Influence of thermal convection in Taylor-Couette system

T. Deters¹, C. Egbers¹, E.-S. Zanoun¹ and R. Guillerm²
¹Department of Aerodynamics and Fluid Mechanics, Brandenburg University of Technology Cottbus, Siemens-Halske-Ring 14, 03046 Cottbus, Germany
²Laboratoire de Mecanique, Physique et Geosciences, UFR Sciences et Techniques, Universite du Havre, 25 rue Philippe Lebon, 75058 Le Havre, France
E-mail: deters@tu-cottbus.de

Abstract. In the research work presented, the influence of a radial temperature gradient on the stability and the generation of convective flow in coaxial cylindrical gap with different aspect ratios are investigated. Brief description of the experimental facilities are given and first results are presented.

1. Introduction
Fluids in coaxial cylindrical gap with stationary temperature gradient are important in questions of many technical applications [1-4]. The priority in the current phase of the project lies on the modification of the aspect ratio of the system and the temperature gradient between inner and outer cylinders. It is observed that the onset of these bifurcations strongly relies on the modulus of the temperature gradient. During the current research process the influence of radial temperature gradients and boundary conditions are investigated.

2. Experimental setup and flow parameters
The experimental setup shown in Fig.1 consists of two coaxial cylindrical tubes. The inner tube is made of an anodized aluminum and has an outer radius \( r_i = 35 \text{mm} \pm 0.24 \text{mm} \) and the outer tube is made of perspex, having an inner radius \( r_o = 69.75 \text{mm} \pm 0.25 \text{mm} \), \( \eta = \frac{r_i}{r_o} \approx 0.5 \). Through the inner tube and in the gap between the outer cylinder and an outer boundary, there are two water circulations from two thermostat baths with controlled temperature. In the current phase, the temperature of the inner cylinder \( T_i \) is higher than the temperature of the outer cylinder \( T_o \), providing the required temperature gradient. It is worth mentioning here that the inner cylinder can be driven by a servo motor. The parameters of experiment are the Rayleigh number \( \text{Ra} = g \beta (r_o - r_i) \frac{\Delta T}{\nu \kappa} \) and the aspect ratio \( \Gamma = \frac{L}{r_o - r_i} \) where \( L \) stands for the difference between the end plates; \( \beta \) is the oil thermal expansion, \( \kappa \) is the thermal diffusivity and \( \nu \) is the kinematic viscosity of the silicon oil used. Possible aspect ratios of the experiment are \( \Gamma = [0, 20] \) and the the maximum temperature difference reached is 25 K (i.e. \( \text{Ra} = 935 \times 10^5 \)).

3. Preliminary experimental results
Following results of previous works by [1] and [3], it is known that by setting a temperature gradient between inner and outer cylinders of the system, a vortex structure arises at a first
critical Rayleigh number $R_{a,crit}$. This state is specified and set to a functional relation with the aspect ratio $\Gamma$ of the measure volume. The viewed aspect ratios are $\Gamma = \{20, 14, 10\}$. In all $\Gamma$, the temperature of the outer cylinder is kept constant and the inner cylinder is heated up by a space of $T=0.1$ K. The time step, $t$, was larger than $\tau$, where $\tau = \frac{(r_o-r_i)^2 \cdot \rho \cdot c}{\lambda}$ is the thermal relaxation time, $\rho$ is density, $c$ is the mean specific heat and $\lambda$ is the coefficient of fluid thermal conductivity.

3.1. Description of state
First results are to verify that the rise of the vortices is induced nearly to the axial middle of the measure volume. It is supposed, that the Kelvin-Helmholtz instability is the mechanism to induce the vortices, Fig.2. The first vortex was built up at the point, where the velocity between the up and down directed fluid layers are maximal. The developed structure can be described as follows. The vortices near the axial middle of the measure volume are classified in
two different kinds of vortices. In Fig.3, the primary vortices have the same direction as the vortex under critical state, driven by convection. The secondary vortices are emerging from the shear flow existing between two primary vortices. These structures were found at the top and the bottom of the system. Therefore $m=n-1$, $n \in \mathbb{N}$, is the number of the secondary vortices.

![Figure 3](image3.png)

**Figure 3.** Primary and secondary vortices using laser-light sheet with time exposure 30s at $Ra=4.3 \times 10^5$ in the axial direction and middle of the measuring volume, $T_o<T_i$, $\Gamma =20$.

where $n$ is the number of the primary vortices. A second feature is the flow structure near the top and bottom of the measuring volume, shown in Fig.4. It is a fragment of the under critical basic convection. By increasing the temperature difference, the number of vortices is increasing, however the boundary flow structure is maintained. The boundary flow structure influences the geometry of the bordering vortices. While there is a point of symmetry in the remaining primary vortices with the respective center of vortex, this symmetry was broken in the bordering vortices.

![Figure 4](image4.png)

**Figure 4.** Influences of the boundary flow structure and the asymmetric bordering vortex, picture of laser-light sheet with time exposure (30s), $Ra=20$

### 3.2. Number of vortices versus aspect ratio of the measure volume

In order to show the dependence of Rayleigh number on the aspect ratio $\Gamma$ of the measuring volume, measurements have been carried out for $\Gamma = \{10, 14, 20\}$. For further increase in
temperature difference between inner and outer cylinders, the number of the primary vortices rises, however the maximum number is depending on the aspect ratio of the experimental setup, see Fig.5.

![Figure 5](image)

**Figure 5.** The dependence of the number of primary vortices on Ra and $\Gamma$.

### 3.3. Ratio between axial length of measure volume and length of vortex-structure

The ratio $z = \frac{L}{L_p}$ where $L$ is the axial length of the measure volume and $L_p$ is the length of the vortex-structure of the primary and secondary vortices cluster, has been considered by $\Gamma = \{10, 14, 20\}$. The base line $b = r_i + \frac{r_o - r_i}{2}$ was set in the radial middle of the measure volume, see Fig.6. The length $L_p$ is therefore defined as the length between the top and the bottom intersection point between the base line and the vortex. It was observed that the ratio $z$ rises with increasing Rayleigh number, see Fig.6. It can be seen also from the figure that the amplitude increases with increasing the aspect ratio, $\Gamma$.

![Figure 6](image)

**Figure 6.** Sketch showing principle of the ratio between the measuring volume length $L$ and the length of the vortex-structure $L_p$ and the ratio of the measuring volume length and the vortex-structure length of the primary and secondary vortices cluster, $\Gamma = [10, 14, 20]$. 
4. Outlook
A further aspect of investigating the dependence of the first critical Reynolds number, which characterizes the transition from Couette flow to temperature dependent Taylor vortex flow, on the Rayleigh number and the aspect ratio $\Gamma$ of the system is planned.

A new measuring approach via thermochromic liquid crystals, see, e.g. [5-7], in order to measure the temperature distribution will be utilized. With this technique, it will be possible to show thermal convection interactions. The liquid crystal thermography appears to be suited for producing a quantitative picture of a two-dimensional field in which the temperature varies both spatially and temporally. The RGB picture is converted to a hue picture from which we can extract the value of the hue angle, $h$, for a given temperature. It is worth noting that the measured temperature associates with the hue angle, $h$, that is defined in a polar chromaticity space determined by the intensities of the red, green and blue primaries recorded by the image acquisition equipment. First calibration curves, see Fig. 7, have been obtained for a sample of micro-encapsulated liquid crystals from Hallcrest. The liquid crystals will then be used as tracer particles to make some Particle Image Velocimetry measurements to get informations about the velocities and the temperature of the flow and thereafter utilizing this technique in the Taylor-Couette system.

![Figure 7. Calibration curve of hue angle (h) versus liquid temperature (T).](image)

Acknowledgments
The experimental work is supported by DFG, project number EG 100/7.
References

[1] Lepiller V, Prigent A, Dumouchel F and Mutabazi I 2007 Transition to turbulence in a tall annulus submitted to a radial temperature gradient Physics of Fluids 19

[2] Ali M and Weidman PD 1990 On the stability of circular Couette flow with radial heating J. Fluid Mechanics 220 53-84

[3] Mutabazi I, Goharzadeh A and Dumouchel F 2001 The circular Couette flow with a radial temperature gradient 12. International Couette-Taylor Workshop, Evanston USA

[4] Sorour MM and Coney JER 1979 The effect of temperature gradient on the stability of flow between vertical, concentric, rotating cylinders Journal Mechanical Engineering Science 21 403

[5] Stasiek J 1997 Thermochromic liquid crystals and true colour image processing in heat transfer and fluid-flow research Heat and Mass Transfer 33 27

[6] Wozniak K, Wozniak G, Rubes D and Heiland H.G. 2006 Konvektionsexperimente mit flüssigkristallinen Tracerteilchen in einem engen vertikalen Spalt Springer Verlag 70 221-229

[7] Wozniak K, Wozniak G and Siekmann J 1996 Non-isothermal flow diagnostics using microencapsulated cholesteric particles Applied Scientific Research 56 145