Journal of Visualization, Vol. 12, No. 2 (2009) 91-92

Short Paper

Numerical Flow Visualization of the Formation of Taylor Cells in a Laminar Taylor-Couette Flow

Desevaux, P. *

* FEMTO-ST-UMR 6174, Dépt ENISYS, Université de Franche-Comté, Belfort F-90000, France
E-mail: philippe.desevaux@univ-fcomte.fr

Received 17 July 2008 and Revised 16 September 2008

1. Introduction

The Taylor-Couette flow in the annular space between a rotating inner cylinder and a fixed outer cylinder is found in many engineering applications which include filtration, liquid extraction, motors and journal bearings. Visualization of the flow in the gap between the cylinders is of great interest for the analysis and the understanding of the different flow instabilities which may appear in this type of flow. Experimentally, flow visualizations are usually carried out using small reflective anisotropic particles, Laser Induced Fluorescence (LIF), dye tracers and laser tomography. Numerically, recent works (Bilson and Bremhorst, 2007) have shown that the Direct Numerical Simulation (DNS) is a very promising approach for the investigation of turbulent Taylor-Couette flows. An alternative to the DNS is the use of commercial CFD codes to study the flow instabilities occuring in this type of flows (Deshmukh et al., 2007, Furukawa et al. 2008). It is this numerical approach which has been adopted in this study in order to visualize the formation and the propagation of Taylor cells in a Taylor-Couette flow of air, and more especially after a sudden-start of the inner cylinder. Such transient flow phenomena are difficult to investigate experimentally and are of great interest for the comprehension of the flow developing process (Watanabe et al., 2001). The results obtained from our simulations are compared with flow visualizations previously performed in our laboratory by laser sheet tomography (Varechon et al., 1994).

2. Numerical approach and test geometry

In order to study the development of Taylor cells, a CFD model is developed using the software package Fluent. This CFD model is a transient three-dimensional model, requiring a fine grid mesh (682000 cells) to correctly model Taylor vortices and eventual non-axisymmetric flow instabilities. The CFD model is applied to the geometric configuration used by Varechon et al. (1994). The apparatus is composed of two-coaxial cylinders with a length of 200 mm. The diameters of the inner and outer cylinders are 100 mm and 120 mm, respectively, with a resulting radius ratio of 0.833 and a aspect ratio (length of cylinders / annular space) of 20. The outer cylinder is stationary and a rotationnal speed is suddenly applied to the inner cylinder. Air flow in the gap between the cylinders is considered as incompressible and laminar (Reynolds numbers based upon the gap width not exceeding 280 during this study). The computational time step is chosen according to the experiments of Varechon et al. (1994) (i.e. photographic sequence recorded at 2 images per second).

3. Results and discussion

Figure 1 compares typical CFD flow visualizations (i.e. axial velocity field) with laser tomography images of the flow in the radial plane of the annular space. The rotating inner cylinder is on the left side of the images and the stationary outer cylinder is on the right side. The CFD runs are chosen to match the experiments of Varechon et al. (1994) : initially, the fluid and the cylinders are at rest. At time t = 0, the inner cylinder suddenly begins to rotate at a constant speed of 40 rpm corresponding to a Taylor number of 7090.

The results obtained show the ability of the CFD model to correctly predict the transition from the Couette flow to the Taylor vortex flow. This transition is known to occur for a Taylor number greater than 1700 and is characterized by the formation of toroidal vortices filling the gap between the cylinders.

The comparison between laser tomography images and numerical flow visualizations shows a good agreement for the number of Taylor cells, their formation time and their propagation within the annular space. Both visualizations show the importance of the end effect. The Taylor vortices are first formed at the extremities of the annular space and then are propagated symetrically from the upper and lower boundaries towards the center. The total time for cells propagation is 6.5 seconds. At the steady state regime, simulations and experimental visualizations show 24 and 20 Taylor cells respectively. This difference between the experimental and numerical results may be explained by :

- the surface roughness of the cylinders which is difficult to be taken into account in the simulations,
- the presence of the incense smoke particles used to seed the flow which certainly affects the viscosity of the air flow during the experiments,
- the effect of the acceleration rate of the inner cylinder on the development of vortex patterns (Furukawa and Watanabe, 2001 ; Watanabe et al., 2005). This dependence of the flow on the acceleration rate may also explain the difference in the cells formation process observed between experiments and CFD results at the middle part of the axial direction at t = 4.5 s.

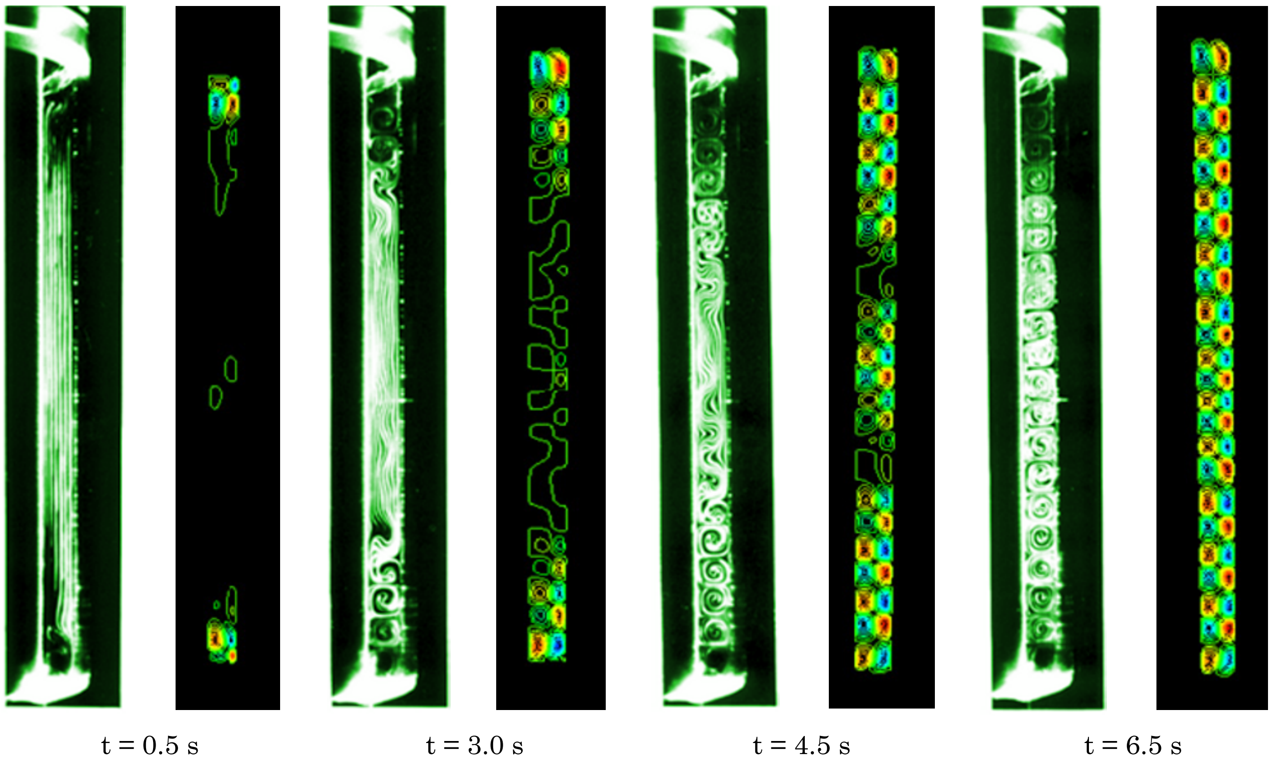

Fig.1. Series of flow visualizations showing the progression of Taylor cells along the annular space

This rapid comparison between experimental and numerical flow visualizations favorably supports the validation of the CFD model. Numerical flow visualizations allow the study of the formation process of Taylor cells and their propagation along the annular space. Furthermore, CFD simulations may provide quantitative information on the flow velocity (axial, radial and azimuthal velocity components). We are now working to improve the present CFD model in order to visualize the second instability (azimutal waves) of flow which appears at the laminar-turbulent transition.

References

Bilson, M. and Bremhorst, K., Journal of Fluid Mechanics, 579 (2007), 227-270.
Varechon, E. et al., Flucome 94, 1 (1994), 577-582.
Deshmukh, S.S. et al., Industrial and Engineering Chemistry Research, 46 (2007), 8343-8354.
Watanabe, T. et al., Journal of Visualization, 4 (2001), 223-230.
Watanabe, T. et al., Journal of Physics : Conference Series, 14 (2005), 9-19.
Furukawa, H and Watanabe, T., 12th International Couette-Taylor Workshop, (2001).
Furukawa, H. et al., ISFV13, (2008).