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EDUCATION AND TUTORIAL ON FLUID MECHANICS ON THE BASIS OF COMPUTER LABORATORY

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Summary Experience in the education and tutorial in modeling of the elementary flows, heat and mass transfer during crystal growth in ground-based and microgravity environment using computer system COMGA is presented. The system supports free and forced convection problems on the basis of the Navier - Stokes equations. The computer laboratory as intellectual shell of this system includes basic double-diffusion gravity-driven and Marangoni problems in enclosures, Bridgman model, and Czochralski model for microgravity and ground-based applications.

INTRODUCTION

Elementary flows and heat/mass transfer processes in real technological range of parameters are nonlinear, unsteady and multiscale. They have a number of important peculiarities in ground-based and in microgravity conditions (see, for instance, [1]). The development of technology needs more detailed analysis as well as modeling systems, access to the education process and modern knowledge for new generation of researchers.

The paper presents experience in the education and tutorial in modeling of the elementary flows, heat and mass transfer in ground-based and microgravity environments using the computer system COMGA (COnvection in MicroGravity and Applications). This system provides modeling free and forced convection on the basis of the Navier - Stokes equations (the Boussinesq approach). It was developed and systematically used in the Laboratory of Mathematical and Physical Modeling in Fluid Dynamics IPM RAS since early of the 90^{th}. The computer laboratory as intellectual shell of this system was realized on the next stage of the development [2] and includes now microgravity and ground-based applications with the use of high performance personal computers. A focus of the paper is the basic aspects of fluid dynamics and heat/mass transfer such as hydrostatic equilibrium stability and stability of steady flow.

BASIC VERSION & INITIAL STAGE OF EDUCATION

A basic version of the system and computer laboratory includes most of classical problem of convective heat and mass transfer with different types of the boundary conditions, external forces, and fluid (gas) properties. Initial stage of education starts from the definition of the physical properties of the typical liquids and gases in crystal growth applications and hydrostatic equilibrium. Convection is induced by the buoyancy and gradient of the surface tension (Marangoni convection). A general mechanism of the onset of convection and convective instability is included. Elements of the modeling theory and the basic knowledge of fluid dynamics and numerical methods should be also studied for understanding the options of the finite difference schemes.

Classical problems of the gravity-driven convection with side heating, Rayleigh-Bernard convection with rigid and free surfaces, and similar types of the Marangoni convection should be firstly studied. A fragment of the solution of the problem on thermocapillary convection in horizontal layer during bottom heating (Marangoni instability) presented in Fig. 1. The onset of Marangoni convection after the loss of hydrostatic equilibrium stability and formation of the steady-state regime is shown for the classical Pearson problem with zero body force [3]. The field of stream function (roll structure) is on the top and isotherms of thermocapillary convection are below. On the right side the temporal evolution of the maximum of stream function is shown. A fragment of Menu of the computer system COMGA_W is shown on the left side. One can see here a title of the problem and items inside the "Problem category", which characterizes only a given problem: parameters Ma, Pr, region L/H, body force (g=0 in this case), and type of initial conditions.

Study all aspects of the problem with output the information in real time make it possible to use this system (together with interface of the input information, library of the problems, physical properties, references of the related papers etc.) as a computer laboratory. The students can study most of the elementary convection problems in real-time calculation during the tutorial process. Research works related to unsolved classical problems may be carried out in the end of this part of education. As an example of the bachelor degree work the result of analysis of temporal bound of the onset of gravity-driven convection in a horizontal layer with bottom heating is shown in [4].

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Following [1] a special version of this system for the applications in microgravity environment was developed. The Navier - Stokes equations for two-dimensional Cartesian coordinates in the Boussinesq approach is used with account of body forces in microgravity environment. The definitions of quasi-steady and vibratory forces are presented in [5].

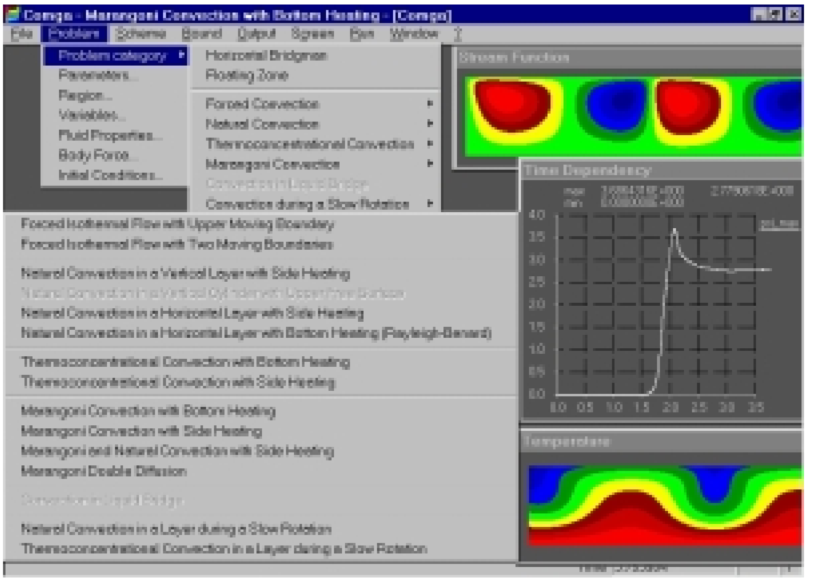

Fig. 1. Example of the benchmark problem of the onset of Marangoni convection in a layer with free surface and bottom heating. Menu of the basic part of the computer laboratory.

EDUCATION IN FLUID DYNAMICS & HEAT TRANSFER IN CZOCHRALSKI MODEL

Last part of the paper illustrates the process of studying of the hydrodynamical (idealized) Czochralski model, which presents a nonlinear multi-parametrical hydrodynamic system with wide range values of governing parameters (Rayleigh, Marangoni, Prandtl, Reynolds numbers, aspect ratio, initial and boundary conditions). The COMGA_W is a full Windows application with friendly interface, which makes it possible to change all of them. General characteristics of the flow and temperature fields and heat/mass transfer as well as local and average Nu numbers, temperature profiles are possible to visualize. For the first tutorial, the simplest benchmark configuration [6] is used. URL Appendix http://www.ipmnet.ru/~yarem/paper3 contains three elementary examples of the unsteady temperature fields behavior for the thermal diffusion processes with different initial conditions and boundary conditions on the melt surface for a given geometry and two elementary examples of the buoyancy-driven convection with low and high Pr numbers, which show the role of the boundary conditions and melt properties in the change of mechanism of convective instability and temperature oscillation in the melt.

CONCLUSIONS

A plan of education and tutorials for basic convective heat/mass transfer processes and applications on the basis of the Navier-Stokes equation (the Boussinesq approach) is presented. They were used during 1998-2001 for the preparing bachelor and master works in Moscow Institute of Physics and Technology. The education process and tutorial include:

- thermal diffusion processes and equilibrim of the hydrostatic stability,
- classical problems of the natural, forced convection,
- convection problem in microgravity, including realistic microgravity environment,
- ground-based melt flow in Bridgman and Czochralki models.

One can find free version of COMGA_W system on URL http://www.ipmnet.ru/~ermakov/comga/download_e.php.

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