CYCLONIC VORTEX IN A ROTATING LAYER WITH ISOLATED HEAT SOURCE

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Abstract Formation of cyclonic vortex from isolated heat source in a rotating fluid layer was studied experimentally and numerically. It was shown that structure of the vortex strongly depends on main governing parameters such as Grasshof number and Rossby number. PIV measurements were carried out for fluids with different values of Prandtl number (from 40 to 250). Numerical simulations were done using CFD software FlowVision.

INTRODUCTION

Natural convection over the local heat sources with and without background rotation has many geophysical and engineering applications and has been widely studied. Most of these studies were focused on heat and mass transfer measurements and qualitative studies of the flow structure. Convection from isolated source for low values of Rossby number, with application to the ocean convection was experimentally studied in [1-3]. These experiments were mainly directed to the study of small eddies formation in a buoyancy source region, their properties and evolution. A systematic study of the dependence of the convective flow regimes on the aspect ratio and the Rayleigh number was carried in [4]. Laboratory modeling of typhoon-like vortex was made in [5] and [6]. Studies of convective flows over isolated heat source in a rotating fluid layer showed that local heat source in a rotating layer always leads to a formation of an intensive cyclonic vortex. The structure of such vortices strongly depends on rotation rate, buoyancy and aspect ratio. Previous studies of convection from isolated heat sources were mainly qualitative and we believe that there is a need of systematic study of cyclonic vortex formation by PIV measurements. Experimental study of convective flows in a rotating layer with non-uniform heating using PIV system was done in [7] but with a focus on angular momentum transfer and differential rotation. Now we return to the problem of vortex formation over localized heat source and begin systematic study of characteristics of such vortices in a wide range of Prandtl number, Rossby number and Grasshof number.

EXPERIMENTAL SETUP

We studied a convective flow in a flat cylindrical vessel placed on a rotating horizontal table. The cylinder radius is R=150 mm. The cylinder is made of acrylic plastic, the fluid is silicone oil, characterized by a high Prandtl number. The layer thickness is constant in all experiments (h=30 mm) and the upper surface is free (Fig.1).

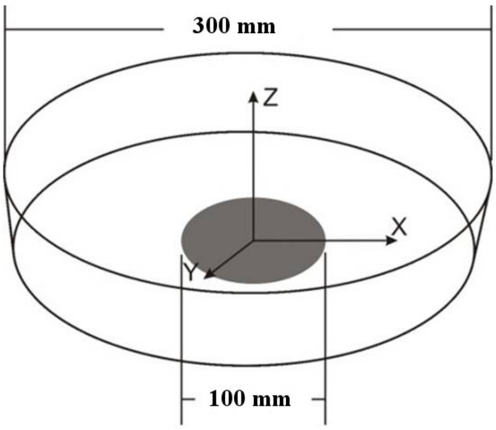

Figure 1. Scheme of experimental setup.

Heater is a copper cylinder of radius 52 mm, installed in the center of the vessel and coinciding with the axes of rotation. The temperature in the layer was measured by copper-constantan thermocouples. For the reconstruction of temperature fields an array of 7 thermocouples mounted on 3-axis translation stage Thorlabs was used. The data from the thermocouples were obtained by an Agilent 34970A data acquisition switch unit with a 16 channel multiplexer module 34902A. Velocity fields were measured by PIV system « Polis ».

RESULTS

Local heating at the center of the bottom generates vertical and horizontal temperature gradients. The horizontal temperature difference provides a toroidal convective cell. The flow in the lower part is directed inward, tending to the central bottom region, where the heat source is located. A strong upward flux is formed at the center above the heat source. In the upper layer, the outward flow is directed toward the periphery. The fluid is cooled at the free surface and finally moves downward along the side wall. The action of Coriolis force on meridional circulation leads to the formation of azimuthal flows [7]. In the central part it is an intensive cyclonic vortex and in the periphery it is relatively weak anticyclonic flow. Example of the vector fields over the heating area at different heights is shown in Fig.2. Our measurements showed that the structure and characteristics of isolated cyclonic vortex strongly depends on the rotation rate, the heat flux and physical properties of the fluid.

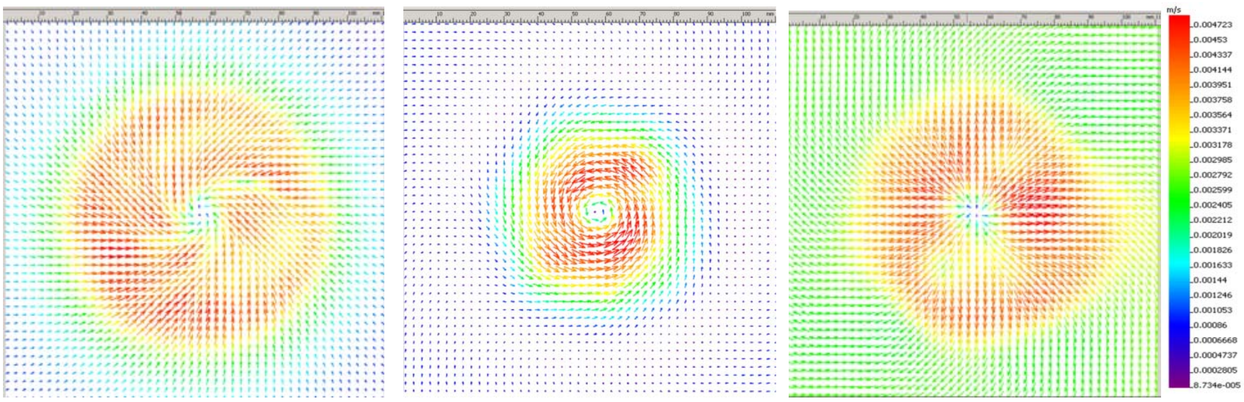

Figure 2. Example of vector velocity fields at different heights (3, 15 and 27 mm).

The financial support of the grant RFBR No.14-01-96011 is gratefully acknowledged.

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