THE SURFACE DEFORMATION EFFECT IN THE PROCESS OF ANOMALOUS THERMO-VISCOUS LIQUID FLOW

Victor Kireev[*,**], Said Urmancheev[*,**a)] & Iskander Akhatov[*,***]
[*]*Center for Micro- and Nanoscale Dynamics of Dispersed Systems, Bashkir State University, Ufa, Russia*
[**]*Institute of Mechanics, Ufa Branch of Russian Academy of Sciences, Ufa, Russia*
[***]*Department of Mechanical Engineering, North Dakota State University, Fargo, ND, USA*

Summary In this work there is a research of a convective flow of anomalous thermo-viscous liquid in a flat channel with specific heat exchange on its walls. A mathematical model of the process is based on the Navier-Stocks generalized equation. According to the Bacon&Fanelli data for sulfur [1], non-monotonous dependence of viscosity on temperature was taken.

INTRODUCTION

Dynamics of thermo-viscous media is determined by interaction of fluid flows with a thermal field. As a rule in classical problems physical parameters, including viscosity, are accepted as constant. The temperature dependence of viscosity peculiar to all liquids gets special significance for the study of the flow of liquid mediums in intensive heat exchange and at large temperature falls that is very important for study of a flow of molten metals, polymer solutions and natural lava. In the scientific literature there are works on hydrodynamics of thermo-viscous medium with various kinds of monotonically decreasing temperature dependences of viscosity. Besides, some substances, capable for polymerization in a liquid state and de-polymerization at a certain temperature interval, can have non-monotone temperature dependence on viscosity. Spacemen of such substances are liquid sulfur, phosphorus and organic compounds. The study of the flow features of thermo-viscous systems having anomalous properties is of great interest for an account and prediction of spreading parameters of high-sulfur magma layers. It is important in technological processes of sulfur utilization at sulfury petroleum refining and for efficiency increase of methylcellulose solutions use as baffling reagents for increase of enhanced oil recovery.

MATHEMATICAL MODEL

Let's consider a flow of anomalous thermo-viscous liquid in a flat channel with a fixed pressure drop Δp. The length of the channel is marked as L, and its width as h. Axes Ox of rectangular Cartesian co-ordinates shall be directed parallel to the walls of the channel. The center shall be located in the left lower angle of the channel. Then, equations set of a mathematical model consisting of equations of continuity, movement and heat penetration, for components of vector of velocity u and v, pressure p and temperature T can be noted as:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0,$$

$$\frac{\partial u}{\partial t}+\frac{\partial}{\partial x}\left(u^2\right)+\frac{\partial}{\partial y}\left(uv-\frac{1}{\mathrm{Re}}\left(1+A\nu(T)\right)\frac{\partial u}{\partial y}\right)=-\varepsilon^2\mathrm{Eu}\,\frac{\partial p}{\partial x},$$

$$\frac{\partial v}{\partial t}+\frac{\partial}{\partial x}\left(uv\right)+\frac{\partial}{\partial y}\left(v^2-\frac{1}{\mathrm{Re}}\left(1+A\nu(T)\right)\frac{\partial v}{\partial y}\right)=-\mathrm{Eu}\,\frac{\partial p}{\partial y}+\frac{1}{\mathrm{Re}}A\nu'(T)\left(\frac{\partial T}{\partial x}\frac{\partial u}{\partial y}+\frac{\partial T}{\partial y}\frac{\partial v}{\partial y}\right)+\frac{1}{\mathrm{Fr}},$$

$$\frac{\partial T}{\partial t}+\frac{\partial}{\partial x}\left(uT\right)+\frac{\partial}{\partial y}\left(vT-\frac{1}{\mathrm{Pe}}\frac{\lambda(T)}{c_P(T)}\frac{\partial T}{\partial y}\right)=\frac{A}{\mathrm{Re}}\mathrm{Ek}\left(\nu(T)+\frac{1}{A}\right)\left(\frac{\partial u}{\partial y}\right)^2+\frac{1}{\mathrm{Pe}}\lambda(T)c_P'(T)\left(\frac{\partial T}{\partial y}\right),$$

where Re, Eu, Fr, Pe – dimensionless simulation criterions – Reynolds, Euler, Frud, Peclet and Eckert numbers; $\alpha_{\max}$ – thermal diffusivity; $\nu=\nu(T)$ – kinematic viscosity, $\lambda=\lambda(T)$ – thermal conductivity, $c_P=c_P(T)$ – factor of a thermal capacity with constant pressure; A – parameter characterizing a degree of temperature dependence on viscosity.
Boundary conditions correspond to the liquid flow in the rectangular channel. Suppose that at the initial moment the liquid in the channel doesn't move and has the temperature equal to the temperature of the channel walls. Suppose as well, that in the initial moment the pressure distribution has a linear character.

NUMERICAL RESULTS

The numerical solutions were obtained with the algorithm SIMPLE [2]. The results of the research are given as isolines of parameters, defining the action of thermohydrodynamic system.

a) Corresponding author. Email: said@anrb.ru

We deal here with high-viscous areas limited in space [3, 4]. At an intensive heat exchange the structure of high-viscous area is in a shape of horseshoe and doesn't touch the walls of the channel. On the other hand, the decrease of heat exchanges intensity results in a flatter isolines system of high-viscous area crossing the walls of the channel. It results in an increase of hydraulic resistance of the channel and, accordingly, in a decrease of consumption.

In Fig. 1 the calculation results of liquid sulfur velocity field in the channel with width to length relation h/L = 100 and intensity of heat exchange characterized by Nusselt number Nu = 2 are given.

a) b)

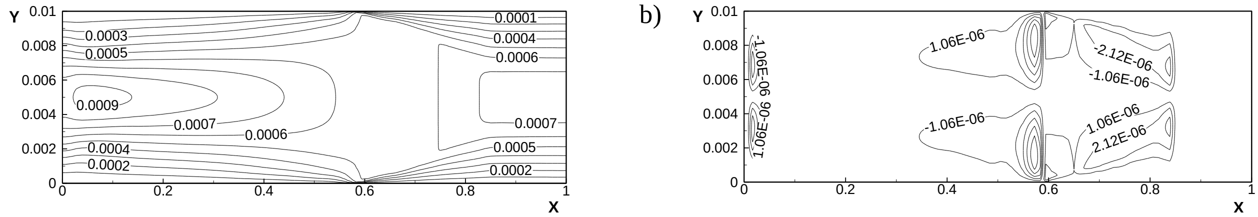

Fig. 1. Steady-state distributions of longitudinal (a) and transversal (b) components of the velocity field (Nu = 2)

During the research it has been found that a flow of liquid sulfur is determined by the character of liquid negotiation of a zone with high viscosity – "a viscous barrier" - a stable structure located in space. The field of values of a longitudinal velocity is characterized by a zone with a rather high velocity. Its position in the internal part of a viscous barrier is an evidence of flow deflecting properties. The flow is also characterized by a transversal component of the velocity field in boundary areas of a viscous barrier. As a whole, the flow has essentially non-Poiseuille's character. Only after full cooling of the liquid the field of velocities acquires distribution, characteristic of Poiseuille's flow. Thus, the intensity of heat exchange largely determines flow hydrodynamic parameters of anomalous thermo-viscous mediums, including consumption.

Solving the problem of stratified flow of viscous and anomalous thermo-viscous liquids with the use of method VOF [5] the intensity of heat exchange on the walls of the channel has proved to be a factor, defining the size and form of the liquid boundary (Fig. 2). It is clear that at more intensive heat exchange (Fig 2-a) viscosity isolines make "a viscous barrier" with precisely outlined localization in the form of a torch. A decrease of heat exchange (Fig. 2-b) results in diffusion of "the viscous barrier" and finally in its full disappearance when Nu < 1. It occurs with the stratum boundary of anomalous thermo-viscous liquid. If at the intensive heat exchange a "threshold" is located in the streamline area of "a viscous barrier", at decreasing the Nusselt number a "threshold" becomes flatter. At Nu = 1 a stratum boundary of anomalous thermo-viscous liquid will be a direct line.

a) b)

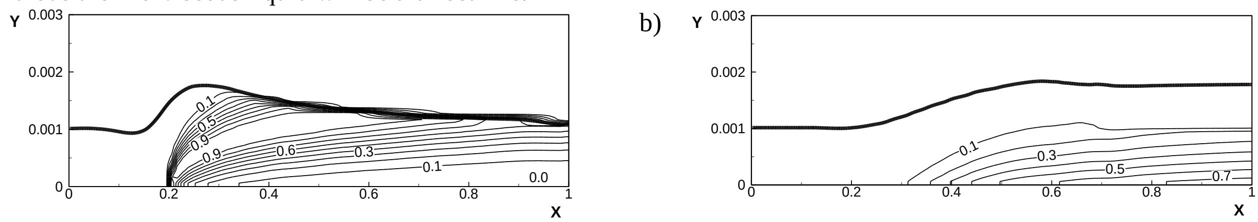

Fig.2. A steady-state position of the boundary and the viscosity isolines: a) Nu = 10; b) Nu = 2

CONCLUSIONS

It is necessary to mark taking the results as basis, that in liquids with essential temperature dependence on viscosity, especially in case of non-monotone dependence, there is a formation of thermo-viscous patterns the occurrence of which is connected with the interaction of a flow with a heat field. At that the main characteristics of the flow can considerably be changed both quantitatively and qualitatively. Thus, the research of the thermo-viscous structures seems to be an important object at solving of thermo- and hydrodynamics problems.

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