaxial cylinders such that the outer smooth cylinder is stationary while the inner rotating cylinder has an axi-symmetric wavy surface. The fluid column is confined axially by two fixed end plates. This geometry can be considered as an extension of Wimmer's cone-cylinder configuration. A closely related case of the flow in a hourglass geometry has been studied by Wiener et al. [7].

Basic Flow

The basic flow in the Couette system having wavy inner cylinder is two-dimensional in meridional plan with an out-of-plan swirl component. It consists of two counter-rotating vortices per wavelength of the inner cylinder. This is due to the imbalance in the centrifugal forces resulting from the periodic nature of the inner cylinder's radius such that the crest points of the wavy surface behave like outflow boundaries and the trough points like inflow boundaries of the geometric vortices.

The radial and axial velocity components crucially influence the generation of the vortices. Both of them depend on the angular speed of the inner cylinder, the local axial position, the amplitude and the wavelength of the wavy surface.



(i) (ii)

Figure 1: Basic Flow with two different cylinders having the same wavelength (λ=71.75 mm) but different amplitudes: (i) a=3.91mm, (ii) a=1.96 mm

Behaviour of Taylor vortex flow

Two-dimensional basic flow has significant influence on the inset, occurrence and behavior of the Taylor vortices. With increasing the rotational speed as the Taylor number exceeds certain critical value the flow becomes supercritical but owing to the wavy surface, the flow becomes supercritical at some points while it remains still sub-critical at the others. The local Taylor number is defined as:

$$T_{local} = \frac{\Omega\left[r_0 + a\cos\left(\frac{2\pi}{\lambda}z\right)\right]\left[R - r_0 - a\cos\left(\frac{2\pi}{\lambda}z\right)\right]}{\nu}\sqrt{\frac{R - r_0 - a\cos\left(\frac{2\pi}{\lambda}z\right)}{r_0 + a\cos\left(\frac{2\pi}{\lambda}z\right)}}$$

Where r_0: the mean radius of the inner cylinder, R: the radius of the outer cylinder, Ω: angular speed (rad/s) and ν: kinematic viscosity, a: wave-amplitude and λ: the wavelength.

The vortices appear first at the trough points as could be anticipated because of the maximum value of T_{local}. The visual observations and the wall shear probe's signals (Figure 2) show that at the on-set of this instability the flow system starts exhibiting an axial spiral motion.

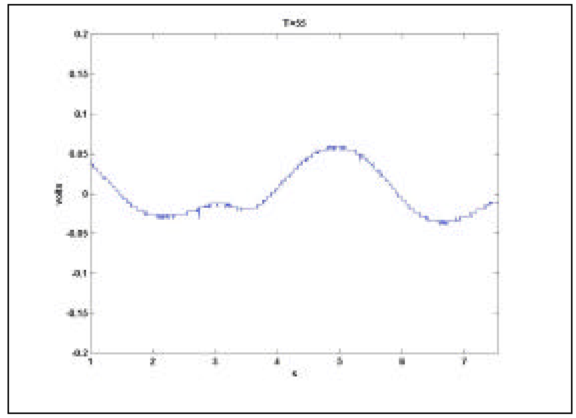
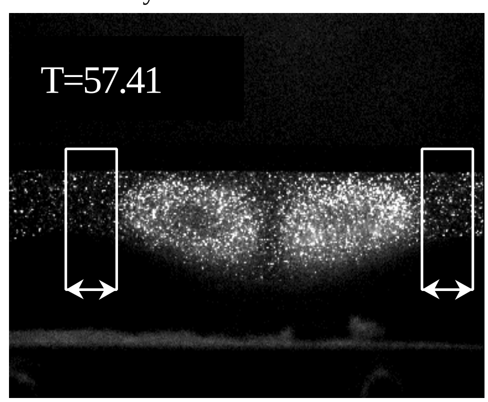
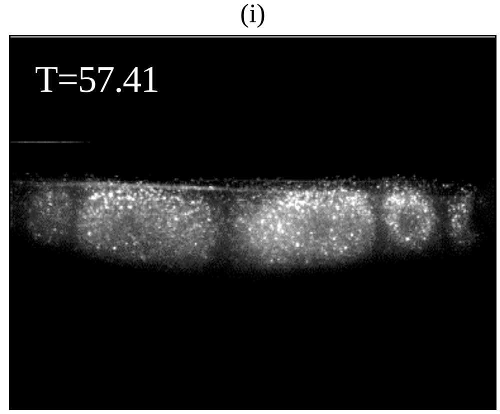


Figure 2: Oscillations due to spiral motion recorded by a wall shear probe placed at the outer cylinder's wall.

This oscillatory state decays out once flow is supercritical everywhere in the annulus.



(i)



(ii)

Figure 3: The Taylor and geometric vortices with two different cylinders having the same wavelength (λ=71.75 mm) but different wave-amplitudes: (i) a=3.91mm, (ii) a=1.96 mm

The duration of the oscillatory flow state, the size and the intensity of the Taylor vortices depend on the amplitude and the wave length of the inner cylinder. Figure 3, shows the Taylor vortices along with the geometric vortices after the decay of these oscillations.

With the increase of the rotation rate, the flow undergoes the subsequent transition and the multi-vortex configuration starts oscillating. If one continues to increase the rotation rate, the oscillations go more and more intense till the moment that the strong geometric vortices start absorbing the less intense Taylor vortices and the flow comes back to its two-vortex per wavelength configuration.

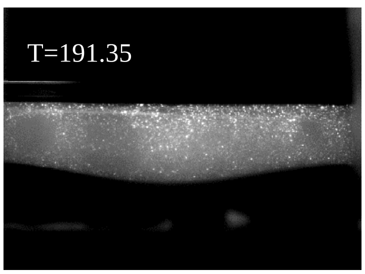


Figure 4: Absorption of Taylor vortices

Experimental and theoretical methods

The velocity field is measured by using Particle Image Velocimetry (PIV). The flow is seeded with fluorescent particles and the respective optical filter is used to avoid the optical noise. The experimental set-up is enclosed in a cubical box. The gap between the cylinders and the box is filled with a refractive index matching motor oil (Shell Flex 212 FC). The inner cylinder is driven by a computer controlled motor. The cylinder rotation is increased slowly to insure the reproducibility of the flow states.

The wall shear probe technique is based on the principle of mass transfer on a micro-electrode, flush-mounted on the wall of the outer cylinder, when a potential difference is applied across the micro-electrode and a reference electrode. When the size of the micro-electrode is very small as compared to the reference electrode and the Schmidt number is high, the mobility of the ions is solely controlled by the diffusion process. The oxidation-reduction couple used in this study is the aqueous solution of Ferri- and Ferro-cyanide (3 and 6 moles/m^3 respectively) with Potassium sulphate as a catalyser. The details of the techniques can be found elsewhere [9, 10].

The numerical simulations are performed using a finite volume based CFD code (Fluent) for laminar steady state fluid flow. In this regard, the mass balance and the momentum balance equations are solved in the cylindrical coordinated. The equations are discretized using up-wind central difference scheme and the pressure-velocity coupling is resolved using the SIMPLE algorithm.

Results

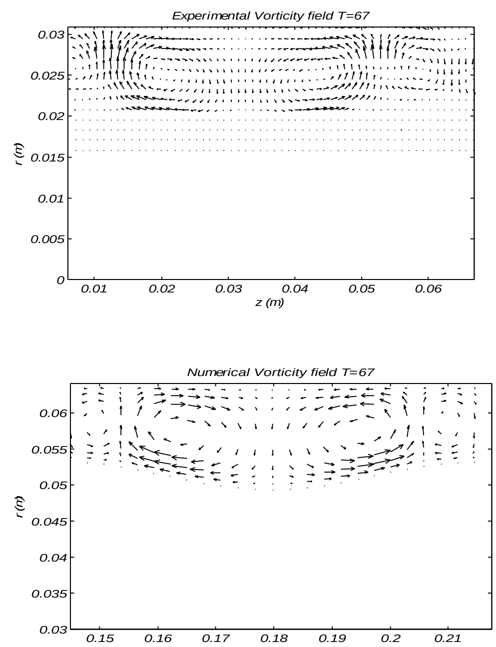


Figure 5: Experimental and Numerical vorticity field

More results will be presented and discussed during the oral presentation.

Conclusion

The experimental and numerical analysis presented here show that in the Taylor Couette system with wavy inner cylinder, there exists a competition between regular Taylor vortices and those imposed by the geometry. Moreover, the vorticity can be controlled by the variation of wavelength and the amplitude of the imposed wavy surface.

The combination of the two flows leads to quite different flow states that do not exist in the Taylor-Couette system with right circular cylinders.

Acknowledgement

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