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Metallurgy

Sequential Transportation of Different Oil Batches through the Industrial Pipeline

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ABSTRACT
In sequential pumping, several liquids with different physical and chemical properties are pumped through one pipeline. The advantages of this method include: using one pipeline to transport different liquids; more complete pipeline loading; and reduced cost of pumping. The paper considers the sequential pumping of two batches of oil blends with different physicochemical properties through an industrial oil pipeline. This is because a batch of high-paraffin oil blend is simultaneously pumped to an oil refinery, and a batch of high-viscosity oil blend is transported further along a pipeline. The difference between the thermal-physical and rheological properties of oil batches imposes a condition on the thermal mode of operation of an industrial pipeline. A mathematical model and algorithm have been created for calculating the sequential transportation of high-paraffin and high-viscosity oil blends. Thermohydraulic calculations of the model show the distribution of hydraulic head, pressure, and temperature of the batches under the operating conditions of pumping units and heating furnaces. The verification and validation of the theoretical analysis was carried out with experimental data measured by the SCADA along the industrial pipeline length. By the thermal mode of sequential pumping, optimal heating temperatures of oil blends were found at the industrial pipeline stations.

Keywords: sequential transportation, batch of oil blends, high-paraffin oil, high-viscosity oil, heating temperature, industrial pipeline.

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Introduction

The method of sequential pumping is widely used in pipeline transportation of oil and oil products [[1], [2], [3], [4], [5], [6]]. In this method at each moment, several oil blends differing in their physical and chemical properties are pumped through one pipeline. At that, each batch displaces the previous one and in turn, is displaced by the next one. Such regimes are non-stationary, as at different moments in each point of the pipe the value of parameters of the passing oil batch changes, which, having different rheological properties, cause different hydraulic losses for each point of the pipe in time.

Sequential pumping technology, or batch transportation, offers several advantages in the context of transporting oil and petroleum products through pipelines [[7], [8], [9]]:

Optimizing Pipeline Capacity. By transporting multiple types of oil in batches, pipeline operators can make the most efficient use of the available space and maximize throughput. This can be especially important in regions with limited pipeline infrastructure.

Economic Efficiency. Utilizing a single pipeline for transporting multiple products is more cost-effective than constructing separate pipelines for each product.

Flexibility and Adaptability. Sequential transportation provides flexibility to respond to changing market conditions.

Reducing Energy Consumption. Transitioning from one type of oil to another within the pipeline can be more efficient than emptying the pipeline before switching.

Efficient Resource Allocation. By transporting multiple types of oil through the same pipeline, resources such as labor, maintenance, and monitoring can be more effectively allocated, reducing overall operational costs.

An approximate theory of sequential pumping of petroleum products by direct contacting was first proposed in the paper [6].

Sequential pumping is used in the pipeline transportation of various oil blends and petroleum products, such as diesel fuel, kerosene, etc. In practice, different types of oil se-quential pumping are applied: 1) the presence of a dividing plate between different batch-es of heavy oil blends and oil products; 2) with separating plug is created by introducing drag reducing additive to the fluid; 3) direct contact methods of oil and oil products.

Most publications on this topic focus on planning the operation of a multi-product pipeline system when the pipeline is connected to multiple tank farms and local consumer markets [[10], [11], [12], [13], [14]].

The problem of mixture formation during the sequential pumping of light oil products through the same pipeline [[9], [15], [16]] is considered. It is known that when one oil product is displaced by another in the contact area of sequentially moving batches, a mixture is formed.

[3] used BFC-POD-ROM to simulate the cyclic transportation of Shengli and Oman oil batches to reduce the time cost. The paper [4] uses the gradient-type flow rate distribution model to increase the calculation accuracy in modelling sequential pumping with a non-constant flow rate. In the paper [17], a mathematical model was developed to describe the sequential pumping of cool and hot oil. It is assumed that the safety of batch-ing of cold and hot oil can be improved by reheating the cold oil ahead or increasing the capacity of the hot oil.

In Kazakhstan, the method of sequential pumping is applied on the Karazhanbas-Aktau and Uzen-Atyrau industrial oil pipelines. The Uzen - Atyrau oil pipeline facilitates the batch pumping of high-viscosity Buzachi and high-paraffin Mangyshlak oil blends. At the outlet of the main oil pumping station (MOPS) 'Uzen,' the pour point temperature of the Mangyshlak crude mixture is Tpt = +27°C, while for the Buzachinsk crude mixture, it is Tpt = -12°C. The difference in pour point temperatures between the Mangyshlak and Buzachinsk crude mixtures requires optimization of the heating temperature to ensure safe cyclic pumping. This operational process is interconnected with the concurrent transfer of a Mangyshlak oil blend batch to an oil refinery. While the batch of Buzachi oil blend is transported further along the industrial pipeline. The peculiarity of this task is that the pumping and heating of oil blends is carried out at several pumping and heating stations located along the length of the oil pipeline. Associated pumping and heating require the development of a model and an algorithm for calculating batch pumping. This paper presents the results of thermohydraulic calculations of sequential pumping of Mangyshlak and Buzachi oil blends through the Uzen - Atyrau industrial pipeline.

Sequential pumping

The longitudinal profile and diagram of the Uzen - Atyrau oil pipeline section are shown in Fig.1. The pipeline section passes through high-relief terrain, which creates static pressure in the pipeline. There are five intermediate stations along the pipeline: Sai Utes, Beineu, Opornaya, Kultumiev, and Shmanov.

Two oil batches with different physicochemical properties are pumped in sequential order through the oil pipeline section.

With this method of pumping, the changeability of the output of a batch of oil blends from the initial station occurs cyclically under a constant condition: the first batch (the first type of oil blend) goes out until it exhausts the pre-set batch volume for it, then the second batch (the second type of oil blend) also comes out until the predetermined volume is also exhausted, then the first batch comes out again with the same condition, etc. For the sequential pumping, different initial temperatures of oil blends can be set for each batch.

Sequential pumping modes are non-stationary, since at different times at each point of the pipe, the values of the parameters of the passing batch of oil change, which, having different rheological properties, causes different hydraulic losses for each point of the pipe in time.

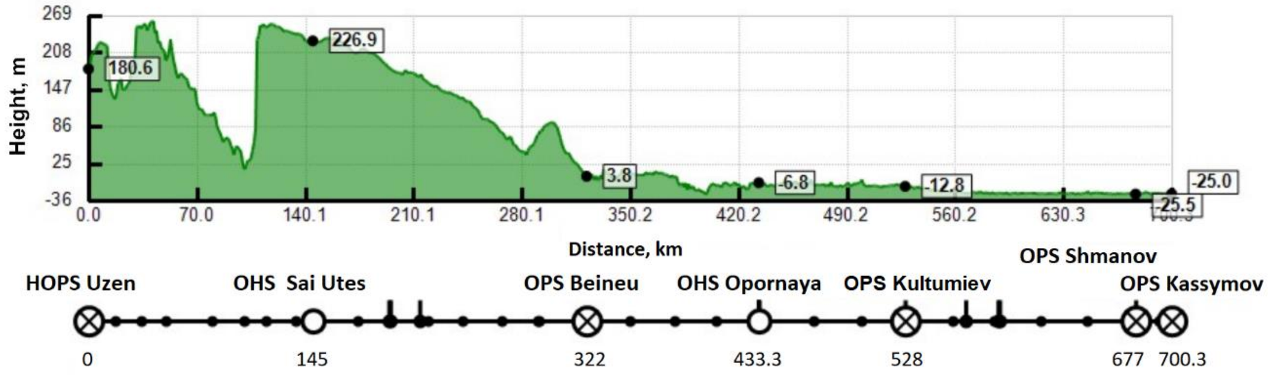


Figure 1 – The Uzen – Atyrau industrial pipeline profile and station location diagram: HOPS is the head oil pumping station; OPS is the oil pumping station; OHS is the oil heating station

Basic assumptions of the sequential pumping model. The batch pumping is considered as a non-stationary process and the following assumptions are made:

- oil is not compressible, the density of oil does not depend on the temperature and pressure;
- different batches of oil do not mix;
- the temperature of the fluid along the radius of each section of the pipe is constant.

Consider a pipeline of a length L, in which there are n operating oil pumping stations (OPS) and m operating oil heating station (OHS). Let each OPS be located in x_i^{ops} along the pipeline and, depending on the oil flow rate, crcreatedditional pressure ΔP_i^{ops} (pressure jumps). Let each OHS be located in x_j^{ohs} along the pipeline and, depending on the oil consumption, creates heating ΔT_i^{ohs} (temperature jumps) and pressure loss ΔP_i^{ops}.

It should be noted that the pressure ΔP_i^{ops} generated by OPS, oil heating ΔT_i^{ohs} in OHS and pressure loss ΔP_i^{ops} are the operating parameters and are set for the sequential pumping.

Model of mass and heat transfer

1. Mass and heat transfer in the linear part of the pipeline

The length of the oil pipeline L reaches hundreds of kilometers, and its diameter is D_1 = 1m, so the batch pumping can be considered in the framework of a one-dimensional model.

Denote the density of the first batch of oil blend as ρ_1, and the second batch as ρ_2. Then the density of the oil blend in the batch pumping can be expressed as $\rho = \rho_1\omega + \rho_2(1-\omega)$, where ω is the specific fraction of the oil blend; the variable ω takes the values ω =1 for the first batch of oil blend or ω =0 for the second batch of oil blend, since batch mixing is not allowed.

The assumption of incompressibility of the oil blend can be formulated as an equation:

$$\frac{\partial \omega}{t} + u\frac{\partial \omega}{\partial x} = 0 \quad (1)$$

The equation of motion, considering the accepted assumptions, can be written as:

$$\rho\frac{\partial u}{\partial t} + \frac{\partial P}{\partial x} = -\zeta\frac{\rho u^2}{2D_1} - \rho g \sin\beta + \sum_{i=1}^{n}\Delta P_i^{ops}\delta(x - x_i^{ops}) - \overset{m}{\underset{j=1}{}}\Delta P_j^{ohs}\ (x - x_j) \quad (2)$$

The heat transfer equation, considering the accepted assumptions, has the form:

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} = -\frac{4K}{\rho C\ D_1}(T - T_w) + \frac{\zeta u^3}{2C_p D_1} + \sum_{j=1}^{m}\Delta T_j^{ohs}\delta(x - x_j^{ohs}) \quad (3)$$

where T is the temperature distribution of oil blends along the pipeline; P is the pressure distribution along the pipeline; u is the linear velocity of fluid flow in the pipe; ζ is the coefficient of hydraulic resistance; g is the acceleration of gravity; D_1 is the inner diameter of the pipe; β is the angle of inclination of the pipe profile; K is the heat transfer coefficient from the oil flow to the surrounding environment; T_w is the temperature of the surrounding soil; C_p is the heat capacity of oil; *δ(x)* is the Dirac function.

The equation (1) describes changes in the distribution of batches of oil blends along the pipeline. The second equation (2) is derived from the equations of motion and continuity, considering the incompressibility of the fluid and the operation of OPS and OHS. The equation (3) is derived from the heat balance equation considering the OHS operation along the pipeline. Equations (2) and (3) are interconnected through the coefficient of hydraulic resistance ζ, which depends on the temperature of the oil blends. There are no diffusion terms in equation (1) since the model assumes that batches of oil blends do not mix. The equation (1) is related to equations (2) and (3) via the parameters ρ, C_p, K, ζ as follows:

$$C_p = C_{p1}\omega + C_{p2}(1-\omega),\ \lambda = \lambda_1\omega + \lambda_2(1-\omega),$$
$$\mu = \mu_1\omega + \mu_2(1-\omega),\ K = K(\alpha, \lambda) \tag{4}$$

Where C_{p1}, C_{p2} are the heat capacity of batches No. 1 and No. 2, respectively; λ_1, λ_2 are the thermal conductivity of batches No. 1 and No. 2, respectively; $\mu_1(T), \mu_2(T)$ are the dependences of viscosity of batches No. 1 and No. 2 on temperature.

2. Initial and boundary conditions

The system of equations (1)–(2) has the following boundary conditions:

$$P(0,t) = P_0, P(L,t) = P_L \tag{5}$$

$$T(0,t) = T_1 \text{ by } \omega = 1,\ T(0,t) = T_2 \text{ by } \omega = 0 \tag{6}$$

$$\omega(0,t) = 1,\ \left\langle \frac{S_0\int_0^t udt}{V_1+V_2} \right\rangle < \frac{V_1}{V_1 \quad V_2};$$
$$\omega(0,t) = 0,\ \left\langle \frac{S_0\int_0^t udt}{V_1+V_2} \right\rangle \geq \frac{V_1}{V_1 \quad V_2}, \tag{7}$$

where P_0 is the pressure at the outlet of the tanks at the initial station; P_L is the pressure at the inlet to the final station; T_1, T_2 are the initial temperature of the oil blends for batch No. 1 and batch No. 2, respectively; S_0 is the cross-sectional area of the pipe at the outlet of the initial station; V_1, V_2 are the volumes necessary for switching for batch No. 1 and batch No. 2, respectively; $\langle \quad \rangle$ is the operation of taking the fractional part of the number.

The boundary condition (7) was derived from the following considerations: let the volume of oil blends $V = V(t)$ that came out of the initial station be known for each moment of time t. Consider switching batches of oil blends from the start of pumping:

$V \in [0, V_1)$ - pumping of batch No. 1;

$V \in [V_1, V_1 + V_2)$ - pumping of batch No. 2;

$V \in [V_1 + V_2, 2V_1 + V_2)$ - pumping of batch No. 1;

$V \in [2V_1 + V_2, 2V_1 + 2V_2)$ - pumping of batch No. 2;

…

$V \in [k(V_1 + V_2), k(V_1 + V_2) + V_1)$ - pumping of batch No. 1

It is easy to notice that during the pumping of batch No. 1, the fractional part of the ratio $\frac{V}{V_1+V_2}$ lies in the range from 0 to $\frac{V_1}{V_1+V_2}$, i.e. $\langle\frac{V}{V_1+V_2}\rangle < \frac{V_1}{V_1+V_2}$, when pumping of batch No.2 $\langle\frac{V}{V_1+V_2}\rangle \in [\frac{V_1}{V_1+V_2}, 1]$. For each moment t, the value of V can be calculated by considering the volume pumped through the section S_0 with linear velocity u, i.e. $V = V(t) = S_0\int_0^t udt$.

3. Closure relations

The values of the additional pressure created on the OPS, as well as heating and pressure loss on OHS are known and depend on the flow rate of oil blends, i.e. they are predefined functions of the flow rate u:

$$\Delta P_i^{ops} = \Delta P_i^{ops}(u),\ \Delta T_j^{ohs} = \Delta T_j^{ohs}(u),$$
$$\Delta P_j^{ohs} = \Delta P_j^{ohs}(u), \tag{8}$$

In the current model, the profile of the oil pipeline and the ambient temperature are known and depend only on the location along the route, i.e. they are predefined functions of space:

$$\beta \quad \beta(x), \quad T_w = T_w(x), \tag{9}$$

The coefficient of hydraulic losses $\zeta = \zeta(u, \mu)$ in equations (2) and (3) can be calculated using well-known formulas or equations [[18], [19], [20]].

The heat transfer coefficient $K = K(\alpha, \lambda)$ from the oil flow to the environment can be found using the formulas described in detail in [[21], [22]].

Soil temperature T_w was taken from measured SCADA data. Since the ground along the considered section of the pipeline is heterogeneous, the values of ground thermal conductivity were calculated using historical actual data of oil flow rate, oil temperature and ground temperature for the given section of the pipeline [23].

The heat capacity of oil blends is described by the Krego's formula [8]:

$$C_p(T) = (53357 + 107.2 \cdot T)/\sqrt{\rho} \text{ [J/(kg·°C)]}, \tag{10}$$

4 Setting the sequential pumping period

Since the boundary conditions (5) and (6) are cyclic, depending on the given constants V_1, V_2, the state of the pipeline will also be cyclic, i.e. after a certain time Δt_{cyc}, the values of the variables u, P, T, ω will be the same:

$$u(x,t) = u(x,t+\Delta t_{cyc}),\ P(x,t) = P(x,t+\Delta t_{cyc})$$
$$T(x,t) = T(x,t+\Delta t_{cyc}),\ \omega(x,t) = \omega(x,t+\Delta t_{cyc}) \quad (11)$$

Thus, to simulate the sequential pumping process, it is sufficient to use some initial distribution of *P*, T, ω. In the process of calculations, such a cycle start time t^0_{cyc} will be found that the conditions $t > t^0_{cyc}$ (11) will be met. Such time t^0_{cyc} can be found by storing variables u, P, T, ω for each moment t and comparing them with the values of the previous time.

In practice, it is enough to compare only the values $u(0,t)$, since this method is less computationally intensive. The condition of the pipeline $t > t^0_{cyc}$ is conditionally called the "steady state" during the sequential pumping of oil blends.

Let batch No. 1 be less viscous than batch No.2, if, with a given pumping mode (OPS and OHS operating modes), the batch pumping of two oil blends is possible, only when pumping of batch No. 1 is possible.

It is also obvious that if pumping batch No. 1 is impossible, then sequential pumping of two batches is also impossible. Therefore, as an initial distribution of P, T, ω for modeling the batch pumping, it would be correct to take the values of the batch of oil blend No. 1:

$$P(x,0) = P^{batch1}(x),\ T(x,0) = T^{batch1}(x),\ \omega(x,0) = 1, \quad (12)$$

where P^{batch1}, T^{batch1} are the distribution of oil pressure and temperature, respectively, along the pipeline for stationary pumping mode of batch No. 1. In this case, for $t < t^0_{cyc}$ a transition process from the stationary oil pumping mode No. 1 to the "steady-state" batch pumping mode will be obtained.

Figure 2 shows the time change u(0,t) for an example of calculating the batch pumping of the Mangyshlak and Buzachi oil batches though the Uzen-Atyrau pipeline section.

As can be seen from Figure 2, after a certain time (t = 55 h), the process of pumping a batch with a given initial condition (12) switches to a "steady state" sequential pumping mode.

Thus, the pumping of 2 batches is impossible if and only if the stationary mode of pumping oil blend No. 1 is impossible or when modeling with the initial condition (12), the value of u at some point in time becomes equal to 0.

So, to simulate the batch pumping of two oil blends, the system of equations (1) - (4) with boundary (5-7) and initial (12) conditions is used. The result of such modeling will be either the "steady state" of the pipe.

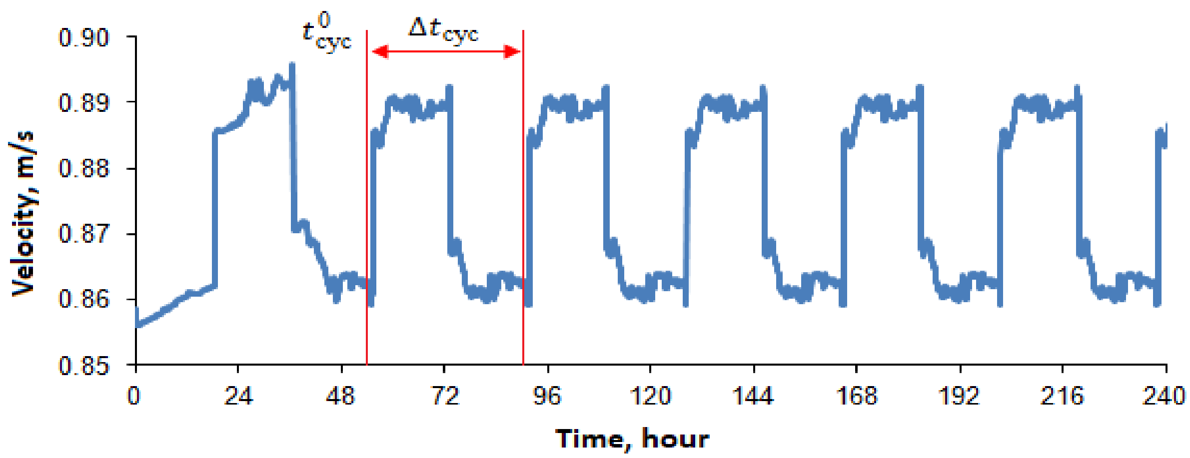


Figure 2 – An example of a change in the flow rate over time for modeling the batch pumping of the oil blends with a given initial condition for transition to the "steady state" at $t > t^0_{cyc}$

Calculation algorithm

The system of equations (1) - (4) with the initial and boundary conditions (5) - (7) and closures of relations (8) - (10) is solved by the numerical method [24]. The value of the hydraulic resistance coefficient ζ_i^n is expressed by the Altshul's formula [20], depending on the flow regime, respectively. This hydraulic resistance coefficient value is put into the momentum equation (2) and the pressure P_i^{n+1}, velocity u_i^{n+1}, temperature T_i^{n+1} values at the difference grid nodes are calculated. According to the obtained temperature distribution T_i^{n+1}, the values of the viscosity $\mu_i^{n+1}(T_i)$ and the Reynolds number Re_i^{n+1} are found. According to the found Reynolds number Re_i^{n+1}, the value of the hydraulic resistance coefficient ζ_i^{n+1} is specified.

The SmartTran software [25] conducts the thermal-hydraulic calculations by the system of equations (1)-(3) with the conditions (5)-(12) for the oil pumping modes through main oil pipelines.

Results and Discussion

For the Mangyshlak oil blend, the density is equal to $\rho_1 = 843.1$ kg/m³, and for Buzachi oil blend is $\rho_2 = 891.9$ kg/m³. The temperature dependences of the viscosity of Mangyshlak and Buzachi oil blends are shown in Fig. 3.

The temperature dependences of viscosity of Mangyshlak and Buzachi oil blends are expressed by the formulas (13) and (14):

$$\mu_1(t) = 1.6838 \cdot \exp(-0.095 \cdot T) \quad (13)$$

$$\mu_2(t) = 0.9109 \cdot \exp(-0.116 \cdot T) \quad (14)$$

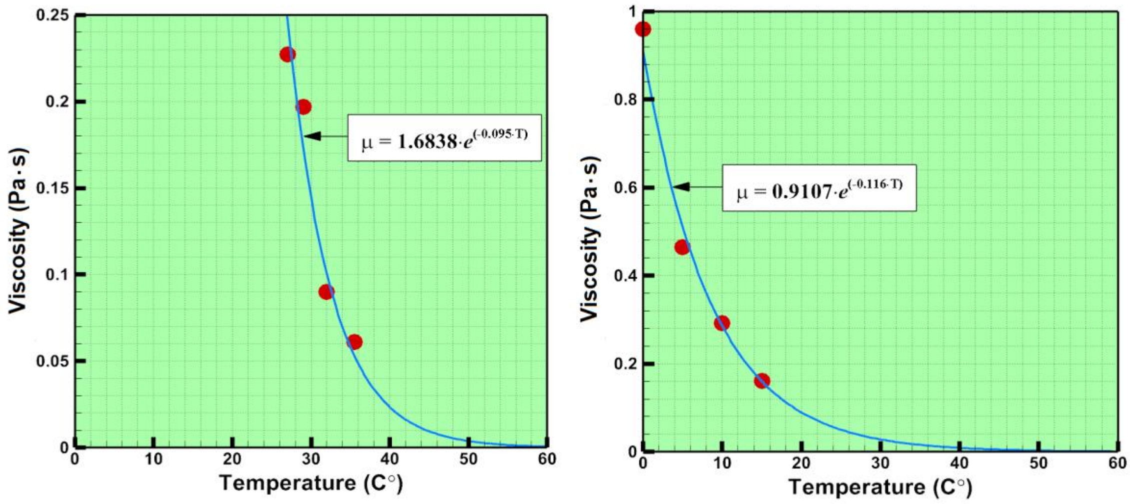
The length of the Usen-Atyrau oil pipeline section is L = 700.3 km (see Fig.1), the pipe inner diameter is D_1 = 1.0 m, and the pipeline laying depth is H = 1.5 m.

The batch pumping of Buzachi and Mangyshlak oil blends takes place through the Uzen-Atyrau oil pipeline. The calculated data is based on the "steady state" sequential pumping with cycle times Δt_{cyc}.

The oil batches are pumped through the considered pipeline section by pumping units of the Uzen, Beineu, Kultumiev and Shmanov oil pumping stations. Along the pipeline section, there are the Uzen, Sai-Utes, Beineu, Opornaya, and Kultumiev oil heating points where the oil batches are heated by fired furnaces.

For the safety of batch pumping, the oil temperature in the pipeline should be 5 °C higher than the pour point of the Mangyshlak oil blend. One batch of the oil blend sequentially displaces the next along the length of the pipeline. The same heating temperature of both oil blends at the stations can provide a thermal mode of sequential pumping and reduce the hydraulic resistance of the Buzachi oil blend.

The calculated data were obtained for the mass of the batch of Mangyshlak oil blend is 20,000 tons and the mass of the batch of Buzachi oil blend is 21,000 tons. The volumetric flow rate of sequential pumping does not change along the length of the pipeline section.



a) b)

Figure 3 – Effective viscosity dependences on temperature: (a) Magyshlak oil blend; (b) Buzachi oil blend

In Fig. 4 the batch of the Buzachi oil blend is painted in white color, and the batch of the Mangyshlak oil blend is painted in yellow. Analysis of calculations is carried out for typical periods within 24 hours.

As can be seen from Fig. 4, the calculation data describe a picture of batch pumping of Buzachi and Mangyshlak oil blends through the Uzen-Atyrau industrial pipeline. The upper diagram illustrates the distribution of hydraulic head, the middle diagram presents the pressure distribution and the lower diagram presents the temperature distribution of oil blends and soil along the route of the section.

Pumping units create pressures to overcome the hydraulic resistance of oil blends and the static pressure of the elevations of the pipeline profile. The temperature distribution shows the heating of oil blends at heating and cooling stations due to heat exchange with the surrounding cold soil.

The batch pumping is carried out by pumping units at the Uzen and Kultumiev stations (see Fig. 4). Oil blends are heated at the following stations: Uzen, Sai-Utes, Beineu, Opornaya, Kultumiev, Shmanov. Wave-like temperature change is caused by the higher heat content of the Mangyshlak oil blend compared to the Buzachi oil blend.

Fig. 5 shows the calculated data (lines) of hydraulic head, pressure and temperature in comparison with the actual data (points) of batch pumping through the Uzen-Atyrau industrial pipeline. The actual data of the hydraulic head, pressure and temperature are obtained by measuring the flow parameters of oil blends by sensors of the SCADA.

As depicted in Figure 5, the actual SCADA data points align closely with the computed values for hydraulic head, pressure, and temperature, represented by the lines.

Referring to the earlier statement, the thermal mode for batch pumping necessitates maintaining the oil blend's temperature within the pipeline at least 5°C above the pour point of Mangyshlak oil blend (Tpp = 27°C). Consequently, the selection of furnace heating temperatures at the respective stations becomes crucial to uphold the desired thermal conditions along the Uzen-Atyrau pipeline.

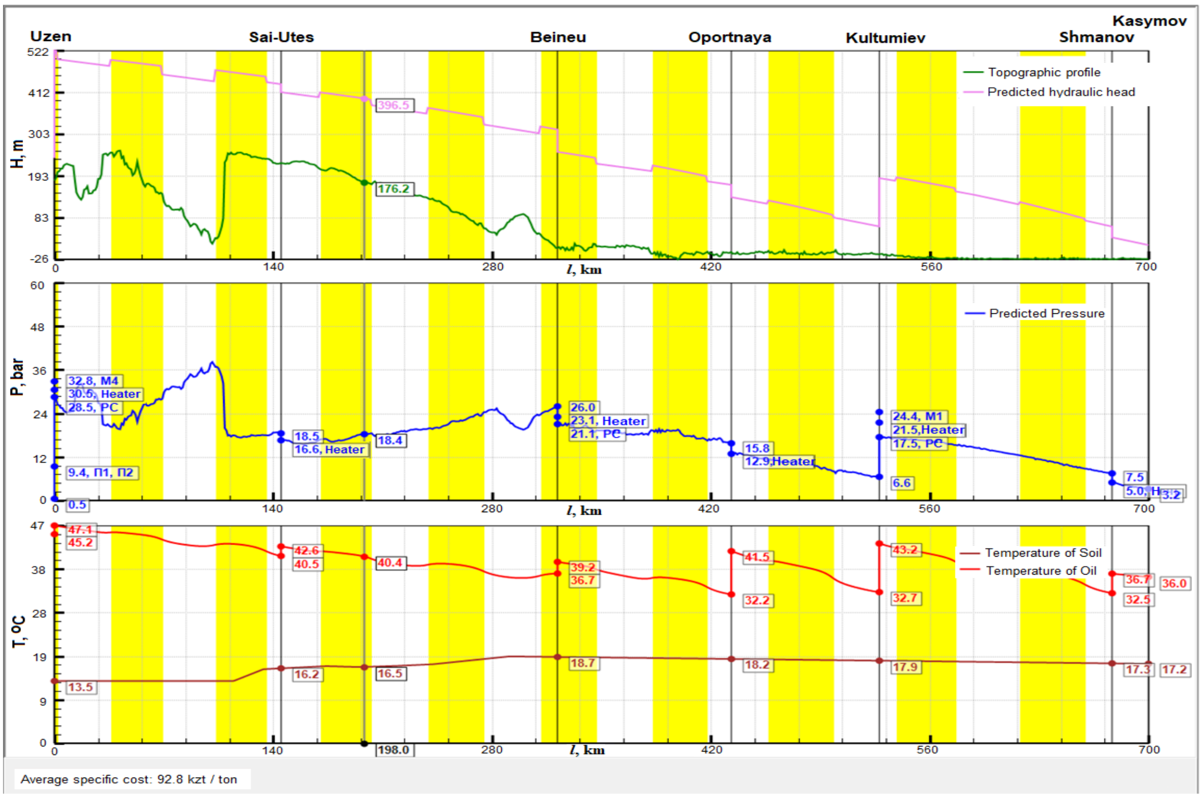


Figure 4 – The sequential pumping mode of the Buzachi and Mangyshlak oil blends

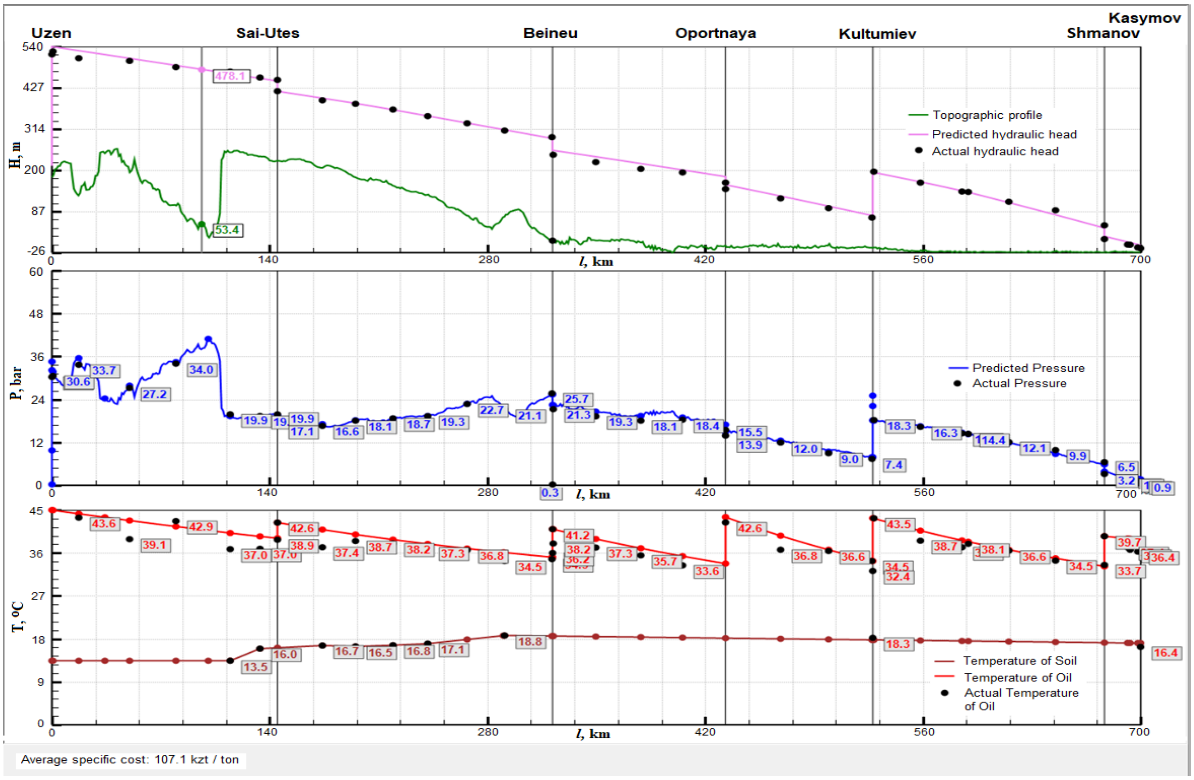


Figure 5 – Distribution of hydraulic head (upper diagram), pressure (middle diagram) and temperature (lower diagram) of the oil batch pumping

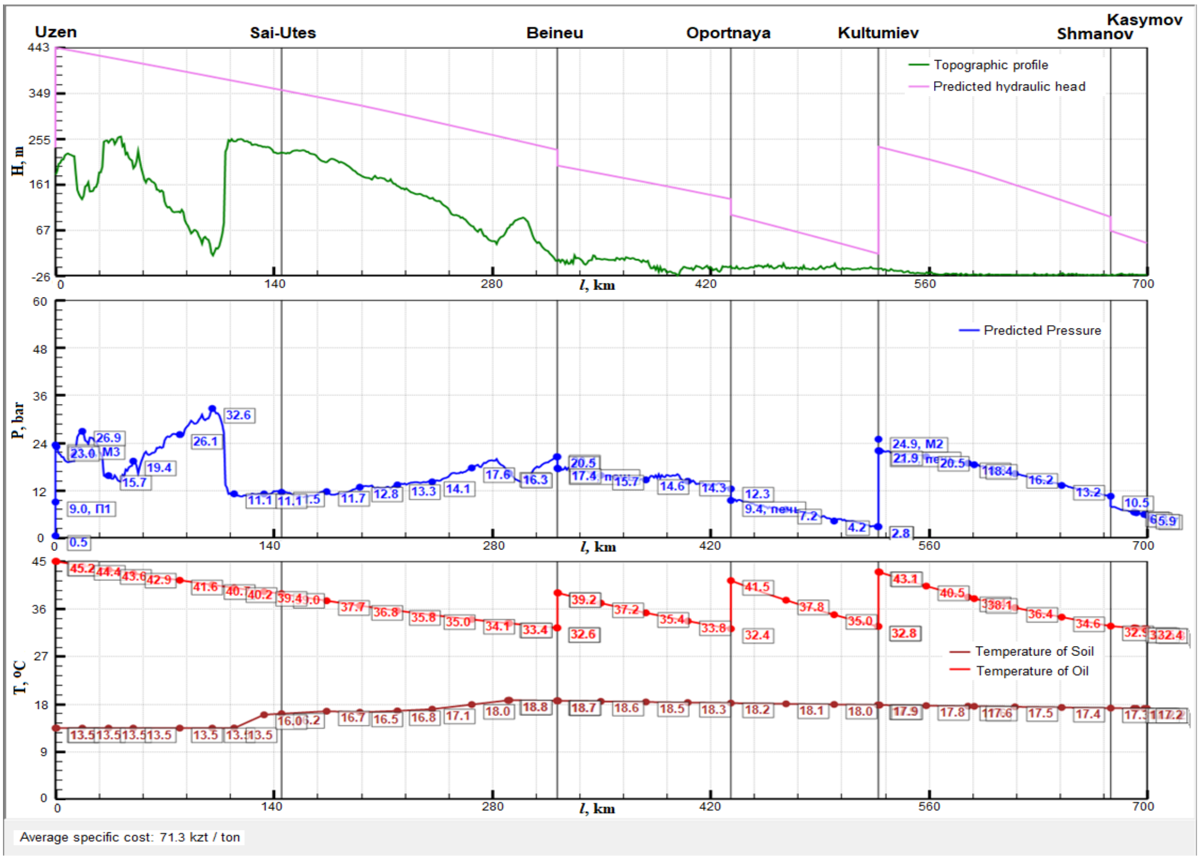


Figure 6 – Distribution of hydraulic head (upper diagram), pressure (middle diagram) and temperature (lower diagram) of batch pumping in optimal mode

According to the algorithm [25], the lower bound of the search for the heating temperature of oil blends at stations is assumed to be 32 °C. Conversely, the upper limit is determined by an optimization criterion.

Figure 6 shows the results of the search for the heating temperature of oil blends at the stations. As a result of the search, the upper limit of the heating temperature at Uzen is 45.2 °C, at Beineu is 39.2 °C, at Opornaya is 41.5 °C, and at Kultumiev is 43.1 °C (see Fig. 6).

The temperature of the oil blends within the pipeline remains consistently above 32°C, ensuring a safe thermal regime for cyclic pumping, as depicted in Figure 6.

The heating temperature decreases at the Beineu, Opornaya and Kultumiev stations, while there is no oil heating at the Sai-Utes and Shmanov stations, as shown in Figure 6. The specific cost of batch pumping decreases from $0.28 per ton (see Fig. 5) to $0.19 per ton (see Fig. 6), resulting in a savings of 32 %.

Conclusion

1. The mathematical model and algorithm for calculating the batch pumping of high-viscosity and high-pour-point oil blends through the Uzen-Atyrau industrial oil pipeline have been developed. The validity and accuracy of the mathematical model's outcomes were confirmed through rigorous validation against real-time data derived from the SCADA system.

2. The calculated data of the batch pumping through the Uzen-Atyrau industrial pipeline have been obtained:

- depending on the volume of pumped batches of Mangyshlak oil blend weighing 20,000 tons and batches of Buzachi oil blend weighing 21,000 tons;
- by searching for the optimal heating temperature of oil blends at stations with a lower limit of 32 °C and a distribution of soil temperature;

3. The identification of optimal operational conditions for the pumping units and heating furnaces has led to a noteworthy reduction of 32% in the unit costs attributed to both oil blend pumping and heating.

Conflict of interest. On behalf of all the authors, the correspondent author declares that there is no conflict of interest.

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Өнеркәсіптік құбыр арқылы мұнайдың әртүрлі партияларын тізбекті тасымалдау

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ТҮЙІНДЕМЕ
Тізбекті тасымалдау әдісінде физикалық және химиялық қасиеттері әртүрлі бірнеше сұйықтықтар бір құбыр арқылы айдалады. Мақалада өнеркәсіптік мұнай құбыры арқылы әртүрлі физикалық және химиялық қасиеттері бар мұнай қоспаларының екі партиясын тізбекті айдау қарастырылады. Жоғары парафинді мұнай партиясы бір мезгілде мұнай өңдеу зауытына айдалады, ал тұтқырлығы жоғары мұнай партиясы құбыр арқылы әрі қарай тасымалданады. Мұнай партияларының жылу физикалық және реологиялық қасиеттері арасындағы айырмашылық құбырдың жылулық жұмыс жағдайларына әсер етеді. Жоғары парафинді және жоғары тұтқыр мұнай қоспаларының кезекпен тасымалдануын есептеудің математикалық моделі мен алгоритмі құрылды. Жылу гидравликалық есептеулер айдау қондырғылары мен қыздыру пештерінің жұмыс жағдайында мұнай қоспалары

партияларының гидравликалық қысымының, қысымының және температурасының таралуын анықтайды. Теориялық талдауды тексеру және валидациялау өнеркәсіптік құбырдың ұзындығы бойынша SCADA тәжірибелік деректерді пайдалану арқылы жүзеге асырылды. Тізбектеп айдаудың жылу режиміне сәйкес өнеркәсіптік құбыр станцияларында мұнай қоспаларын қыздыру үшін оңтайлы температуралар табылды.

Түйін сөздер: тізбекті тасымалдау, мұнай қоспаларының партиясы, жоғары парафинді мұнай, жоғары тұтқырлы мұнай, қыздыру температурасы, өндірістік құбыр

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Последовательная перекачка различных партий нефти по промышленному трубопроводу

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АННОТАЦИЯ

При последовательной перекачке по одному трубопроводу перекачивается несколько жидкостей с разными физико-химическими свойствами. В статье рассматривается последовательная перекачка двух партий нефтесмесей с различными физико-химическими свойствами по промышленному нефтепроводу. Это связано с тем, что партия высокопарафинистой нефтесмеси перекачивается на нефтеперерабатывающий завод, а партия высоковязкой нефтесмеси транспортируется далее по трубопроводу. Разница между теплофизическими и реологическими свойствами партий нефти накладывает условие на тепловой режим работы трубопровода. Создана математическая модель и алгоритм для расчета последовательной транспортировки высокопарафинистых и высоковязких нефтяных смесей. Теплогидравлические расчеты показывают распределение гидравлического напора, давления и температуры партий нефтесмечей в условиях работы насосных агрегатов и печей нагрева. Верификация и валидация теоретического анализа проводилась с помощью экспериментальных данных SCADA по длине промышленного трубопровода. В соответствии с тепловым режимом последовательной перекачки найдены оптимальные температуры нагрева нефтяных смесей на станциях трубопровода.

Ключевые слова: последовательная перекачка, партия нефтяных смесей, высокопарафинистая нефть, высоковязкая нефть, температура подогрева, промышленный трубопровод.

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