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## Mathematical model of non-isothermal flow of oil through the trunk pipeline

In this article are described a non-isothermal current of high-viscosity oil. A non-isothermal current of viscous liquid on the trunk pipeline it is characteristic of transportation of oil and oil products with preliminary heating from places of production to a customer, of a current of hot water from combined heat and power plant to inhabited arrays and production locations, etc. The one-dimensional mathematical model of a non-isothermal current of viscous liquid and a formula of cost fuel – power expenses for the stationary mode of a current are examined. It is spoken in detail the process of calculation of optimum speed of a current for transportation of high-viscosity oil and oil products in the warmed-up state on pipelines at which the total cost of energy costs of pumping and heating of oil would be minimum.

*Keywords:* high-viscosity oil, viscous liquid, non-isothermal current, stationary mode of a current, pipeline, energy expenses, speed of current.

### Introduction

The Kazakhstan oil is considered very viscous, and its transportation in the warmed-up state on pipes requires big energy expenses. On the other hand, the considerable time pipelines work with plan underload. Therefore, the choice of the modes of a current in case of which the cost of pumping will be minimum is very demanded. The purpose of work – to investigate process of non-isothermal flow of high-viscosity oil in the main pipeline and to find such management of process of a flow at which the total cost for power expences of pumping and for heating of oil would be minimum when transporting by the pipelines working with planned under loading [1].

For achieving the purpose it is necessary to solve the following problems:

- to study process of non-isothermal flow of high-viscosity oil in the main pipeline;
- to put and solve the problem of a thermo - hydraulic flow of liquid in the pipeline;
- to estimate the cost of transportation of high-viscosity oil;
- to calculate the optimum speed of a flow of oil at which cost would be minimum.

### Basic calculations

Computation of optimum speed of operation of the underloaded oil pipeline were executed by means of object-oriented programming language C#.

#### *Calculation of temperature, pressure and energy consumption for operation of the pipeline*

Calculation of temperature at an entrance to each site. Calculation of temperature is calculated by means of the following formula

$$T_{j-1}^+ = T_{env} + (T_j^- - T_{env}) \cdot e^{\frac{\alpha_{j-1}}{w}};$$

$$T_j^- = T_{min} = 33^\circ C.$$

For finding of temperatures on sites, it is necessary for us a difference of sites, which they are provided in drawing from above under  $L_j$  value (Fig. 1) [2].

$$L_j = [x_1, x_2, x_3, x_4, x_5] = [145000, 177000, 111000, 95000, 213000] km.$$

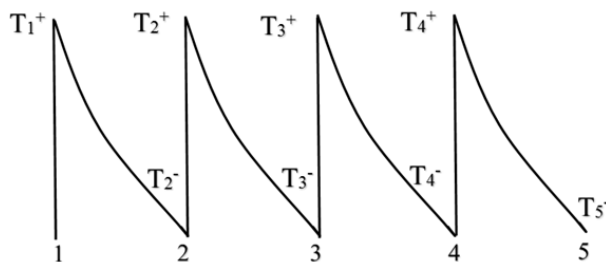


Figure 1. Distribution of temperature along the route of the oil pipeline

Calculation of pressure on an entrance to each site (Fig. 2). Calculation of pressure on an entrance to each site is calculated by means of the following formula

$$\Delta P_j = P_j^+ - P_j^- = H_{j-1} + E \cdot w^{2-m} [A_{j-1} - B_{j-1} \cdot \Delta T_{env} \cdot w (e^{\frac{\alpha_{j-1}}{w} (x_{j-1} - x_j)} - 1)];$$

$$P_j^- = P_{min} = 2 atm.$$

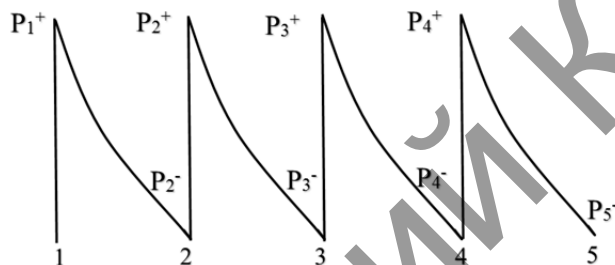


Figure 2. Distribution of pressure along the route of the oil pipeline [2]

Calculation of energy consumption for exploitation of the pipeline. Calculation of cost is calculated by means of the following formula

$$S = ae \cdot w \cdot \sum_{j=1}^N \varphi_j \Delta P_j + \delta \cdot w \cdot \sum_{j=1}^N y_j \Delta T_j.$$

*Calculation of optimal speed*

Calculation of optimal speed is calculated by means of the following formula

$$w = \delta \cdot \Delta T_{env} \sum_{j=1}^N y_j \alpha_j \cdot e^{\frac{\alpha_{j-1}}{w}} + \alpha e \cdot E \cdot w^{3-m} [(4-m) \cdot \Delta T_{env} \cdot w \cdot \sum_{j=1}^N y_j B_j (e^{\frac{\alpha_{j-1}}{w}} - 1) - (3-m) \sum_{j=1}^N y_j A_j - \Delta T_{env} \sum_{j=1}^N y_j B_j \alpha_j e^{\frac{\alpha_{j-1}}{w}}] :$$

$$: [\alpha e \sum_{j=1}^N \varphi_j H_j + \delta \cdot \Delta T_{env} \sum_{j=1}^N y_j (e^{\frac{\alpha_{j-1}}{w}} - 1)].$$

By means of the found speeds, we find anew temperature, pressure and cost. In which speed, cost will be minimum – it will be optimum speed [3-5].

*Results of thermal-hydraulic calculation for different seasons*

Heat hydraulic calculation for spring. For spring temperature surrounding will be  $T_{env} = 10 \text{ }^\circ\text{C}$ .

In Figure 3 provides the view of interface which gives the results of thermal-hydraulic calculation for spring.

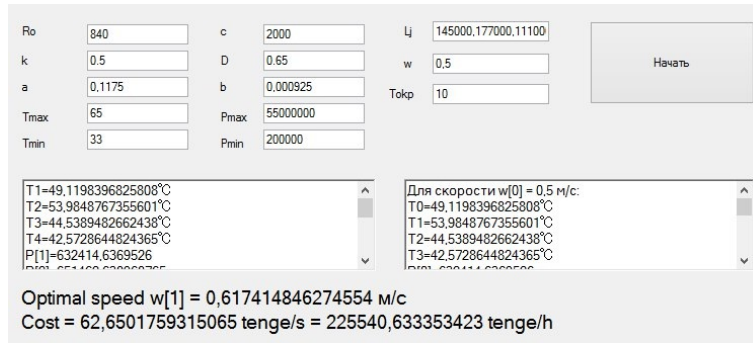


Figure 3. Window of results of thermal-hydraulic calculation for spring

From Figure 4, we can assume that at  $w = 0,61$  speed, we have the minimum cost. Therefore, for spring it will also be optimum speed.

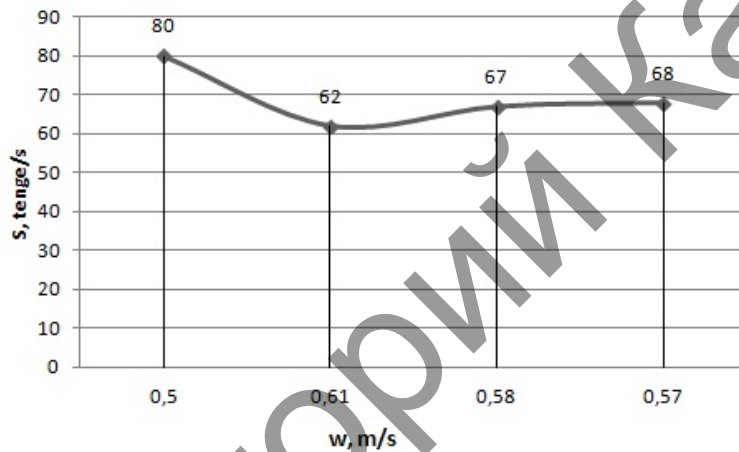


Figure 4. Dependence of working cost of the oil pipeline on speed

Thermal-hydraulic calculation for summer. For summer temperature surrounding will be  $T_{env} = 18^\circ C$ .

In Figure 5 provides the view of interface which gives the results of thermal-hydraulic calculation for summer.

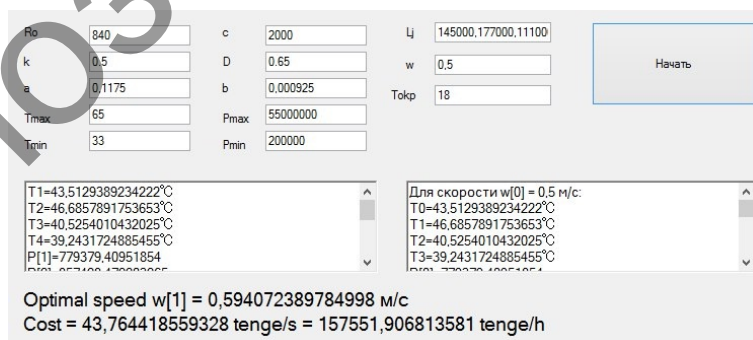


Figure 5. Window of results of thermal-hydraulic calculation for summer

From Figure 6, we can assume that at  $w = 0,59$  speed, we have the minimum cost. Therefore, for summer it will also be optimum speed.

Thermal-hydraulic calculation for winter. For summer temperature surrounding will be  $T_{env} = 2^\circ C$ .

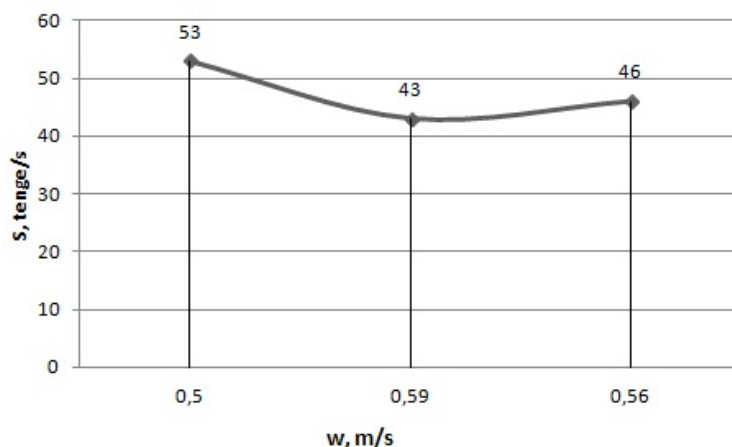


Figure 6. Dependence of working cost of the oil pipeline on speed

In Figure 7 provides the view of interface which gives the results of thermal-hydraulic calculation for winter.

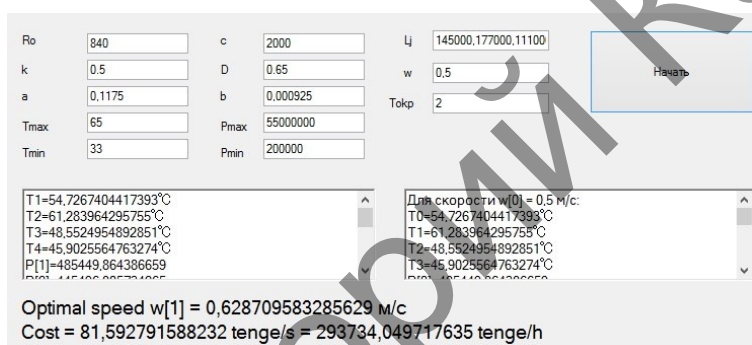


Figure 7. Window of results of thermal-hydraulic calculation for winter

From Figure 8, we can assume that at  $w = 0,62$  speed, we have the minimum cost. Therefore, for winter it will also be optimum speed.

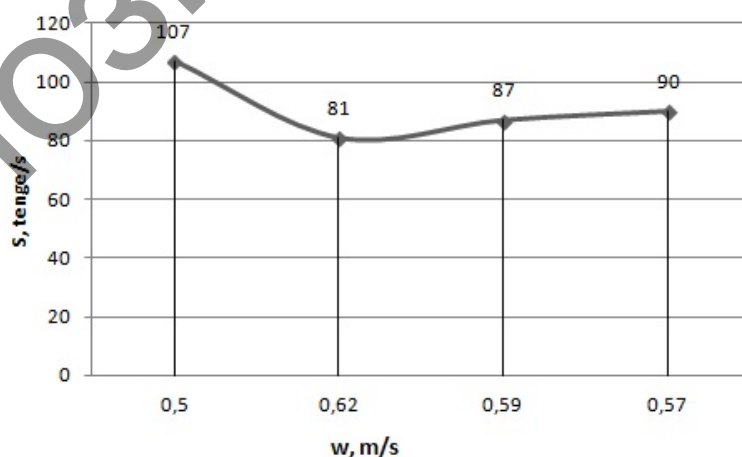


Figure 8. Dependence of working cost of the oil pipeline on speed

In Figure 9 provide the change of optimum speed at different seasons, i.e. for spring, summer and winter.

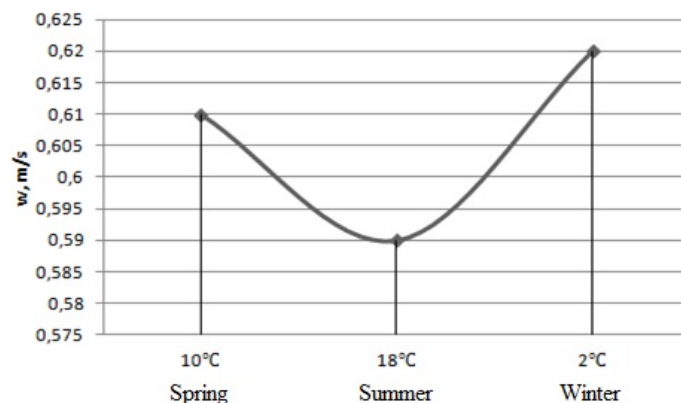


Figure 9. The change of optimum speeds at different seasons

We can assume, in winter that transportation requires more speed than in other two seasons. And respectively, there will be more energy consumption in the winter than in other two [6].

#### *The received results*

As a result of the conducted research, we can draw the following conclusions:

1. Process of transportation of oil through the pipeline is investigated.
2. Not isothermal current of high-viscosity oil is explored.
3. The one-dimensional mathematical model of not isothermal current of viscous liquid is investigated.
4. Calculation of temperature and pressure for different speeds of a current of oil with estimation of cost is executed.
5. The technique of obtaining optimum speed of a current of oil at which working costs of the oil pipeline are minimum is developed.

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## Мұнайдың магистралды құбыр арқылы изотермиялық емес қозғалысының математикалық моделі

Мақалада тұтқырлығы жоғары мұнайдың изотермиялық емес ағыны сипатталған. Магистралдық мұнай құбыры бойынша тұтқыр сұйықтықтың изотермиялық емес ағыны, мұнай мен мұнай өнімдерін өндіру алаңынан тұтынушыға дейін, ЖЭО-нан тұрғын үйлер мен өндірістік нысандарға дейін ыстық су ағымын және тағы басқа тасымалдау үшін тән. Тұтқыр сұйықтықтың изотермиялық емес ағынының бірөлшемді математикалық моделі және тұрақты ағын тәртібіне арналған отын-энергия шығындарын есептеудің негізгі формуласы зерттелді. Тұтқырлығы жоғары мұнай мен мұнай өнімдерін қыздырылған күйінде құбырлар бойынша тасымалдау үшін мұнайды айдауға және жылытуға кететін отын-энергия шығындарының жалпы құны аз болатындай ағынның оңтайлы жылдамдығын есептеу үдерісі толық сипатталған.

*Клт сөздер:* тұтқырлығы жоғары мұнай, тұтқыр сұйықтық, изотермиялық емес ағын, ағынның стационарлық тәртібі, құбыр, энергетикалық шығын, ағын жылдамдығы.

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## Математическая модель неізотермического движения нефти по магистральному трубопроводу

В статье описано неізотермическое течение высоковязкой нефти. Неізотермическое течение вязкой жидкости по магистральному трубопроводу характерно для транспортировки нефти и нефтепродуктов с предварительным подогревом от мест добычи к потребителю, для течения горячей воды от ТЭЦ до жилых массивов и производственных помещений и т.п. Исследованы одномерная математическая модель неізотермического течения вязкой жидкости и формула стоимости топливно-энергетических затрат для стационарного режима течения. Подробно описан процесс вычисления оптимальной скорости течения для транспортировки высоковязкой нефти и нефтепродуктов в подогретом состоянии по трубопроводам, при котором общая стоимость энергетических затрат на перекачку и подогрев нефти была бы минимальной.

*Ключевые слова:* высоковязкая нефть, вязкая жидкость, неізотермическое течение, стационарный режим течения, трубопровод, энергетические затраты, скорость течения.

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