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The Longitudinal Flow of Oil and Petroleum Products in the Channels and Pipes

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A model associated fluid flow and heat transfer of longitudinal flows of oil in pipes and channelsis considered. The model is based on the existence of a solid core or two such cores and fluid flow part. The flow is considered for the fluid part of Newtonian fluid, for power-law fluidsand for a Newtonian fluid in a turbulent regime. The amendments related to the nonlongitudinal to the flow equations of fluid dynamics and heat transfer, and their impact on core characteristics arediscussed.

1. Introduction

The study of the process of oil transportation is a quite actual problem. The huge quantities of oil are moved through oil pipelines. Oil and oil products are moved in significant quantities and in-plant pipelines. And in both cases oil and oil products are subjected to thermal stress, which leads to their cooling and heating. While oil and oil products undergo changes in their physical properties. In the fullness of these changes can be understood in the case that oil not be considered as a homogeneous fluid, but as a heterogeneous multiphase mixture. The original models such a mixture can be models of suspensions, liquid emulsions and gas. In these models the rheological characteristics of the mixtures depend on the volumetric concentrations of the components of the mixture. This is true in the case of low-inertia flows. In the case where the inertia of the dispersed phase becomes significant, should be taken into account and the mass concentration of the mixture components. This is true both in isothermal and non-isothermal conditions of the flow, however, in the latter case, in the petroleum and petroleum products may cause the formation or disappearance of individual phases. Namely, upon cooling may form a solid phase and when heated – liquid phase. Typical is this situation in which oil or oil product is heated or cooled by the boundaries of the flow domain. If heating is implemented the process flow represents a flow of a heterogeneous mixture of a fluid part, which is adjacent to the boundaries, and in the middle of the flow solid core. If you implement cooling the solid core is adjacent to the boundaries, and in the middle of current is flowing. Viscous flow located outside of areas occupied by the solid core represents a flow of a heterogeneous mixture the dispersed phase which is solid particles, droplets and gas bubbles. For particles and droplets, their concentration can often be considered constant. For gases, this assumption cannot be considered true, since the pressure along the flow always changes so that the proportion of dissolved gases is also changing.
The problem of creating model of flow and heat transfer of oil and oil products, which takes into account their multi-phase, melting and solidification, is extremely actual. The current model is single-phase Newtonian and, in principle, cannot take into account specified features of flow and heat transfer.

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2. Formulation of the problem

In the present work an attempt is made to consider the flowing of oil and petroleum products in a pipe or channel taking into account the heating or cooling across borders, in which a poly-phase fluid part and a solid core are. Both parts of currents can change their sizes and properties.
As appropriate ones the model of Bingham flow with variable viscosity and the yield strength are described. This model is generalized to the non-isothermal case. Heat transfer and hydrodynamics are considered as interrelated so that the hydrodynamic model is included in the model of heat transfer through the boundary coordinates of the solid core. The coupling of the hydrodynamics and heat transfer is considered in one-dimensional approximation. All the main characteristics of the flow are considered to be dependent on the longitudinal coordinate. All hydrodynamic parameters such as flow rate, energy dissipation are considered to be dependent on the velocities of the boundaries of the pipe or channel boundaries and a solid core. The model of heat transfer is three-temperature: separately for core temperature and fluid temperatures. Changing the boundaries of the solid core treated as a phase transition which is accompanied by the release and absorption of heat, which should be taken into account in the total heat balance. When modeling of heat transfer on the assumption of unregulated flow. This means that at the boundaries the fluid parts of the flow thermal boundary layers exist. On these boundaries is considered to be a running Newton's law for heat transfer. This means that the calculated heat fluxes can be tested using the expressions for heat transfer coefficients. Characteristics such as heat capacity, density and thermal conductivity, are included in the heat transfer coefficients should be adapted to the case of heterogeneous mixtures.

3. Main part

The heat transfer model represents a system of three first order equations for the temperatures of the solid core and fluid parts. For concreteness the case of heat flow from the borders is considered, when a solid core is located inside of flow. The system of equations of the longitudinal current has the following general form:

$$\begin{aligned}
\rho C_p \dot{V}^+ \frac{dT^+}{dx} &= \alpha^+(h)[T(h) - T^+] + \alpha_{k\Gamma}^+(T^+ - T_{k\Gamma}^+) + \dot{e}^+\Sigma^+ + \xi_w^+ \cdot r \cdot \frac{d\Gamma^+}{dx} \\
\rho C_p \dot{V}^- \frac{dT^-}{dx} &= \alpha^-(-h)[T(-h) - T^-] + \alpha_{k\Gamma}^-(T^- - T_{k\Gamma}^-) + \dot{e}^-\Sigma^- + \xi_w^- \cdot r \cdot \frac{d\Gamma^-}{dx} \\
\rho_k C_{pk} \dot{V}_k \frac{dT_k}{dx} &= \alpha_{k\Gamma}^+ \cdot (T_{k\Gamma}^+ - T_k) + \alpha_{k\Gamma}^- \cdot (T_{k\Gamma}^- - T_k) + \xi_k^+ \cdot r \cdot \frac{d\Gamma^+}{dx} + \xi_k^- \cdot r \cdot \frac{d\Gamma^-}{dx}
\end{aligned} \tag{1}$$

in which ρ and ρ_k – is the density of the substance in the fluid part and solid core, respectively, kg/m^3; C_p and C_{pk} – is the heat capacity of the substance in the fluid part and solid core, respectively, J/kg·grad; $\dot{V}^\pm$, $\dot{V}_k$ – cost substances in the fluid part above and below the solid core and the solid core, respectively, m^3/s; $T^\pm$, T_k – are the average of the cross – section of the flow temperature of a fluid part and a solid core, deg; $\alpha^\pm(\pm h)$ – the heat transfer coefficients at the boundaries of the flow area, J/s·m·grad; $T_{k\Gamma}^\pm$ – temperature limits of the solid core, grad; r – specific heat of melting and solidifying substances, solid core, J/kg·grad; $G^\pm$ – coordinates of the boundaries of the solid core, m; $\xi_k^\pm, \xi_w^\pm$ – fraction of heat that is allocated or absorption, get into a solid core and a fluid part, respectively, dimensionless; x – longitudinal coordinate of the pipe or channel, m; h – the width of the pipe or channel, m; $\dot{e}^\pm$ – specific energy dissipation due to the viscous friction, J/s·m^3; $\Sigma^\pm$ – square cross sections of a fluid part, m^2.
Schemes of flow and heat transfer are presented in Figures 1a and 1b, 2a and 2b. The system of equations (1) corresponds to Figure 1a, 2a, Figure 1b, 2b corresponds to the scheme of cooling of the flow with formation of solid nuclei at the borders of the flow.
To estimate $\xi_k^\pm$and$\xi_w^\pm$use the following hypothesis:

$$\xi_w^\pm + \xi_k^\pm = 1\,; \quad \frac{\xi_w^\pm}{\xi_k^\pm} = \frac{\alpha_{kG}^\pm \cdot (T_{kG}^\pm - T^\pm)}{(\lambda_k/G^\pm) \cdot (T_{kG}^+ - T_{kG}^-)}\,. \tag{2}$$

Writing equations of heat transfer in the form of (1) literally means in directions transverse coordinate of the second flow space extends to 1 m.
The system of equations of heat transfer for cooling of flow corresponding to Figure 1b, 2b may be by analogy with Eq. (1) written in the following form:

$$\begin{aligned}
\rho_k C_{pk} \dot{V}_k^+ \frac{dT_k^+}{dx} &= \alpha_{k\Gamma_1}^+ \cdot \left[T(h) - T_{k\Gamma_1}^+\right] - \alpha_{k\Gamma_1}^- \cdot \left(T - T_{k\Gamma_1}^-\right) + \xi_k^+ \cdot r \cdot \frac{d\Gamma_1^-}{dx} \\
\rho_k C_{pk} \dot{V}_k^- \frac{dT_k^-}{dx} &= \alpha_{k\Gamma_2}^+ \cdot \left[T(-h) - T_{k\Gamma_2}^-\right] - \alpha_{k\Gamma_2}^- \cdot \left(T - T_{k\Gamma_2}^+\right) + \xi_k^- \cdot r \cdot \frac{d\Gamma_2^+}{dx} \\
\rho C_p \frac{dT}{dx} &= \alpha_{k\Gamma_1}^- \cdot \left(T_{k\Gamma_1} - T\right) + \alpha_{k\Gamma_2}^+ \cdot \left(T_{k\Gamma_2} - T\right) + \xi_k^- \cdot r \cdot \frac{d\Gamma_1^-}{dx} + \xi_k \cdot r \cdot \frac{d\Gamma_2^+}{dx} + \dot{e} \cdot \Sigma
\end{aligned} \tag{3}$$

in which axiliary generally follows that which refers to Eq(1) with the changes that now two solid cores; and they are assigned to the indexes "1" and "2" and fluid part – one. Eq(3) describes the flow with G_1^- and G_2^+ is regular, since they are limited by the boundaries of the pipe or channel.

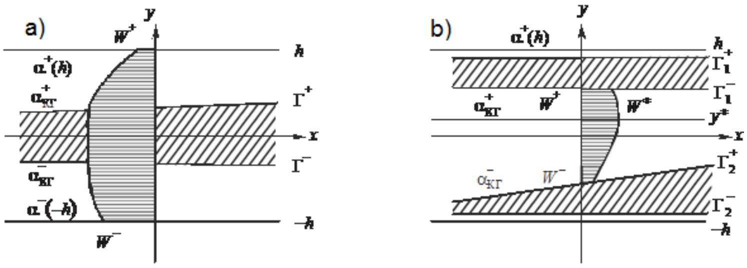

Figure 1: Viscous flow in a pipe or channel: speed

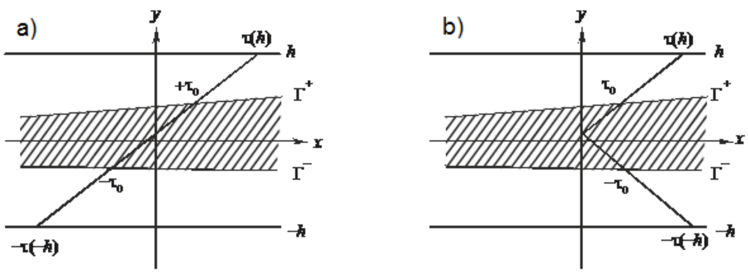

Figure2: Viscous flow in a pipe or channel: effort

The system of Eq. (1) can be reduced to a system of two equations for the temperatures $T^{\pm}$, if the process of heat transfer in the solid core is considered, pure conduction, which is distributed across the solid core and demolished in the longitudinal direction with the speed of a solid core. The corresponding equations are written in the following form:

$$\rho_k C_{pk} \dot{V}_k \frac{dT_k}{dx} = \dot{Q}_k \; ; \quad -\lambda_k \frac{dT_k}{dy}\bigg|_{\Gamma^+} = \alpha_{k\Gamma}^+ (T_{k\Gamma}^+ - T^+) \; ;$$
$$\lambda_k \frac{d^2 T_k}{dy^2} = \dot{Q}_k \; ; \qquad -\lambda_k \frac{dT_k}{dy}\bigg|_{\Gamma^-} = \alpha_{k\Gamma}^- (T_{k\Gamma}^- - T^-) \; . \tag{4}$$

Solving Eq. (4) for unknown values $T_{k\Gamma}^{\pm}$produces the following expressions:

$$T_{k\Gamma}^+ = \frac{\Delta}{2} \cdot \frac{(\alpha_\Gamma^- + \alpha_\lambda)}{\alpha_\Gamma^+ \alpha_\Gamma^- + \alpha_\lambda(\alpha_\Gamma^+ - \alpha_\Gamma^-)} \cdot \dot{Q}_k + \frac{\alpha_\Gamma^+(\alpha_\Gamma^- + \alpha_\lambda)}{\alpha_\Gamma^+ \alpha_\Gamma^- + \alpha_\lambda(\alpha_\Gamma^+ - \alpha_\Gamma^-)} \cdot T^+ - \frac{\alpha_\Gamma^- \cdot \alpha_\lambda}{\alpha_\Gamma^+ \alpha_\Gamma^- + \alpha_\lambda(\alpha_\Gamma^+ - \alpha_\Gamma^-)} \cdot T^- \; ;$$
$$T_{k\Gamma}^- = \frac{\Delta}{2} \cdot \frac{(-\alpha_\Gamma^+ + \alpha_\lambda)}{\alpha_\Gamma^+ \alpha_\Gamma^- + \alpha_\lambda(\alpha_\Gamma^+ - \alpha_\Gamma^-)} \cdot \dot{Q}_k + \frac{\alpha_\Gamma^+ \alpha_\lambda}{\alpha_\Gamma^+ \alpha_\Gamma^- + \alpha_\lambda(\alpha_\Gamma^+ - \alpha_\Gamma^-)} \cdot T^+ - \frac{\alpha_\Gamma^-(\alpha_\Gamma^+ - \alpha)}{\alpha_\Gamma^+ \alpha_\Gamma^- + \alpha_\lambda(\alpha_\Gamma^+ - \alpha_\Gamma^-)} \cdot T^-; \tag{5}$$
$$\alpha_\lambda = \frac{\lambda_k}{\Delta} \; ; \quad \Delta = \Gamma^+ - \Gamma^- .$$

Substitution of Eq(5) in Eq(1) allows the third equation of system in Eq(1) only be expressed through the temperature $T^{\pm}$ so that the temperature T_k is obtained the following equation:

$$\rho_k C_{pk} \dot{V}_k \frac{dT_k}{dx} = \frac{\alpha_\Gamma^+(1 - a) - \alpha_\Gamma^- a_2}{1 + \alpha_\Gamma^+ b_1 + \alpha_\Gamma^- b_2} \cdot T^+ + \frac{\alpha_\Gamma^-(1 - c_1) + \alpha_\Gamma^- c_2}{1 + \alpha_\Gamma^+ b_1 + \alpha_\Gamma^- b_2} \cdot T^- + \xi_k^+ r \frac{d\Gamma^+}{dx} + \xi_k^- r \frac{d\Gamma^-}{dx} \tag{6}$$

in which to reduce the recording introduced the following designations:

$$a_1 = \frac{\alpha_\Gamma^+(\alpha_\Gamma^- + \alpha_\lambda)}{\alpha_\Gamma^+ \alpha_\Gamma^- + \alpha_\lambda(\alpha_\Gamma^+ - \alpha_\Gamma^-)} \; ; \quad b_1 = \frac{\Delta}{2} \cdot \frac{\alpha_\Gamma^- + 2\alpha_\lambda}{\alpha_\Gamma^+ \alpha_\Gamma^- + \alpha_\lambda(\alpha_\Gamma^+ - \alpha_\Gamma^-)} \; ;$$
$$a_2 = \frac{\alpha_\Gamma^+ \alpha_\Gamma^-}{\alpha_\Gamma^+ \alpha_\Gamma^- + \alpha_\lambda(\alpha_\Gamma^+ - \alpha_\Gamma^-)} \; ; \quad b_2 = \frac{\Delta}{2} \cdot \frac{-\alpha_\Gamma^+ + 2\alpha_\lambda}{\alpha_\Gamma^+ \alpha_\Gamma^- + \alpha_\lambda(\alpha_\Gamma^+ - \alpha_\Gamma^-)} \; ; \tag{7}$$
$$c_1 = \frac{-\alpha_\Gamma^+ \cdot \alpha_\lambda}{\alpha_\Gamma^+ \alpha_\Gamma^- + \alpha_\lambda(\alpha_\Gamma^+ - \alpha_\Gamma^-)} \; ; \quad c_2 = \frac{\alpha_\Gamma^-(\alpha_\Gamma^+ - \alpha_\Gamma^-)}{\alpha_\Gamma^+ \alpha_\Gamma^- + \alpha_\lambda(\alpha_\Gamma^+ - \alpha_\Gamma^-)} \; .$$

The heat transfer coefficients, which in all the above formulas and the expressions in the case of laminar fluid part can be written as follows:

$$\alpha^{\pm}(\pm h)=\frac{\lambda}{\left(\pm h\mp\Gamma^{\pm}\right)}\cdot Nu(\pm h)\,;\quad \alpha_{k\Gamma}^{\pm}\left(\Gamma^{\pm}\right)=\frac{\lambda}{\left(\pm h\mp\Gamma^{\pm}\right)}\cdot Nu\left(\Gamma^{\pm}\right);$$

$$Nu(\pm h)=\frac{2^{2/3}}{3}\cdot\frac{\left(\pm h\mp\Gamma^{\pm}\right)}{x^{1/3}}\cdot\left[\frac{1}{\chi}\cdot\frac{\partial\vartheta^{\pm}}{\partial\left(\pm h\mp\Gamma^{\pm}\right)}\right]^{1/3}\;; \tag{8}$$

$$Nu\left(\Gamma^{\pm}\right)=\frac{2^{3}}{3\cdot 5}\cdot\frac{\left(\pm h\mp\Gamma^{\pm}\right)}{x^{1/4}}\cdot\left[\frac{1}{\chi}\cdot\frac{\partial^{2}\vartheta^{\pm}}{\partial\left(y-\Gamma^{\pm}\right)^{2}}\right]^{1/4}\;;\quad \chi=\frac{\lambda}{\rho C_{p}}\,.$$

where $\vartheta^{\pm}$– velocity of the fluid parts that should be determined from the equations of hydrodynamics model, m/s.

The dependence of Nusselt number on longitudinal coordinate and the derivative of the velocity have a standard view on the boundaries of the pipe or channel. On the borders of a solid nucleus this dependence changes and becomes weaker. The reason is that at the boundaries of the solid core becomes zero the first derivative of speed. Therefore, the decomposition of the expression for the velocity of the flow close to the nucleus begins with the second derivative and the velocity in the vicinity of the solid core is proportional to the square of the distance to the boundaries of the solid core. A similar change of speed in the vicinity of the boundaries of the pipe or channel is proportional to the first power of the distance.

In the case where the current fluid is in the turbulent regime, the expressions for the Nusselt number at the boundaries of the pipe or channel and the kernel can be written as follows:

$$N(\pm h)=constRe^{\pm 0.8}\cdot Pr^{0.5}\cdot\left[\frac{x}{2h\cdot Re^{\pm 1/4}}\right]^{1/5}\;;\qquad Re^{\pm}=\frac{\rho\bar{\vartheta}^{\pm}\left(\pm h\mp\Gamma^{\pm}\right)}{\mu}\;;$$

$$N\left(\Gamma^{\pm}\right)=constRe^{\pm 0.8-\varepsilon_{1}}\cdot Pr^{0.4-\varepsilon_{2}}\cdot\left[\frac{x}{2h\cdot Re^{\pm 1/4}}\right]^{1/5-\varepsilon_{3}}\;;\qquad Pr=\frac{\mu C_{p}}{\lambda}\,. \tag{9}$$

where const~10^{-2}; ε_1, ε_2, ε_3 – constant, determined from data of experience, dimensionless; $\bar{\vartheta}^{\pm}$ – average velocity of a fluid part, m/s.

For the system of equations remains valid everything said in relation to the system of equations in Eq. (1) with the only changes caused by the presence of two solid cores and one area of strength, namely: instead of a single set of equations and boundary conditions in Eq(4) will be two. Instead of one Eq(6) will be two. Size T_{kG}^{+}should be attributed to the lower border of the upper nucleus, and the magnitude T_{kG}^{-}should be attributed to the upper boundary of the lower core, etc. there are two possible different cases. In the first from them upper bound of upper core and the lower boundary of the bottom core adjoin the borders of a pipe or channel. In this case, will follow the terms $T_k^{+}(+h)=T(h)$and$T_k^{+}(-h)=T(-h)$, but only for the lower boundary of the upper core will remain the second boundary condition on G^{-} from Eq(4), the first boundary condition on G^{+} from Eq. Eg(4). In this case, the speed of movement of the upper and lower cores should be considered equal to the corresponding velocities of the boundaries of the pipe or channel. In the second case, there may be a narrow border flows between the solid nuclei and the boundaries of the pipe or channel. This situation is equivalent to the hard cores slide along the borders. In this case, speed and temperature limits of the solid cores do not coincide with speeds and temperatures of the boundaries of the pipe or channel. Such currents can be considered as a set of two parallel longitudinal flows with heat transfer of a type that to the equations are related Eq(1).

The speed of the lower part of the upstream solid core inside should smoothly be interfaced with the speed of the upper part of the downstream solid core inside. Heat exchange in such a "doubled" the flow is described by the doubled system of equations of type Eq(1) with all subsequent expressions. The condition of thinness of the upper part of the upper reaches and the lower part of the bottom can be performed, assuming that the thresholds that yield the upper and lower currents depend on friction, i.e. the shear rate. In narrow they are great layers so that the thresholds of fluidity at the boundaries of the pipe or channel become very small. In this case value $(h-\Gamma^{+})$ and $(-h-\Gamma^{-})$ are small compared to h. To find the temperature $T_{k\Gamma}^{\pm}$ in the upper and lower currents should be used twice a set of equations and boundary conditions (4), one for the upper and lower currents. Due to the clarity of the issue and complexity of the relevant results and also their similarity with the results Egs(1), (2), (4)÷(9) they are not given here.

The results represented by Eqs(1)÷(9), form a model of heat transfer in viscous-plastic flow with one or two solid cores. The left parts of Eqs(1) and (3) contain the product of the magnitudes of the costs of fluid and solid parts of the flow on the longitudinal gradient of average temperatures. This means that in the derivation have been omitted all correlations between the velocities and derivatives of the temperatures on the x and y coordinates. The convective part of the equation of heat transfer can always be represented as follows:

$$\vartheta_x \frac{\partial T}{\partial x} + \vartheta_y \frac{\partial T}{\partial y} = \dot{V} \frac{\partial \bar{T}}{\partial x} \cdot R_1 \cdot R_2 \; ; \quad \begin{matrix} \dot{V} = \dot{V}^{\pm}, \dot{V}_k \; ; \\ \bar{T} = T^{\pm}, T_k \; ; \end{matrix} \tag{10}$$

where $\dot{V}$ – is flow rate, m^3/s; $[T - T(x,y)]$ – is the temperature at the point with coordinates x, y, grad; $\bar{T}$ – is the average section temperature, grad. The value ofR_1 andR_2can be qualitatively evaluated with the help of hydrodynamic and heat transfer data. Such estimates lead to the following expressions for R_1, R_2:

$$R_1 = 1 + \frac{2\left[T(\pm h) - T_{k\Gamma}^{\pm}\right]}{T(\pm h) + T_{k\Gamma}^{\pm} - 2T_{нач}};$$

$$R_2 = 1 + \frac{2\left[T(\pm h) - T_{k\Gamma}^{\pm}\right]}{T(\pm h) + T_{k\Gamma}^{\pm}} + 2\frac{W^{\pm} - \vartheta_k}{W^{\pm} + \vartheta_k} + 2\frac{T(\pm h) - T_{k\Gamma}^{\pm}}{T(\pm h) + T_{k\Gamma}^{\pm}} \cdot 2\frac{W^{\pm} - \vartheta_k}{W^{\pm} + \vartheta_k} \; , \tag{11}$$

where$T_{initial}$ – temperature, that average initial cross-section$x = 0$, grad; ϑ_k – speed hard core m/s. The expression (11) is the result of simple estimates derived temperature and velocities included in the left part of (10).

The system of Eq(1) and the expressions for heat transfer coefficients in addition to the temperatures$T^{\pm}, T_k$such hydrodynamic values as$G^{\pm}$, ϑ_k, $\vartheta^{\pm}(x,y)$, $\dot{V}^{\pm}$, $\dot{V}_k$. To define them one should use the hydrodynamic model of flow. This model is based on the Bingham model the flow because the latter allows for considerable generalization. The Bingham model consists of one equation of equilibrium in terms of stresses; the pressure dependence on longitudinal coordinates is linear; from transverse coordinate depends on only the speed; the border nuclei have constant values; the presence of moving boundaries of the pipe or channel shifts the solid core relative to the middle region of the flow without changing its thickness.

4. Discussion of the results

The main result of this study is the model of coupling the heat transfer and hydrodynamics of the oil flow as a multiphase mixture, which may include a solid core based on the generalization of the model of longitudinal heat transfer model and Bingham flow with Newtonian fluid part. The longitudinal heat transfer model covers the cases of the location of the solid core inside the current and two solid cores are separated by internal currents and currents separating the core from the boundaries of the pipe or channel. The latter can be stationary or moving. Different number and arrangement of the rigid cores is in the cases of the flow of oil from the heating or cooling that is carried out across borders. The heat transfer model takes into account emissivity and absorption of heat when the change of boundaries of the nuclei. It is believed that the dissipation in these processes are distributed in the transverse direction is inversely proportional to the thermal resistances and concentrated on the surfaces of the cores. The model of heat exchange is a system of one-dimensional equations for the temperature of the fluid cores and threads; each thread and each core have its temperature. Temperature determined by the heat transfer model is the average of the corresponding cross sections. In the heat transfer model includes heat transfer coefficients, related to the limits of the cores and the pipe or channel. In the case of laminar flow at the boundaries of the cores of the heat transfer coefficient depends on the second derivative of the flow velocity in degree one quarter and on the borders of the pipe or channel has a standard look. In the equations the thermal model consists of flow characteristics such as cost the first and second derivatives of the flow rates taken at the boundaries of the solid cores and the pipe or channel the boundaries of the nuclei. All these values should be determined from the hydrodynamic model. The latter is a generalization of the Bingham model to the cases of power-law flow and turbulent fluids. The latter can be considered as such the viscosity of which depends on the coordinates and shear rate. All hydrodynamic characteristics appearing in the model of heat exchange are determined using the coordinates of the boundaries of the solid cores. The thickness of the cores and their locations depend on the difference of the velocities of the boundaries of the pipe or channel. The fact, that all hydrodynamic characteristics are defined by the boundaries of the nuclei, allowing to reducing the hydrodynamic model to the system of equations for these boundaries. For the equations of heat transfer proposed update, due to the fact that the model does not take into account the presence of correlations between derivatives of temperature and velocity components. The source of such correlations is the heat transfer in the transverse direction. For the equations of hydrodynamic models are also offered clarification, which allows to reduce the full two-dimensional problem to one-dimensional flow so that the components are clarifying amendments to a strictly longitudinal course of the degree of smallness of the ratio of longitudinal and peppered in size to the second, inclusive. The presented in the present work model has a number of limitations, chief among which are the following. In the thermal model for average section temperature T±,Tk is solved strictly longitudinal task. But since this task requires knowledge of the temperatures at the boundaries of the solid core, we have to solve for the temperature in the core of cross-task that a few logic breaks. Refining the model associated with the correlations of the convective terms is of a qualitative nature and is rude. A waiver from such refinement entails the necessity of solving the full three-temperature areal task. It is written in an almost fully applies to the refinement of the hydrodynamic model with the observation that this clarification is not rude, but occurs smallness relationship of the transverse and longitudinal dimensions of the pipe or channel. It should be noted that this clarification could be done with the decision of the transverse thermal problem in the solid core, but the price for that will be the transformation of the task to determine the core temperature of the problem with initial data in the boundary-value problem on an interval of finite length. Given the fact that the task of determining the temperatures of the fluid are the problems with the initial data, it is obvious they are incompatible in a logical sense. The following important assumption relates to the existence of thermal boundary layers. Essentially this means that the flow is not stable in the thermal sense. The rejection of this assumption leads to considerable complication based longitudinal velocity from transverse coordinates, complicates the equation to determine the boundaries of solid cores, greatly enhances the nonlinearity of the equations of the thermal model. The disadvantages of hydrodynamic models include the fact that the presence of two-phase fluid part on the level of abstraction presented only in relation to the viscosity of power-law fluid, but does not deal with such quantities as thermal conductivity and heat capacity. For the latter to take into account two-phase is not difficult because it is a cumulative characteristic of the mixture. A similar problem for the heat conductivity is much more complicated, requires special consideration for cases of suspensions, liquid emulsions and gas emulsion. The difficulty lies in the fact that emulsions contribution to the thermal conductivity of the mixture make a micro-scale of the flow inside the elements of the dispersed phase.

5. Conclusions

The presented in this manuscript the three-temperature heat-transfer model based on the viscous-plasticity generalization of the Bingham flow model in a pipe or channel, allows, in principle, to find the longitudinal distribution of temperatures. This model allows extension without change of its major provisions on a wide range of phenomena occurring in the flow of oil and oil products, namely: the melting and hardening, the change of the threshold yield stress, slip at the boundaries of the flow region, the viscosity change from the content of the dispersed phase.

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