Numerical Investigation of Three-Dimensional Convective Flows in Horizontal Canals

D.V. Lyubimov[1], T.P. Lyubimova[2*], G.A. Sedelnikov[1]

[1]Perm State University, Bukireva, 15, Perm, 614990, Russia

[2]Institute of Continuous Media Mechanics, UBI RAS,
Koroleva, 1, Perm, 614013, Russia

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The buoyancy-driven flows (natural convection) in cylinders with differentially heated endwalls (axial temperature gradient) is a topic of practical interests for many applications, particularly for material processing. Crystallisation from the melt has gained ever increasing importance in the processing of semi-conductors, insulators and metals. The study of stability of buoyancy convection in horizontal canals with differentially heated endwalls is actual and attracts high attention of researchers. However, in most works numerical investigation is restricted to two-dimensional approach. Exceptions are the papers [1], [2], where three-dimensional numerical investigation is performed for differentially heated horizontal cylinder with circular cross-section and comparison with the results of experiments and two-dimensional numerical calculations is made and [3], where three-dimensional numerical investigation for zero Prandtl number is carried out. Laser Doppler anemometry studies, conducted by Schiroky and Rosenberger [4], have shown that in reality the buoyancy convective flows in such configurations are highly three-dimensional. Three-dimensional numerical investigation of convective flow stability and supercritical convective flows in a horizontal rectangular canal and close parallelepiped cavity for non zero Prandtl number have not been made.

Present work deals with the numerical investigation of three-dimensional convection in a horizontal rectangular canal and in a closed parallelepiped subjected to uniform longitudinal temperature gradient and gravity field. The case of conductive boundaries is considered. The stability loss character of basic flow and secondary flow regimes for large supercriticalities and different values of aspect ratio and Prandtl number are studied.

The temperature difference applied across the two ends of a horizontal canal induces a natural counterflow in which a colder fluid flows along the bottom of the canal towards the warm end while a warmer fluid moves in opposite direction along the top.

Governing equations in this case coincide with usual equation of thermal buoyancy convection in Boussinesq approximation [5].

System of governing equations with corresponding boundary conditions is solved numerically by finite-difference methods, in primitive variables. High-order boundary conditions for the pressure are obtained from the normal projection of Navier-Stokes equations at the boundary. Poisson equation for the pressure field obtained from the continuity equation is solved using successive over-relaxation method.

Effective solving of the problem under consideration is possible only with using high-performance computers, to organize the calculations on multi-processor computers parallel algorithms are to be implemented.

In the context of programming paradigm MPI (The Message Passing Interface), for the exchange of information between processors, nonblocking and collective operations are used. The interaction between processors takes place in the context of topology Ring and Line, for

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[*] Email: lubimova@psu.ru

horizontal rectangular canal and in a closed parallelepiped respectively. For this work the computational domain is decomposed into the sub-domains, the number of these sub-domains is determined by a number of used processors (depending on a number of available processors), in order for each processor to carry out calculations in its own sub-domain. In such topology all processors have two “neighbours” (except for the first and last sub-domains in line topology), with which it makes a transfer of necessary information for resolving finite-difference scheme.

Fortran is taken as programming language.

With using the resources (IBM SP and SGI ORIGIN 3800) of National Computer Centre of Higher Education (Montpellier, France), numerical investigations are performed for a horizontal canal of rectangular cross-section, at Pr=2 and aspect ratio (the ratio of the width of parallelepiped to its height) is equal to four. Analysis of the amplitude curve and hydrodynamical fields allows to conclude that at the parameter values under consideration the basic stationary flow becomes unstable to spiral mode and new secondary flow is chaotic in time and has quite regular structure. Numerical results are found to be in a good agreement with previously obtained results of two-dimensional investigation.

At present, the calculations are conducted for the horizontal canal of square cross-section and small values of Prandtl number (liquid metals) where linear theory predicts new interesting effects of sharp stabilization of basic flow with the increase of Prandtl number .

Further investigation will concern the influence of longitudinal acoustic wave, propagating along the canal, on a stability of basic flow and secondary flow regimes is planned.

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