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ABOUT ONE MODEL OF PUMPING OIL MIXTURE OF DIFFERENT VISCOSITIES THROUGH A SINGLE PIPELINE IN AN UNSTEADY THERMAL FIELD

Abstract. The paper discusses the calculation of the flow of oil mixture of different viscosity with decreasing temperature, produced under the action of the classification of loads with I-III types. Flows of the volume of oil mixture of different viscosity can be reduced as much as possible by desalination and separation of impurities.
Keywords: viscous oil, pumped liquid, pipeline, flow rate, differential equation, flow calculation.

Introduction. The study of the prospects of development of the oil refining industry on the example of the Western Kazakhstan oil features allows to determine one of the urgent problems of refining – a high percentage of paraffin-containing and high-sulfur oils. The presence of such impurities indicates a large percentage of high-viscosity oils, which in turn poses the task of analyzing the flow of oil through the pipeline, taking into account the increased viscosity of the medium. **The purpose of the study:** development of the most effective analysis of the model of pumping oil mixtures of different viscosity through a single pipeline in an unsteady thermal field, which allows the refining process to be facilitated with the most economical energy consumption.The considered model allows, in order to be economical and to benefit the region's ecology, to use certain conditions where it is advisable to pump any oil of different viscosity through a single pipeline in order to minimize the volume of the mixture depending on the flow regime of each of them under assumptions.

Methods. For analysis purposes, the following **methodological assumptions** are introduced:

- Mixing at the interface of pumped liquids is negligible, although the number of collisions between elements in the allocated volume is large, compared with the number of collisions of elements with a limiting surface volume, depending on the energy desiccation, flow velocity, distance from solid walls, the geometric shape of the filler cross section, the velocity of the free jet placed in the flow with a longitudinal direction.
- The pressure at the end section of the pipeline remains constant throughout the change of liquids, heavy liquid flows out along the lower tinder forming, the light rises along the upper forming at an unsteady temperature effect in the pipeline system.
- The splitting of the flow velocity allows to obtain a correct viscous solution in one main passage in the direction of flow, where the viscous friction stress is due to the molecular momentum transfer, and the viscosity coefficient of the mechanical system depends on the friction stress itself.
- There are some laminar sublayers between movements in the boundary layer and in the pipe, as a result of which the methods of warm and hydraulic pressure of the oil mixture and the transfer phenomenon make it possible to find the limiting amount of heat and mass according to the Euler integral theorem.

$$k_{in} - k_{out} = \sum(q_k + p_k),$$

where k_{in} – amount of inflowing liquids; k_{out} – amount of outflowing liquids; q_k – impulse of active forces; p_k – impulse of reactive forces.

Results. Under the above assumptions of the flow of petroleum liquids of different viscosities through a single pipeline under unsteady temperature field 80 °C ≥ T ≥ 30 °C can be represented as a mechanical-physical-mathematical model [1-3]:

$$\frac{\partial^2}{\partial x^2}\left[\varepsilon(x)\frac{\partial^2 w}{\partial x^2}\right] = {q_k}/{D}\,\lambda^2\frac{c\rho}{k}c(w)\frac{\partial w}{\partial t}, \tag{1}$$

where $\varepsilon(x)$ is the coefficient of liquid of the cross-sectional area of the tubular structure, depending on the temperature; k – coefficient of thermal conductivity,

$$q_k/D = \lambda_k\frac{N}{Q}\gamma^2\frac{1}{1+\lambda_k'\gamma^2}\left(\frac{h}{R}\right)^{5/2}\left(R/2\right) -$$

active external load (impulse) $c(w) = \beta$ – heat capacity per unit volume; k – coefficient of thermal conductivity; c – heat capacity; ρ – density. $W(x,t)$ – displacement function in OZ axis direction and

$$W(x,t) = W(x)T(t), \tag{2}$$

then

$$\frac{d^2}{dx^2}\left[\varepsilon(x)\frac{\partial^2 w}{\partial x^2}\right]\cdot T(t) = \frac{q_k}{D}\frac{c\rho}{k}\beta W(x)\frac{dT}{dt}, \tag{3}$$

where

$$\frac{\frac{d^2}{dx^2}\left[\varepsilon(x)\frac{\partial^2 w}{\partial x^2}\right]}{\frac{q_k}{D}\frac{c\rho}{k}\beta W(x)} = \frac{1}{T}\frac{dT}{dt}; \tag{4}$$

$$\frac{d^2}{dx^2}\left[\varepsilon(x)\frac{\partial^2 w}{\partial x^2}\right] = -\lambda^2\frac{q_k}{D}\frac{c\rho}{k}\beta W(x); \tag{5}$$

$$\left.\begin{array}{l}\frac{dT}{dt} + \lambda^2 T = 0, \frac{d^2T}{dt^2} + CO_4^2 T = \frac{Q}{a_0} \\ Q = \int_0^l q_k(x,t)W(x)dx, \lambda^2 = \frac{n\pi h}{L}\end{array}\right\}. \tag{6}$$

The ordinary differential equation (6) is easily solved, the expression of potential, kinetic energy is written and the Lagrange equation is involved, and the ordinary differential equation (5) is the Euler equation.

$$\left[\varepsilon(x)\frac{d^4W}{dx^4} + 2\varepsilon'(x)\frac{d^3W}{dx^3} + 2\varepsilon''(x)\frac{d^2W}{dx^2}\right] + aW = 0, \tag{7}$$

where $a = \frac{q_k}{D}\lambda^2\beta\frac{c\rho}{k}$.

In particular:

$$\varepsilon(x) = Dx^4. \tag{8}$$

Then

$$\left[x\frac{d^4W}{dx^4}+8x^3\frac{d^3W}{dx^3}+12x^2\frac{d^2W}{dx^2}\right]+aW=0. \tag{9}$$

The following cases are possible:

A) for 0 < a < 1, for example $a=\frac{3}{4}$, then ($a=\frac{q_k}{D}\lambda^2\beta\frac{c\rho}{k}$)

$$W(x)=x^{-1/2}\left(C_1x^{m_1}+C_2x^{m_2}+C_3x^{m_3}+C_4x^{m_4}\right), \tag{10}$$

where

$$m_{1,2}=5/4+\sqrt{1-a}. \tag{11}$$

B) for a = 1, then

$$W(x)=x^{-1/2+m_1}\left(C_1+C_2\ln x\right)+x^{-1/2+m_2}\left(C_3+C_4\ln x\right), \tag{12}$$

where

$$m_{1,2}=\pm 1/2+\sqrt{5}. \tag{13}$$

C) for a > 1, for example a = 5, 1< x < 4 $\beta=1/2\sqrt{1/2\left(\sqrt{89}-5\right)},\alpha=1/2\sqrt{1/2\left(\sqrt{89}+5\right)}$

$$W(x)=x^{-1/2}\left[\left(C_1x^{\alpha}+C_2x^{-\alpha}\right)\cos(\beta\ln x)+\left(C_3x^{\alpha}+C_4x^{-\alpha}\right)\right], \tag{14}$$

where $\alpha=\sqrt{2}\cos(\varepsilon/2),\beta=\sqrt{2}\sin(\varepsilon/2),r=a+\frac{9}{16}$;

$$\sin\varepsilon=\frac{\sqrt{a-1}}{r},\cos\varepsilon=\frac{5}{4r}. \tag{15}$$

Since we have considered the tubular structure under the action of an external active force, it is necessary to further consider the nonhomogeneous equation of the form

$$\frac{d^2}{dx^2}\left[x^4\frac{d^2W}{dx^2}\right]+om=x^2-2x+2. \tag{16}$$

A particular solution of which is

$$W^*(x)=\frac{1}{a+24}x^2-\frac{2}{a}x+\frac{2}{a}. \tag{17}$$

Then, on the basis of formulas (10) – (15), we have:

Case A).

$$W(x)=x^{-1/2}\left(C_1x^{m_1}+C_2x^{m_2}+C_3x^{m_3}+C_4x^{m_4}\right)+\frac{1}{a+24}x^2-\frac{2}{a}x+\frac{2}{a}, \tag{18}$$

where $0<a<1,m_{1,2}=\frac{5}{4}\pm\sqrt{1-a};a=\frac{q_k}{D}\lambda^2\beta\frac{c\rho}{k}$.

The general solution of the differential equation (6) we write in the form

$$T(t) = T_0 e^{-\lambda^2 t}, \tag{19}$$

where $T(0) = T_0$.

Consequently:

$$W(x) = T_0 \left[x^{-1/2} \left(C_1 x^{m_1} + C_2 x^{m_2} + C_3 x^{m_3} + C_4 x^{m_4} \right) + \frac{1}{a+24} x^2 - \frac{2}{a} x + \frac{2}{a} \right] e^{-\lambda^2 t}. \tag{20}$$

Case B)

$$W(x) = x^{-1/2 + m_1} \left(C_1 + C_2 \ln x \right) + x^{-1/2 + m_2} \left(C_3 + C_4 \ln x \right) + \frac{1}{a+24} x^2 - \frac{2}{a} x + \frac{2}{a}, \tag{21}$$

where $a = 1; m_{1,2} = \pm \frac{1}{2}\sqrt{5}$.

The general solution of the differential equation (6) we will write in the form:

$$T(t) = T_0 e^{-\lambda^2 t}$$

then

$$W(x) = T_0 \left[x^{-1/2 + m_1} \left(C_1 + C_2 \ln x \right) + x^{-1/2 + m_2} \left(C_3 + C_4 \ln x \right) + \frac{1}{a+24} x^2 - \frac{2}{a} x + \frac{2}{a} \right] e^{-\lambda^2 t} \tag{22}$$

$$\lambda^2 = \frac{n\pi h}{L}, T_0 = \{1,2,3,4,5\}.$$

Case C) similarly:

$$W(x) = T_0 \{ x^{-1/2} \left[C_1 x^{\alpha} + C_2 x^{-\alpha} \right) \cos(\beta \ln x) + \left(C_3 x^{\alpha} + C_4 x^{-\alpha} \right) \sin(\beta \ln x) \right] + \\ + \frac{1}{a+24} x^2 - \frac{2}{a} x + \frac{2}{a} \} e^{-\lambda^2 t} \tag{23}$$

where $\alpha = \sqrt{r} \cos(\varepsilon/2), \beta = \sqrt{r} \sin(\varepsilon/2); r^2 = a + \frac{9}{16};$

$$\sin \varepsilon = \frac{\sqrt{a-1}}{r}; \cos \varepsilon = \frac{5}{4r}. \tag{24}$$

Static deflection is determined from natural oscillations

$$\frac{d^2}{dx^2} \left[\varepsilon(x) \frac{d^2 W}{dx^2} \right] = 0. \tag{25}$$

A particular solution of which is

$$W(x) = c_1 + c_2 x + \int_a^x \frac{x-t}{\varepsilon(t)} \left(c_3 + c_4 t \right) dt, \tag{26}$$

or

$$W(x) = c_1 + c_2 x + c_3 \varphi(x) + c_4 \varphi(x), \tag{27}$$

where

$$W(x)=\int_a^b \frac{|x-t|}{\varepsilon(t)}dt,\quad \varphi(x)=\int_a^b \frac{|x-t|^t}{\varepsilon(t)}dt. \tag{28}$$

On an interval [*a*,*b*], on which $\varepsilon(x)\neq 0$ and twice continuously differentiable.

Fundamental solution

$$g_1(x,\xi)=\int_a^b \frac{|x-t||\xi-t|}{4\varepsilon(t)};$$

$$g_2(x,\xi)=\frac{|x-\xi|}{|x-\xi|}\int_\xi^x \frac{(x-t)(t-\xi)}{2\xi(t)}dt. \tag{29}$$

In the case of transverse vibrations of the tubular structure, the following right conditions are encountered:

$$\text{A) } \mathrm{W(x)}\Big|_{\substack{x=0\\x=L}}=0;\quad \frac{dW}{dx}\Big|_{\substack{x=0\\x=L}}=0; \tag{30}$$

stringently

$$\text{B) } \mathrm{W(x)}\Big|_{\substack{x=0\\x=L}}=0;\quad \frac{d^2W}{dx^2}\Big|_{\substack{x=0\\x=L}}=0; \tag{31}$$

$$\text{C) } \frac{\mathrm{d}^2W}{dx^2}\Big|_{\substack{x=0\\x=L}}=0;\quad \frac{d^3W}{dx^3}\Big|_{\substack{x=0\\x=L}}=0; \tag{32}$$

free boundary conditions.

Possible mixed boundary conditions.

We introduce the notations

$$D)\ \alpha=\int_a^b \frac{dt}{\varepsilon(t)};\quad \beta=\int_a^b \frac{tdt}{\varepsilon(t)};\quad \gamma=\int_a^b \frac{t^2dt}{\varepsilon(t)}; \tag{33}$$

Then, in the accepted notation for the Green function of various boundary value problems, we have:

$$\text{I)}\quad \Gamma^{\mathrm{I,I}}=g_1(x,\xi)+\frac{1}{4(\alpha\gamma-\beta^2)}\{\varphi(x)[\beta\varphi(\xi)-\gamma\varphi(x)]+\varphi(x)[\beta\varphi(\xi)-\alpha\varphi(\xi)]\}, \tag{35}$$

where $\alpha\gamma-\beta^2\neq 0$.

$$\text{II)}\quad \begin{aligned}4\Gamma^{\mathrm{II,II}}&=4g_1(x,\xi)+\gamma+(\beta-2\gamma)\xi-\varphi(\xi)+[\beta-2\gamma+(\alpha-4\beta+4\gamma)\xi+\\&+2\varphi(\xi)-\varphi(\xi)]x-\xi\varphi(x)+(2\xi-1)\varphi(x)\end{aligned} \tag{35}$$

for $a=0, b=1; 0\le t\le 1$.

III) $\Gamma^{\mathrm{III,III}}$ – does not exist. In these cases, it is possible to construct generalized Green's functions, since the boundary value problems have a nonzero solution c_1+c_2x.

IV) $$N\Gamma^{I,II} = Ng_1(x,\xi) + (x-b)[(\xi-b)(2\gamma-\beta^2) + (\gamma-b\beta)\varphi(x) + (b\alpha-\beta)\varphi(x)] - \varphi(x)[(\xi--b)(b\beta-\gamma) + b^2\varphi(\xi) - b\varphi(\xi)] + \varphi(x)[(\xi-b)(b\alpha-\beta) + b\varphi(\xi) - \varphi(\xi) \quad (36)$$

where $N = 4(b^2\alpha - 2b\beta + \alpha) \neq 0$.

V) $$4\Gamma^{I,III} = 4g_1(x,\xi) + \gamma - \beta\xi - \varphi(\xi) + [\alpha\xi - \beta + \varphi(\xi)]x + \xi\varphi(x) - \varphi(x). \quad (37)$$

VI) $\Gamma^{II,III}$ – does not exist, since it has a nonzero solution. We can construct a generalized Green's function $c(x-\alpha)$.

Graphs 1–3 show the flow of the oil mixture with different viscosities when changing the shear modulus $\mu(T)$, the Poisson's ratio $\upsilon(T)$ and the linear expansion coefficient $\alpha(T)$ for the elastic-viscous region according to figures 1, 2.

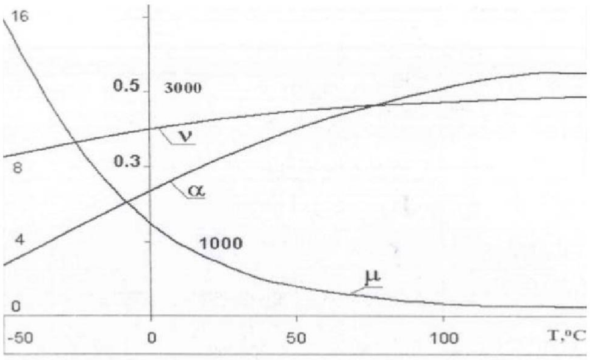


Figure 1 – Dependence of the shear modulus, the Poisson's ratios and the linear expansion on temperature

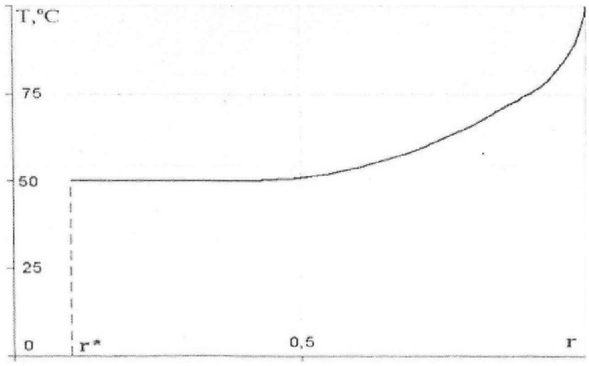
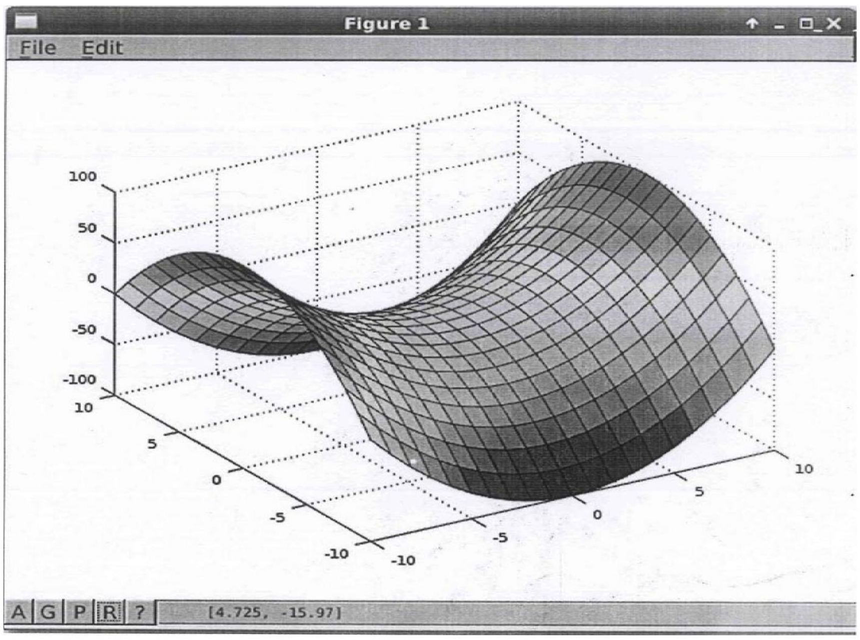
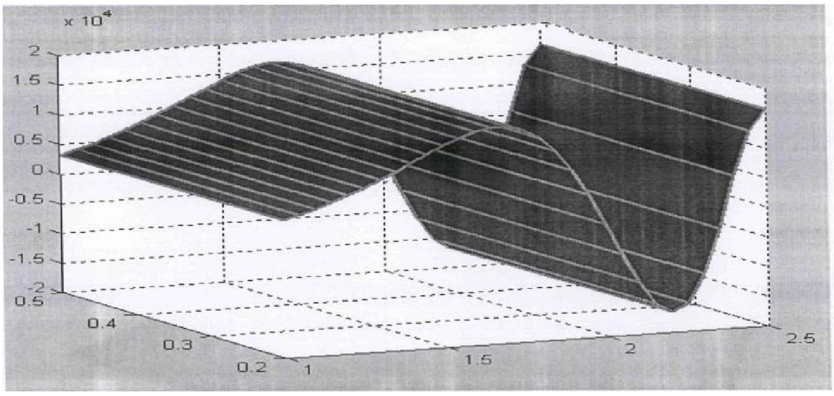


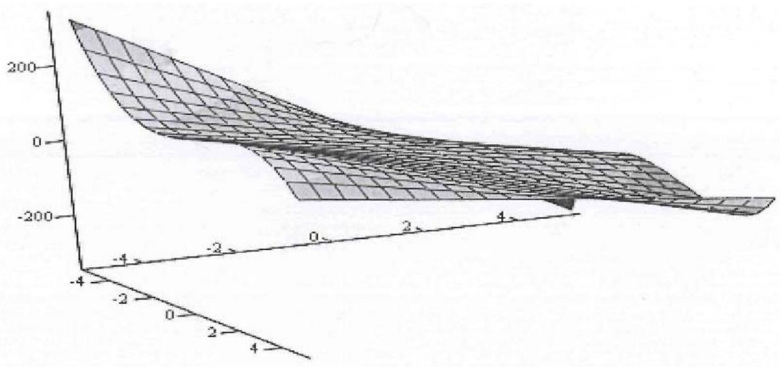
Figure 2 – The temperature distribution over pipe thickness



Graph 1 – The flow of oil mixture of different viscosities with decreasing temperature from 80 °C to 60 °C, when $a = \frac{3}{4}$



Graph 2 – The flow of oil mixture of different viscosities
with decreasing temperature from 60 °C to 30°C, when *a* = 1



Graph 3 – The flow of oil mixture of different viscosities
with decreasing temperature from 29 °C to 23 °C, when *a* = 5

Conclusion. As a result of the study, the following calculations have been analyzed and obtained:

– The calculation of the flow of the oil mixture of different viscosities with a decrease in temperature from 80 °C to 60 °C is performed under the classification of loads of 1-type

– The calculation of the flow of the oil mixture of different viscosities with a decrease in temperature from 60 °C to 30°C is performed under the classification of loads of 2-type

– The calculation of the flow of the oil mixture of different viscosities with a decrease in temperature from 29 °C to 23 °C is performed under the classification of loads of 3-type.

The dependencies have been determined, i.e. depending on the flow regime, the volume of the oil mixture of different viscosities can be reduced as much as possible by desalination and separation of impurities, heavy sediments and stratification, under the influence of combined power factors on the type of classification of loads of the 1st –III types. In this case, depending on the power factors, the original equation is reduced to an equation of the Riccati and Weber type, and in some cases to the Bessel and Euler equations.

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ӘР ТҮРЛІ ТҰТҚЫРЛЫҚТАҒЫ МҰНАЙ ҚОСПАЛАРЫНЫҢ АҒЫНЫН ЕСЕПТЕУ

Жұмыста I–III-типтегі жүктемелердің жіктелуінің әсерінен өндірілетін температураның төмендеуімен әр түрлі тұтқырлықтағы мұнай қоспаларының ағынын есептеу қарастырылған. Әр түрлі тұтқырлықтағы мұнай қоспасының көлемін ағынды тұзсыздандыру және қоспаларды бөлу арқылы азайтуға болады.

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РАСЧЕТ ТЕЧЕНИЯ НЕФТЯНОЙ СМЕСИ РАЗНОЙ ВЯЗКОСТИ ПРИ УМЕНЬШЕНИИ ТЕМПЕРАТУРЫ

Аннотация. В работе рассматривается расчет течения нефтяной смеси разной вязкости при уменьшении температуры, производимые под действием классификации нагрузок с I–III-видов. Течения объема нефтяной смеси разной вязкости можно максимально снизить путем опреснения и разделения примеси.

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