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Mismatch problem of the model and topology of oil pumping facilities

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ABSTRACT

The mismatch of the model and the topology of real objects is important in modeling technological processes, which is the purpose of this paper. The problem is considered when modeling hot oil pumping in the "Kasymov–Bolshoy Chagan" oil pipeline. In this problem, the topology of objects consists of the linear part of the pipeline and technological equipment (pumps and heating furnaces) of the stations. The accuracy of the simulation results is determined by the calculations of pressure and temperature in the oil pipeline. The pressure in the pipeline is created by pumps at the stations and is determined by the dependence of the pressure and efficiency of the pump on the oil flow rate. These characteristics change depending on the service life of the pump. The identification of the actual dependences of the pressure and efficiency of the pump on the oil flow rate was carried out by the regression analysis of experimental data. The pressure in the linear part is determined by the hydraulic resistance of the pipeline. The actual dependence of the hydraulic resistance coefficient on the Reynolds number and wall roughness was obtained by regression analysis of experimental data. The temperature in the oil pipeline is created at the stations by heating furnaces. The identification of the actual characteristics of the heating furnace was also found by regression analysis of the experimental data. The temperature distribution in the linear part is determined by the heat transfer of oil with the surrounding environment. An undefined parameter for calculating heat transfer is the soil thermal conductivity, which depends on the type of rock and the degree of soil moisture. The soil thermal conductivity is determined in such a way that at a given oil flow rate, oil temperatures at the beginning of the section and soil at the section, the calculated oil temperature at the end of the section has the smallest discrepancy with the actual one. Thus, the determination of the actual dependencies of the objects makes it possible to increase the accuracy of the results of hot pumping modeling and eliminates the mismatches of the model and the topology of the objects.

Keywords: regression analysis, mismatches of the model and topology of oil pumping facilities, the actual data of pressure, temperature and flow rate sensors.

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Introduction

Machine learning is becoming a tool for researching technological processes in various fields of technology and production. In particular, machine learning finds application in industry, such as rolling, sheet metal forming, oil production, and transportation, well logging in uranium deposits, etc. The application of machine learning methods

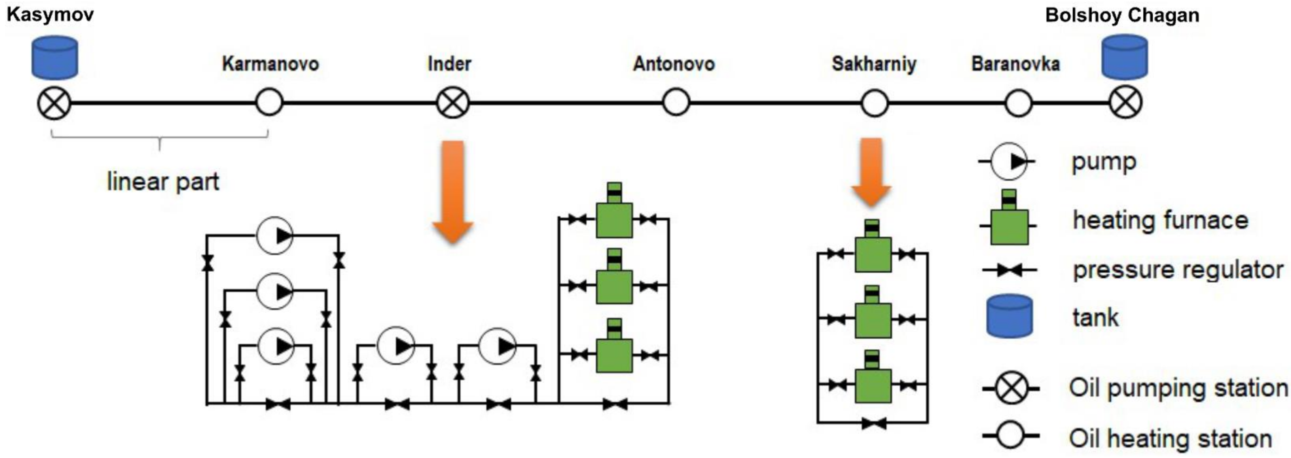


Figure 1 - Pipeline structural diagram: tanks, linear part, stations, heating furnaces, pumps, and pressure

allows analyzing and generalizing actual data to describe the patterns of processes. However, this will require a large amount of reliable empirical data. The presence of fuzzy data among them can have an impact on the results of machine learning. For the first time, Zadeh [1] introduced the concept of data oddness. Currently, the theories, models, and methods of decision-making based on fuzzy data have been developed [[2], [3], [4], [5], [6]]. The mismatch of the model and the topology of real objects is important in modeling and optimizing technological processes [[7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21]]. In this paper, this problem is considered when modeling the technological process of oil pumping. The accuracy of the pumping simulation results eliminates the mismatches of the model and the topology of real objects and expresses the novelty of this work. Below are the results of a study on achieving accuracy in calculating the pressure and temperature of hot oil transfer.

Nomenclature

OPS	Oil pumping station
OHS	Oil heating station

Problem statement

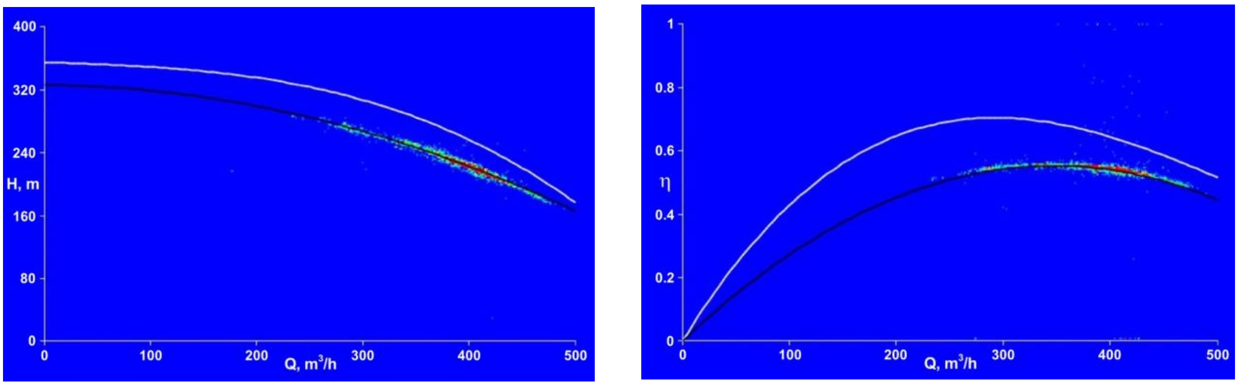
Oil is pumped in the technological sections of the "Kasymov–Bolshoy Chagan" main oil pipeline (see Figure 1). This main oil pipeline has only one starting point for the beginning of the flow (the "Kasymov" OPS) and only one endpoint for the end of the flow (the "Bolshoy Chagan" station). Oil flows through the pipeline in exactly one direction from the start station to the end station. There are intermediate stations in the pipeline. The topology of the object consists of the topology of the linear part of the pipeline and the topology of the stations. The accuracy of the simulation results of hot oil pumping is determined by the calculations of pressure and temperature in the oil pipeline [[22], [23]].

The pressure in the pipeline is created by pumps at the stations and is determined by the dependence of the pressure and efficiency of the pump on the oil flow rate. These characteristics change depending on the service life of the pump (see Fig. 2). The pressure in the linear part is determined by the hydraulic resistance of the pipeline. This value varies depending on the Reynolds number and the roughness of the pipeline wall (see Fig. 3).

The temperature in the oil pipeline is created at the stations by heating furnaces and the energy costs of the furnaces depend on the efficiency of the furnace. The temperature distribution in the linear part is determined by the heat transfer of oil to the environment and depends on the accuracy of determining the thermal conductivity of the soil (see Fig. 4).

Machine learning regression analyzes the accuracy of determining the characteristics of pumps and heating furnaces, as well as the hydraulic and thermal characteristics of the pipeline. For this, the actual readings of sensors (pressure, temperature, and flow) in the "Kasymov–Bolshoy Chagan" oil pipeline are used.

The accuracy of the simulation results depends on the accuracy of determining the characteristics of objects at the station (pumps and heating furnaces), as well as the hydraulics and heat transfer of the linear section of the oil pipeline.



a) Head curves b) Efficiency curves

Figure 2 - Identification of the characteristics of the pump at the "Kasymov" OPS by the regression analysis of experimental data.

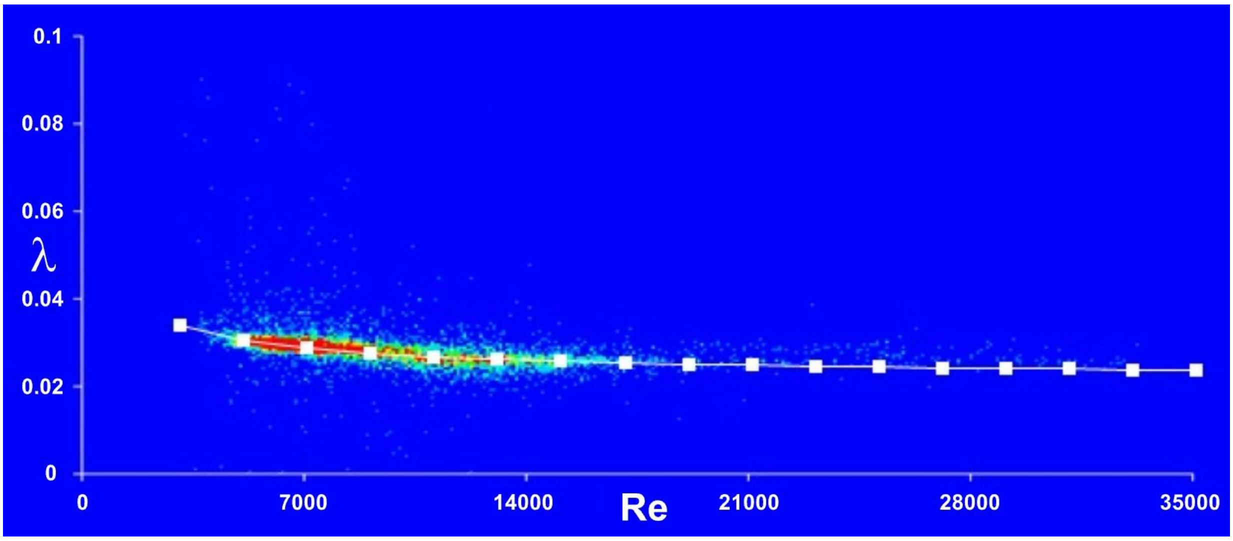


Figure 3 - Identification of the hydraulic resistance coefficient of the "Kasymov–Bolshoy Chagan" oil pipeline by the regression analysis of experimental data

Pressure distribution calculation along the pipeline

The pressure in the oil pipeline can vary at the stations and at the linear part. In the stations, the pressure in the pipe can increase due to the operation of pumps.

It is known that the pressure and efficiency of the pump functionally depend on the flow rate of pumped oil. This dependence, as a rule, is revealed as a result of factory tests and is indicated in the pump passport as the pressure and efficiency characteristics of the pump. During operation, the pressure and efficiency characteristics of the pump change. Practice shows that using the correct actual sensor data, for each pump, it is possible to obtain a clear actual dependence of head and efficiency on the flow rate of oil.

Figure 2 shows an example of the obtained actual characteristics of the pump (main pump No. 1 at the "Kasymov" OPS), using data on flow rate, oil density, pressure at the inlet and outlet of the pump, and electricity consumption. The colored dots are the actual pairs of head and flow rate values (see Figure 2, a), as well as the pairs of efficiency and flow values (Figure 2, b). The colors of the dots indicate the concentration of data in the area: from blue (no data) to red (maximum data concentration). The white lines show the passport head and efficiency curve, the black lines show the actual curve.

Thus, for each pump, it is possible to accurately calculate its generated pressure (by a head) and power consumption (based on efficiency) at a given

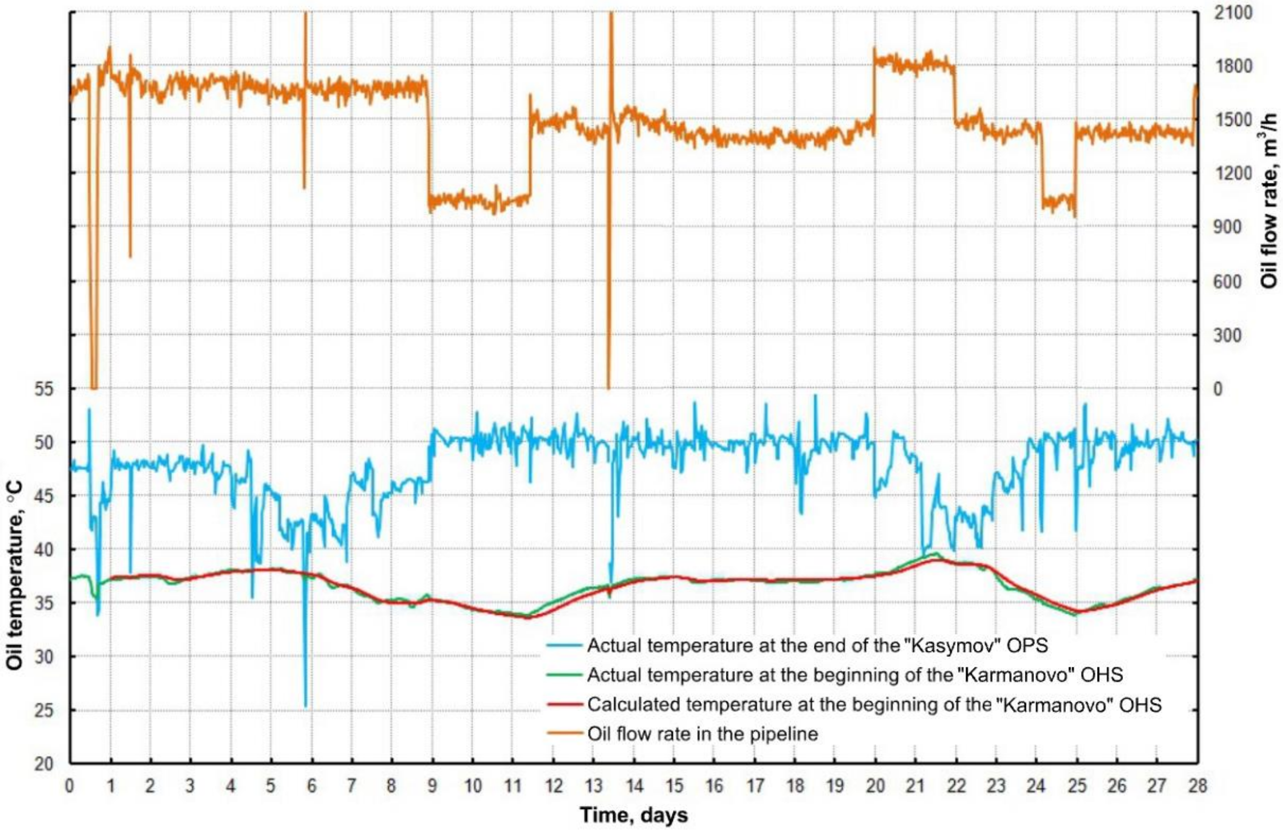


Figure 4 - Comparison of the actual and calculated temperature at the end of the section with the thermal conductivity value in the period of the month of February 2021 at the section of the "Kasymov" OPS–the"Karmanovo" OHS.

oil consumption by using the machine learning regression analysis.

At the linear part, the pressure changes due to the loss of the resistance of the oil flow through the pipeline. In the "Kasymov–Bolshoy Chagan" oil pipeline, the oil flow regime is turbulent. Hydraulic losses in the pipeline are calculated according to the well-known Darcy-Weisbach formula [24]. The hydraulic resistance coefficient of the Darcy-Weisbach formula depends on the Reynolds number and the wall roughness, which is determined by the empirical formulas of the following works [[25], [26], [27], [28], [29]].

The roughness coefficient changes during pipeline operation. As well as the pipe roughness, it can be non-uniform along the pipeline length, for example, as a result of repairs, the pipe sections can be replaced in the pipeline. It follows that without actual data on the condition of the pipes, the calculated values of total hydraulic losses in the pipe may differ significantly from the actual ones. Using the actual pressure and temperature data by the machine learning regression analysis, it is possible to construct the pipe hydraulic resistance coefficient dependence and determine the wall roughness effect. Figure 3 shows the found actual dependence of the hydraulic resistance coefficient of the Darcy-Weisbach formula on the Reynolds number in the turbulent flow regime in the "Kasymov–Bolshoy Chagan" oil pipeline.

Temperature distribution calculation along the pipeline

The temperature in the pipeline may vary in the stations and the pipeline linear part. In the stations, the temperature can rise due to heating in the furnaces. Using the actual data from the data of heating furnace sensors, it is possible to build actual dependences for the efficiency of heating furnaces, as in the case of the pump (see Figure 2, b).

In the linear part, the oil temperature decreases due to heat exchange with the surrounding soil of the pipeline, and there are various models for calculating the heat exchange of the oil flow with the surrounding soil [[22], [23]].

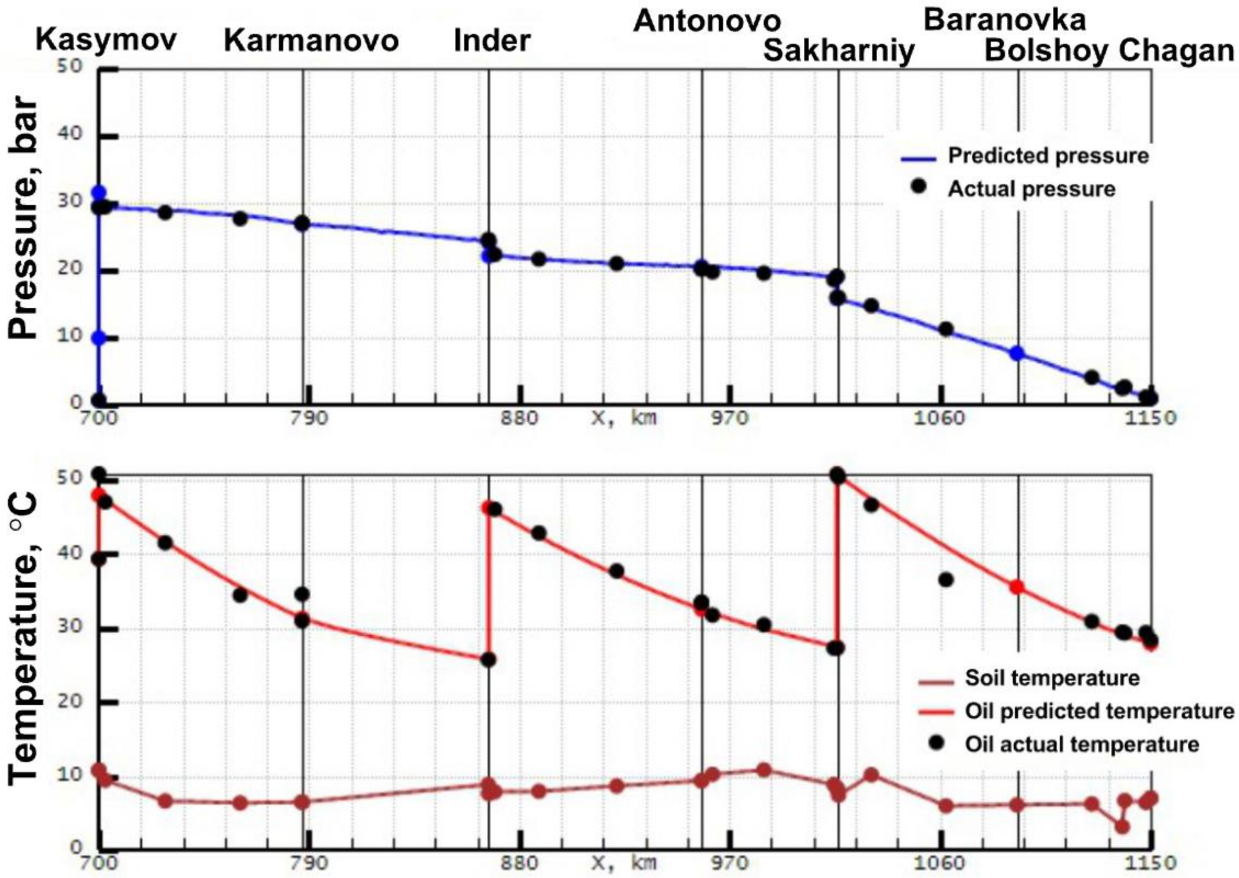


Figure 5 - Comparison of calculated and experimental data on the distribution of pressure (the blue line on the top diagram) and temperature (the red line on the bottom diagram) along the length of the "Kasymov–Bolshoi Chagan" oil pipeline at an oil flow rate of 1143 m^3/hour. In the diagrams: the lines are the calculated data, and the dots are the experimental data.

Some calculation parameters are known: flow rate, insulation, soil temperature, and the properties of oil and metal pipes.

The undefined parameter is the soil thermal conductivity. It is known that the soil thermal conductivity depends on the type of soil rock (sand, sandy loam, loam, clay, etc.) and on the degree of soil moisture.

It is obvious that the soil thermal conductivity value is not constant along the pipeline length and over time (it depends on the snowmelt season and the frequency of rains for a given area). Therefore, without investigating the actual data, the calculated oil temperature distributions along the pipeline may differ significantly from the actual one. When finding the calculated thermal conductivity, its value is averaged over the length and time. Averaging over the length depends on the distribution density of temperature sensors along the pipeline. In the "Kasymov–Bolshoy Chagan" main oil pipeline, temperature sensors are located quite often (at a distance of 5-15 km). Averaging over time is sufficient to carry out by month or by 10-15 days (for some months). The determination of the soil thermal conductivity is carried out in such a way that for a given oil flow rate in the pipe, oil temperatures at the beginning of the section and soil temperatures at the section, the calculated oil temperature at the end of the section has the least discrepancy with the actual one. Figure 4 shows the comparison of the actual and calculated temperature (see the red and green lines in the figure) at the end of the section with the found value of the soil thermal conductivity in the section of the "Kasymov" OPS–the"Karmanovo" OHS.

Thus, by the regression analysis of the actual data, the dependencies of the topology of oil pumping facilities are determined and used for the accuracy of thermal-hydraulic calculations. As can be seen from Figure 5, the calculated pressure and temperature distributions agree with the actual data along the length of the "Kasymov–Bolshoy Chagan" oil pipeline.

Conclusions

The mismatches of the model and topology of objects are determined by the accuracy of pressure and temperature calculations along the "Kasymov–Bolshoy Chagan" oil pipeline length. The results of pressure and temperature calculations depend on the actual dependencies of the pumps and heating furnaces, as well as the hydraulic and thermal characteristics of the pipeline.

The machine learning regression analysis makes it possible to analyze the accuracy of determining the actual dependencies of pumps and heating furnaces, as well as the hydraulic and thermal characteristics of the pipeline.

By the regression analysis of the actual data, the following were obtained:

1) the dependences of the pressure characteristics and efficiency of pumps, as well as the efficiency of heating furnaces, considering their operating resources;

2) the pipeline hydraulic resistance coefficient dependence on the Reynolds number;

3) the dependences of the soil thermal conductivity to determine the oil flow heat transfer coefficient in the pipe with the environment.

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

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Мұнай айдау объектілерінің моделі мен топологиясының сәйкессіздігінің проблемасы

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ТҮЙІНДЕМЕ

Нақты нысандардың моделі мен топологиясының арасындағы сәйкессіздік технологиялық процестерді модельдеген кезде маңызды және осы мақаланың мақсаты болып табылады. Қасымов-Большой Шаған мұнай құбырында ыстық мұнай айдауды модельдеу мәселесі қарастырылды. Бұл мәселеде нысандардың топологиясы құбырдың сызықтық бөлігінен және станциялардың технологиялық жабдықтарынан (сорғылар мен жылыту пештері) тұрады. Модельдеу нәтижелерінің дәлдігі мұнай құбырындағы қысым мен температураның есептеулерімен анықталады. Құбырдағы қысым станциялардағы сорғылармен жасалады және сораптың қысымы мен ПӘК-нің мұнай ағынына тәуелділігімен анықталады. Бұл сипаттамалар сорғының қызмет ету мерзіміне қарай өзгереді. Эксперименттік мәліметтерді регрессиялық талдау арқылы қысым мен сорғы тиімділігінің мұнай шығынына нақты тәуелділігі анықталды. Сызықтық бөліктегі қысым құбырдың гидравликалық кедергісі арқылы анықталады. Гидравликалық кедергі коэффициентінің Рейнольдс санына және қабырға кедір-бұдырлығына нақты тәуелділігі тәжірибелік мәліметтерді регрессиялық талдау арқылы алынды. Мұнай құбырындағы температура станцияларда қыздыру пештері арқылы жасалады. Жылыту пешінің нақты сипаттамаларын анықтау тәжірибелік мәліметтерді регрессиялық талдау арқылы да жүргізілді. Сызықтық бөліктегі температураның таралуы мұнайдың қоршаған ортамен жылу алмасуымен анықталады. Жылу беруді есептеудің анықталмаған параметрі топырақтың жылу өткізгіштігі болып табылады, ол тау жыныстарының түріне және топырақтың ылғалдылық дәрежесіне байланысты. Топырақтың жылу өткізгіштігі мынадай түрде анықталады. Мұнайдың шығыны, учаскенің басында оның температурасы және участкедегі топырақтың температурасы беріледі. Осындай жағдайларда участкенің соңында мұнайдың есептелген температурасы фактімен сәйкес келуі керек. Осылайша, объектілердің нақты тәуелділіктерін анықтау ыстық айдау модельдеу нәтижелерінің дәлдігін арттыруға мүмкіндік береді және модель мен объектілер топологиясы арасындағы сәйкессіздіктерді жояды.

Түйін сөздер: регрессиялық талдау, айдау объектілерінің моделі мен топологиясының сәйкессіздігі, қысым, температура және шығын датчиктерінің нақты деректері

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Проблема несоответствия модели и топологии объектов перекачки нефти

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АННОТАЦИЯ

Несоответствие модели и топологии реальных объектов важно при моделировании технологических процессов, что и является целью данной статьи. Задача рассмотрена при моделировании перекачки горячей нефти в нефтепроводе «Касымов–Большой Чаган». В этой задаче топология объектов состоит из линейной части трубопровода и технологического оборудования (насосов и нагревательных печей) станций. Точность результатов моделирования определяется расчетами давления и температуры в нефтепроводе. Давление в трубопроводе создается насосами на станциях и определяется зависимостью напора и КПД насоса от расхода нефти. Эти характеристики изменяются в зависимости от срока службы насоса. Выявление реальных зависимостей напора и КПД насоса от расхода нефти осуществлялось путем регрессионного анализа экспериментальных данных. Давление в линейной части определяется гидравлическим сопротивлением трубопровода. Фактическая зависимость коэффициента гидравлического сопротивления от числа Рейнольдса и шероховатости стенки была получена путем регрессионного анализа экспериментальных данных. Температура в нефтепроводе создается на станциях нагревательными печами. Выявление реальных характеристик нагревательной печи также было установлено путем регрессионного анализа экспериментальных данных. Распределение температуры в линейной части определяется теплообменом нефти с окружающей средой. Неопределяемым параметром для расчета теплоотдачи является теплопроводность грунта, которая зависит от типа породы и степени влажности грунта. Теплопроводность грунта определяют таким образом, чтобы при заданных расходе нефти, температурах нефти в начале участка и грунта на участке расчетная температура нефти в конце участка имела наименьшее расхождение с фактической. Таким образом, определение реальных зависимостей объектов позволяет повысить точность результатов моделирования горячей откачки и устраняет несоответствия модели и топологии объектов.

Ключевые слова: регрессионный анализ, несоответствия модели и топологии объектов перекачки, фактические данные датчиков давления, температуры и расхода.

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