MECHANICAL ENGINEERING | RESEARCH ARTICLE

Oil pipeline hydraulic resistance coefficient identification

Timur Bekibayev¹, Uzak Zhapbasbayev¹, Gaukhar Ramazanova¹* and Daniyar Bossinov¹

Abstract: The purpose of the study is to identify the hydraulic resistance coefficient of the main oil pipeline. Oil transportation through pipelines is the most efficient way to deliver oil from suppliers to consumers. The volume of transported oil depends on the pipeline hydraulic resistance. In practice, the hydraulic resistance coefficient is determined by the value of the Reynolds number and the pipeline internal surface roughness. The Reynolds number depends on the oil viscosity, which changes in a non-isothermal pipeline due to the heat exchange of the oil flow with the environment. The pipeline internal surface roughness changes during main oil pipeline operation. The identification of the pipeline hydraulic resistance coefficient is necessary for accurate calculations of the technological modes of the main oil pipeline. The SCADA (supervisory control and data acquisition) system determines the actual oil data (pressure, temperature, flow rate) along the main oil pipeline length in real time. Based on the results of the thermal-hydraulic calculations and the SCADA system, the hydraulic resistance coefficient identification method was built. The methodology was tested in

ABOUT THE AUTHOR
Timur Bekibayev is the Laureate of the State Prize of the Republic of Kazakhstan in the field of science and technology, Master of Information Systems, Head of the Department at Satbayev University. His research interests are related to the theory of algorithms and data structures, optimization methods, neural networks and programming problems in physics and technology. Uzak Zhapbasbayev is the Laureate of the State Prize of the Republic of Kazakhstan in the field of science and technology, Doctor of Technical Science, Professor, Head of the Research Laboratory at Satbayev University. He has written more than 190 publications. He has been the scientific supervisor of more than 25 international and Kazakhstan scientific projects. Gaukhar Ramazanova is the Candidate of Physical and Mathematical Sciences, Senior Researcher at Satbayev University. She has written more than 60 publications, including “Modeling of the beryllia ceramics formation process”, “Management of Oil Transportation by Main Pipelines”. Her research interests are related to rheological models, non-Newtonian flows, data mining.

PUBLIC INTEREST STATEMENT
The crude oil pipeline transport is a complex energy industry, including trunk pipelines, pumping and heating stations, oil terminals, etc. One of the most important tasks of the pipeline transport is the energy-saving problem. We have developed the SmartTran software to optimize the crude oil transport technological modes. It allows automatically to calculate the energy-saving modes and to solve the optimal planning problem of the oil transport volumes from oil suppliers to consumers.

The SmartTran is integrated with the SCADA system to perform the thermal-hydraulic calculations in real-time.

The accuracy of the thermal-hydraulic calculations depends on the identification of the hydraulic resistance coefficient, which depends on the parameters of oil flow and pipeline. The integration of the SmartTran with the SCADA made it possible to identify the change in the hydraulic resistance of the pipeline.

As a result, it is possible to significantly increase the speed and efficiency of decision-making and reduce the operating costs of the crude oil transport.

© 2021 The Author(s). This open access article is distributed under a Creative Commons Attribution (CC-BY) 4.0 license.
the OPS-3—Koschagil, Severnye Buzachi—Karazhanbas, Prorva—Kultumiyev, Kassymov—Bolshoi Chagan main pipeline sections. The approbation results have shown sufficient accuracy in identifying the hydraulic resistance coefficient of oil pipelines. The obtained hydraulic resistance coefficient dependences were used to determine the oil transportation technological modes in industrial pipelines.

**Subjects:** Mathematical Modeling; Mechanical Engineering; Heat Transfer

**Keywords:** identification methodology; hydraulic resistance coefficient; oil flow; thermal-hydraulic calculation; actual data of SCADA system

1. **Introduction**

Pipeline transportation is the main means of delivering oil to consumers. Pipeline capacity is determined by the technological modes and the hydraulic losses when pumping oil (Aliyev et al., 1988).

Pipeline hydraulic resistance depends on many factors when pumping high-pour-point and high-viscosity oil (Zhumagulov et al., 2002). The oil temperature changes due to the heat exchange with the environment, causes an increase in viscosity and an increase in pipeline hydraulic resistance. The pipeline internal surface roughness changes because of the pipeline operation. All this leads to a change in the hydraulic resistance coefficient. These processes occur most intensively in cases of improper use of the pipeline operation technological modes.

A large number of the empirical formulas are used to determine the pipeline hydraulic resistance coefficient (Akers et al., 2006; Altshul, 1982; Colebrook, 1939; Colebrook & White, 1937; Idel’chik, 1992; Morozova & Korshak, 2007; Munson et al., 2006; Schlikhting, 1974; Tugunov et al., 2002).

The application of the Colebrook equation has difficulties in the hydraulic calculations of the pipelines. Brkić (2011) performed a review of the existing explicit approximations and constructed an algorithm for calculating the Colebrook equation. It has been shown that most of the available approximations of the Colebrook formula (including the Altshul’s formula) are accurate with a difference of a few percent.

Brkić and Praks (2019), (Praks & Brkić, 2020) showed a way to construct accurate and efficient approximations of the Colebrook equation. The use of the shifted Lambert W function, also known as the Wright omega function, made it possible to speed up the calculations and obtain the data with a relative error of 0.0096% to 0.000024%.

Swamee (1993) considered the hot crude oil flow in subsea oil pipeline. As the flow progresses, the hot crude oil gradually cools, increasing the viscosity and the hydraulic resistance. When cooling the crude oil, the flow can change the regime from turbulent to laminar. The unified equation of the hydraulic resistance coefficient is obtained, which acts both in the laminar and in the turbulent flows of subsea oil pipelines.

Brkić and Praks (2018) presented a new unified formula for Newtonian fluids, valid for all flow regimes in the pipe from a laminar to fully turbulent flow.

This formula follows the bended shape of the curves obtained in the Nikuradze’s experiments, rather than the monotonic shape proposed by Colebrook and White. The unified formula uses the switching functions and the interchangeable formulas for the laminar, transient and fully turbulent flow regimes.

Aida-Zade and Kuliev (2016) considered the pipeline hydraulic resistance coefficient identification approach using the finite-dimensional optimization problem.
Savic et al. (2009) examined the temperature dependence of the viscosity influence on the hydraulic resistance coefficient value.

Zholobov (2019) presented the numerical method of the pipeline hydraulic model identification. Zholobov (2019) established the structural dependence on the parameters for calculating friction losses in pressure pipelines based on the experimental data. A numerical calculation algorithm was proposed, permitting the structural dependence parameter values of the hydraulic resistance coefficient to be restored.

Currently, the implementation of the SCADA system has made it possible to directly monitor the main pipeline state. In real time, it is possible to collect data on the operation of the technological equipment, the valve interlocks, the pressure regulators and the oil pumping modes. The SCADA system sensors measure flow rate, pressure, oil and soil temperatures. The actual data of the SCADA system can be used to identify the pipeline hydraulic resistance coefficient.

In this paper, a hydraulic resistance coefficient identification methodology by using the actual data of the SCADA system and the results of the thermal-hydraulic calculations of the SmartTranPro software (Beisembetov et al., 2020) is proposed.

2. Mathematical model
A section of an underground pipeline with a length L and an inner diameter D₁ is considered (see Figure 1). The SCADA sensors can determine the actual data when pumping oil (flow rate, pressure, temperature) in the main pipeline section.

The oil flow is considered a Newtonian fluid. The length of the pipeline L is measured in kilometers, while the diameter is measured in meters (D₁, D₂). Therefore, a one-dimensional model can be applied.

The continuity equation for the flow is:

\[ \frac{\partial p}{\partial t} + \frac{\partial \rho u}{\partial x} = 0 \]  \hspace{1cm} (1)

The momentum equation for the flow is:

\[ \rho \frac{\partial u}{\partial t} + \frac{\partial p}{\partial x} = -\zeta \left( \frac{\rho u |u|}{2D_1} \right) - \rho g \sin \beta (x) \]  \hspace{1cm} (2)

Figure 1. The diagram of the pipeline section.
The energy equation for the flow is:

$$\frac{\partial t}{\partial t} + u \frac{\partial t}{\partial x} = -\frac{4k}{\rho \mu D_1} (t - t_w) + \frac{\zeta u^3}{2 \rho \mu D_1}$$

(3)

where $\rho$ [bar] is the pressure; $u$ [m/s] is the flow velocity; $\tau$ [s] is the time; $x$ [m] is the coordinate; $t$ [°C] is the oil temperature; $c_p$ [J/(kg⋅°C)] is the heat capacity; $\zeta = \zeta(Re, \epsilon)$ is the hydraulic resistance coefficient; $Re = \rho u D_1 / \mu$ is the Reynolds number; $k$ [W/(m² °C)] is the heat transfer coefficient; $\epsilon$ is the pipeline internal surface roughness; $t_w$ [°C] is the soil temperature; $\beta = \beta(x)$ is the pipeline inclination angle.

The system of equations (1)–(3) is solved at the initial and boundary conditions:

$$\tau = 0: \ u(x) = u_0, \ p(x) = p^0, \ t(x) = t_w$$

(4)

$$\tau \geq 0, \ x = 0: \ u = u_0, \ p = p_0, \ t = t_0$$

(5)

In the equation (2), the head loss coefficient $\zeta$ is determined by comparing the calculation with the actual data of the SCADA system. In the laminar regime of a Newtonian fluid, in accordance with the Poiseuille’s formula $\zeta = 64/Re$ (Schlikhting, 1974), the regression model was used:

$$\zeta(Re) = \frac{a}{Re^b}$$

(6)

where $a, b$ are the calculated coefficients.

For the turbulent regime, in accordance with the Altshul’s formula (Altshul, 1982; Idel’chik, 1992), the regression model was used:

$$\zeta(Re) = a \left( \frac{64}{Re} + \epsilon \right)^b$$

(7)

where $\epsilon = \delta/D_1$ is the pipeline internal surface roughness, $a, b$ are the calculated coefficients.

In the classical Altshul’s formula, the constants $a, b$ have the values $a = 0.11, b = 0.25$.

3. Closures of relations

The experimental data on the dependences of the oil heat capacity and the oil density on the temperature are described by the empirical formulas (Tugunov et al., 2002):

$$c_p(t) = (53357 + 107.2 \cdot t) / \sqrt{\rho_20}$$

(8)

$$\rho(t) = \rho_20 [1 + \zeta \cdot (20 - t)]$$

(9)

where $\zeta = 0.000738$ [°C⁻¹] is the oil volume expansion coefficient.

The value of the heat transfer coefficient $k$ is found according to the standard formula:
\[
\frac{1}{kD_1} = \frac{1}{\alpha_1D_1} + \sum_{i=1}^{n-1} \frac{1}{2\lambda_i} \ln \frac{D_{i+1}}{D_i} + \frac{1}{\alpha_2D_2}
\]

(10)

where \(\alpha_1\) [W/(m²°C)] is the internal heat transfer coefficient; \(\alpha_2\) [W/(m²°C)] is the external heat transfer coefficient; \(D_2\) [m] is the pipeline outer diameter; \(D_i\) [m] are the outer diameters of the insulation layers; \(\lambda_i\) [W/(m·°C)] are the thermal conductivity coefficients of the pipeline wall and the insulation coating layers.

The internal heat transfer coefficient from oil to the pipe wall \(\alpha_1\) is defined as:

\[
\alpha_1 = \lambda_n \cdot \frac{Nu}{D_1}
\]

(11)

where \(\lambda_n\) [W/(m·°C)] is the oil thermal conductivity; \(Nu\) is the Nusselt number of heat transfer from oil to the pipe wall.

The heat transfer coefficient \(\alpha_1\) is found using the criterion dependences of the Nusselt number (Cebeci & Bradshaw, 1987).

The Nusselt number for the laminar regime is equal to \(Nu = 4.364\).

The Nusselt number for the turbulent regime is found by the following formula:

\[
Nu = 0.021 \cdot Re^{0.8} Pr^{0.4}
\]

(12)

where \(Pr\) is the Prandtl number.

The thermal conductivity coefficients of the wall and the insulation \(\lambda_i\) [W/(m·°C)] are found by the reference material.

As calculations have shown, the underground oil pipeline heat transfer coefficient \(\alpha_2\) mainly depends on the external heat transfer coefficient \(\alpha_2\) determined by Forchheimer-Vlasov’s formula (Tugunov et al., 2002):

\[
\alpha_2 = \frac{2\lambda_w}{D_2 \ln \left[ \frac{2H}{D'_2} + \sqrt{\left( \frac{2H}{D'_2} \right)^2 - 1} \right]}
\]

(13)

where \(\lambda_w\) [W/(m·°C)] is the soil thermal conductivity coefficient, \(H\) [m] is the pipeline laying depth. The soil thermal conductivity coefficient \(\lambda_w\) and the soil temperature \(t_w\) were found from the measurement data of the SCADA system sensors.

4. Calculation algorithm

The system of equations (1)—(3) with the initial and boundary conditions (4), (5) and closures of relations (6)—(13) is solved by the numerical method (Anderson et al., 1990). The value of the hydraulic resistance coefficient \(\zeta_i^{n+1}\) is expressed by Poiseuille’s or Altshul’s formulas, depending on the flow regime, respectively. This hydraulic resistance coefficient value is put into the equation of momentum (2) and the pressure \(p_j^{n+1}\), velocity \(u_j^{n+1}\), temperature \(t_j^{n+1}\) values at the difference grid nodes are calculated. According to the obtained temperature distribution \(t_j^{n+1}\), the values of the viscosity \(\mu_j^{n+1}(t_j^{n+1})\) and the Reynolds number \(Re_j^{n+1}\) are found. According to the found Reynolds number \(Re_j^{n+1}\), the value of the hydraulic resistance coefficient \(\zeta_j^{n+1}\) is specified. The found pressure and temperature field is compared with the actual data of the SCADA system. Where there is
a difference of the calculated and actual values of pressure and temperature, the iteration process continues until the calculated and actual data of pressure and temperature do not coincide with accuracy up to 0.01.

The SmartTranPro software conducts the thermal-hydraulic calculations by the system of equations (1)-(3) with the conditions (4)-(13) for the oil pumping modes in the main oil pipelines.

5. Results and discussion

The calculations of identifying the hydraulic resistance coefficient were carried out in the OPS-3—Koschagil, Severnye Buzachi—Karazhanbas, Prorva—Kultumiyev, Kassymov—Bolshoi Chagan main oil pipelines.

5.1. The OPS-3—Koschagil main oil pipeline

The OPS-3—Koschagil main oil pipeline profile is shown in Figure 2, the OPS-3 is located 62.2 m above the sea level, whereas the Koschagil OPS, is 15.4 m below the sea level.

The oil pipeline length is $L = 119.864$ km, the inner diameter is $D_1 = 0.309$ m, the occurrence depth is $H = 1.1$ m, and the pipeline internal surface roughness is $\Delta = 0.5$ mm. The oil density at a temperature of 20 °C is 894.4 kg/m$^3$. The dependence of the oil viscosity $\mu$[Pa⋅s] on the temperature was found according to the SCADA system and is expressed by the following formula:

$$\mu(t) = 0.5334 \cdot \exp(-0.074 \cdot t)$$

(14)

The SCADA system determines the oil flow parameters in real time along the pipeline length (see Figure 1). The oil viscosity and the Reynolds number Re are determined from the oil temperature. The Darcy-Weisbach formula (Tugunov et al., 2002) is used to determine the experimental values of the hydraulic resistance coefficient $\zeta$. The experimental data of $\text{Re}$ and $\zeta$ were processed by the regression model and the dependence of $\zeta(\text{Re})$ was plotted (see Figure 3).
The obtained dependence $\zeta(Re)$ satisfies Poiseuille’s law (see Figure 3). The thermal-hydraulic calculations of the OPS-3—Koschagil oil pipeline were carried out using the dependence of $\zeta(Re)$. The mode (operating) parameters of the thermal-hydraulic calculations of the oil pipeline are given in Table 1. The calculations were carried out in four modes with different values of volumetric flow rate, pressure and temperature of oil at the outlet of the OPS-3 (see Table 1). Soil temperatures are also different, and cover different periods of pipeline operation.

The comparison of the results of the thermal-hydraulic calculations of pressure and temperature nearly matches the actual data of the SCADA system (see Table 2).

5.2. The Severnye Buzachi—Karazhanbas main oil pipeline

The Severnye Buzachi—Karazhanbas main oil pipeline profile is practically horizontal (see Figure 4).

The oil pipeline length is $L = 25$ km, the inner diameter is $D_i = 0.414$ m, the occurrence depth is $H = 1.2$ m, the pipeline internal surface roughness is $\Delta = 0.75$ mm. The oil density at a temperature of 20 °C is $\rho_{20} = 938.9$ kg/m$^3$. The dependence of the oil viscosity $\mu$[Pa·s] on the temperature was found according to the SCADA system and is expressed by the following formula:

$$\mu(t) = 3.0676 \cdot \exp(-0.064 \cdot t)$$  \hspace{1cm} (15)

The pumping takes place at a volumetric oil flow rate of 160–270 m$^3$/h and temperatures of 54–56 °C at the outlet of the Severnye Buzachi HOPS.

The SCADA system determines the oil flow parameters in real time along the pipeline length. From these data, the values of the Reynolds number $Re$ and the hydraulic resistance coefficient $\zeta$ were calculated. The experimental data of $Re$ and $\zeta$ were processed by the regression model and the dependence of $\zeta(Re)$ was plotted (see Figure 5).

The actual points on the graph lie in the laminar flow zone ($Re < 2100$) and are described by the formula $\zeta = 71.6/Re$.

As can be seen from Figure 5, the actual data of the hydraulic resistance coefficient is 11.875% higher than the theoretical Poiseuille dependence. Such a discrepancy can be explained by the presence of the additional losses in the pipeline on the local resistance (taps, valves, pipe bends, etc.).

The hydraulic resistance coefficient identification in the Severnye Buzachi—Karazhanbas main oil pipeline shows the importance of determining the head loss in the pipeline for calculating the operating costs of pumping units.
| Name of parameters | Value of parameters |  
|--------------------|---------------------|  
|                    | at 01/26/2019 12:00 pm | at 03/12/2019 04:00 pm | at 05/22/2019 07:00 pm | at 07/19/2019 7:00 am |  
|                    | calculated data | actual data | calculated data | actual data | calculated data | actual data | calculated data | actual data |  
| Flow rate, m³/h | 100.2 | 100.6 | 96.0 | 96.1 | 154.7 | 154.3 | 187.2 | 186.7 |  
| Pressure at the outlet of the OPS-3, bar | 40.3 | 40.1 | 35.7 | 34.8 | 33.3 | 33.0 | 28.4 | 28.2 |  
| Pressure at the inlet of the Koschagil OPS, bar | 0.97 | 0.95 | 0.74 | 0.72 | 0.88 | 0.85 | 0.96 | 0.94 |  
| Oil temperature at the outlet of the OPS-3, °C | 29.4 | 29 | 23.1 | 23 | 23 | 23 | 29.4 | 29 |  
| Oil temperature at the inlet of the Koschagil OPS, °C | 4.9 | 4.2 | 5.4 | 5.1 | 16 | 16.6 | 22.7 | 22.4 |  

Table 2. The comparison of the calculated and actual data on the OPS-3—Koschagil oil pipeline 

Bekboiye et al., Cogent Engineering (2021), 8: 1950303

https://doi.org/10.1080/23311916.2021.1950303
5.3. The Prorva—Kultumiyev main oil pipeline

The Prorva—Kultumiyev main oil pipeline profile is below sea level from −24.6 m to −12.3 m (see Figure 6).

The oil pipeline length is \( L = 102.872 \) km, the inner diameter is \( D_1 = 0.514 \) m, the occurrence depth is \( H = 1.47 \) m, the pipeline internal surface roughness is \( \Delta = 1 \) mm. The oil density at the temperature of 20 °C is \( \rho_{20} = 868.8 \text{ kg/m}^3 \). The dependence of the oil viscosity \( \mu \) [Pa·s] on temperature was found according to the SCADA system and is expressed by the following formula:
\[ \mu(t) = 0.0226 \cdot \exp(-0.055 \cdot t) \]  

(16)

The oil contains no paraffin, the pour point is \( T_{pp} = -27 \, ^\circ C \), which allows pumping a Newtonian fluid at low temperatures. The pumping takes place at volumetric flow rates of oil in the range of 250–470 m\(^3\)/h and temperatures of 9–32 °C at the outlet of the OPs Prorva.

The SCADA system determines the oil flow parameters in real time along the pipeline length. From these data, the values of the Reynolds number \( Re \) and the hydraulic resistance coefficient \( \zeta \) were calculated. The experimental data of \( Re \) and \( \zeta \) were processed by the regression model and the dependence of \( \zeta(Re) \) was plotted (see Figure 7).

The actual points on the graph lie in the turbulent flow zone \( (Re>5000) \) and are described by the modified Altshul's formula:

\[ \zeta = 0.1 \cdot \left( \frac{68}{Re} + \epsilon \right)^{0.25} \]  

(17)

The comparison of the results of the thermal-hydraulic calculations and the actual data of the SCADA system on the Prorva—Kultumiiev main oil pipeline is shown in Figure 7. The value of the volumetric flow rate is \( Q = 404.5 \, m^3/h \), the temperature is \( T_{out} = 9.7 \, ^\circ C \) at the outlet of the Prorva OPs.

As can be seen from Figure 8, the calculated data of hydraulic head (upper graph), pressure (middle graph) nearly matches SCADA system indicators in the Prorva—Kultumiiev section. It should be noted that the indicators of the tags of hydraulic head, pressure and temperature of oil are stable, which shows sufficient accuracy of the pressure and temperature sensors of the SCADA system.

5.4. The Kassymov—Bolshoi Chagan main oil pipeline

The Kassymov—Bolshoi Chagan main oil pipeline profile is shown in Figure 9, increases from—25 m in the Kassymov OPs up to 29.3 m in the LODS Bolshoi Chagan.

The oil pipeline length is \( L = 400 \, km \), the inner diameter is \( D_1 = 1.0 \, m \), the occurrence depth is \( H = 1.4 \, m \), the pipeline internal surface roughness is \( \Delta = 2 \, mm \). The oil density at a temperature of 20 °C is \( \rho_{20} = 872.4 \, kg/m^3 \). The oil blend viscosity \( \mu [Pa \cdot s] \) dependence on temperature was found according to the SCADA system and is expressed by the following formula:

\[ \mu(t) = 0.5218 \cdot \exp(-0.097 \cdot t) \]  

(18)
The oil blend is high-viscosity and high-pour-point, the pour point is equal to $T_{pp} = 15^\circ C$. The pumping takes place at volumetric flow rates of oil in the range of 1600–2042 $m^3/h$ and temperatures of 45–55 $^\circ C$ at the outlet of the Kassymov OPS.

Based on the actual data of the SCADA system, the values of the hydraulic resistance coefficient $\zeta$ and the Reynolds number $Re$ were determined. The experimental data of $Re$ and $\zeta$ were processed by the regression model and the dependence of $\zeta(Re)$ was plotted (see Figure 10).

The actual points on the graph lie in the turbulent flow zone ($Re > 30,000$) and are described by the modified Altshul's formula (see Figure 10).

The results of the thermal-hydraulic calculations of hydraulic head (top graph), pressure (middle graph) and temperature (bottom graph) are shown in Figure 11. The actual data of the SCADA system are shown with the black points in Figure 11.
As can be seen from Figure 11, the hydraulic resistance coefficient, identified by the modified Altshul’s formula, quite accurately determines the hydraulic head losses and the pressure distribution on the Kassymov—Bolshoi Chagan main oil pipeline.

6. Conclusion

(1) The identification of the hydraulic resistance coefficient in the main oil pipelines is carried out by comparing the results of the thermal-hydraulic calculations and the actual data of the SCADA system. In the laminar regime, the differences of the actual data of the SCADA system with Poiseuille’s theoretical formula of the hydraulic resistance coefficient are obtained. In the turbulent regime, the actual data of the SCADA system are described by a modified version of Altshul’s formula.

(2) The identification methodology of the hydraulic resistance coefficient was tested in the laminar regime on the OPS-3—Koschagil, Severnye Buzachi—Karazhanbas main oil
pipelines, and in the turbulent regime on the Prorva—Kultumiyev, Kassymov—Bolshoi Chagan main oil pipelines. The approbation results have shown the applicability of the proposed methodology for identifying the hydraulic resistance coefficient of the pipeline.

The methodology reliability of the hydraulic resistance coefficient identification was shown by comparing the thermal-hydraulic calculations of the SmartTranPro software with the actual data of the SCADA system. The calculated data of hydraulic head, pressure and temperature of the OPS—3—Koschagil, Severnye Buzachi—Karazhanbas, Prorva—Kultumiyev, Kassymov—Bolshoi Chagan main oil pipelines nearly matches with the actual data.

List of abbreviations

| Acronym | Description                          |
|---------|--------------------------------------|
| OPS     | Oil pumping station                  |
| HOPS    | Head oil pumping station             |
| OHS     | Oil heating station                  |
| LODS    | Line operation dispatcher station    |

Acknowledgements

This research was funded by the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan (Grant #AP08855607) for 2020–2021.

Funding

This work was supported by the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan (AP08855607).

Author details

Timur Bekibayev
ORCID ID: http://orcid.org/0000-0001-7030-0015
Uzak Zhabpasbayev
ORCID ID: http://orcid.org/0000-0001-5973-5149
Gaukhar Ramazanova
E-mail: gaukhar.ri@gmail.com
ORCID ID: http://orcid.org/0000-0002-8689-9293
Danyyar Bossinov
ORCID ID: http://orcid.org/0000-0003-3757-6460

Citation information

Cite this article as: Oil pipeline hydraulic resistance coefficient identification, Timur Bekibayev, Uzak Zhabpasbayev, Gaukhar Ramazanova & Danyyar Bossinov, Cogent Engineering (2021), 8: 1950303.

References

Alda-Zade, K. R., & Kuliev, S. Z. (2016). Hydraulic resistance coefficient identification in pipelines. Automation and Remote Control, 16(7), 1225–1239. https://doi.org/10.1134/S0005117916070092
Aker, A., Gassman, M., & Smith, R. (2006). Hydraulic power system analysis. CRC/Taylor & Francis. https://doi.org/10.1201/9781420014587
Aliyev, R. A., Belousov, V. D., Nemudrov, A. G., Yufin, V. A., & Yokovlev, E. I. (1968). Pipeline transportation of oil and gas. Textbook for higher education. Nedra.
Altshul, A. D. (1982). Hydraulic resistance. Nedra.
Anderson, D., Tannell, J. C., & Fletcher, R. H. (1990). Computational fluid mechanics and heat transfer. Mir.
Beisembetov, I. K., Bekibayev, T. T., Zhapbsbayev, U. K., Makhmatov, E. S., & Kenzhaliyev, B. K. (2016). Management of energy-saving modes of oil mixtures transportation by the main oil pipelines. KBTU.
Beisembetov, I. K., Bekibayev, T. T., Zhapbsbayev, U. K., Ramazanova, G. I., & Panfilov, M. (2020). SmartTran software for transportation of oil JSC KazTransOil. News of the National Academy of Sciences of the Republic of Kazakhstan. Series of Geology and Technical Sciences, 204(0), 6–13. https://doi.org/10.32014/2020.2518-170X.25
Brikić, D. (2013). Review of explicit approximations to the Colebrook relation for flow friction. Journal of Petroleum Science and Engineering, 77(1), 34–48. https://doi.org/10.1016/j.petrol.2011.02.006
Brikić, D., & Proks, P. (2018). Unified friction formulation from laminar to fully rough turbulent flow. Applied Sciences, 8(11), 2036. https://doi.org/10.3390/app8112036
Brikić, D., & Proks, P. (2019). Accurate and efficient explicit approximations of the Colebrook flow friction equation based on the Wright ω-function. Mathematics, 7 (1), 34. https://doi.org/10.3390/math7010034
Cebeci, T., & Bradshaw, P. (1987). Physical and Computational Aspects of Convective Heat Transfer. Mir.
Colebrook, C. F. (1939). Turbulent flow in pipes, with particular reference to the transition region between the smooth and rough pipe laws. Journal of the Institution of Civil Engineers, 114(4), 133–156. https://doi.org/10.1680/jio.i.1939.13150
Colebrooke, C. F., & White, C. M. (1937). Experiments with fluid friction in roughened pipes. Proceedings of the royal society of London. Series A-Mathematical and Physical Sciences, 161(906), 367–381. https://doi.org/10.1098/rspa.1937.0150
Idel’chik, I. E. (1992). Handbook of hydraulic resistance. Mashinostroenie.
Morozova, N. V., & Korshak, A. A. (2007). About the boundaries of friction zones at the hydraulic calculation of oil and oil product pipelines. Oil and Gas Business, 5(1), 120–125.
Munson, B. R., Young, D. F., & Okishi, T. H. (2006). Fundamentals of fluid mechanics. John Wiley & Sons.
Proks, P., & Brikić, D. (2020). Review of new flow friction equations: Constructing Colebrook’s explicit correlations accurately. Revista Internacional De Métodos Numéricos Para Cálculo Y Diseño En Ingeniería, 36(3), 41. https://doi.org/10.23967/rimni.2020.02.001
Savic, V., Knezevic, D., Lovrec, D., Jocanovic, M., & Karonovic, V. (2009). Determination of pressure losses in hydraulic pipeline systems by considering temperature and pressure. Journal of Mechanical Engineering, 55(4), 237–243. https://www.sv-jme.eu/article/determination-of-pressure-losses-in-hydraulic-pipeline-systems-by-considering-temperature-and-pressure
Schlichting, H. (1974). Boundary-layer theory. Nauck.
Swamee, P. K. (1993). Design of a submarine oil pipeline. Journal of Transportation Engineering, 119(1), 159–170. https://doi.org/10.1061/(ASCE)0733-947X (1993)119:1(159)
Tugunov, P. I., Novoselov, V. F., Korshak, A. A., & Shammasov, A. M. (2002). Typical calculations in the
design and operation of oil and gas pipelines. DizainPoligrafServis. Zholobov, V. V. (2019). Numerical method for identification of a hydraulic model of a pipeline linear section. Science & Technologies: Oil and Oil Products Pipeline Transportation, 9(6), 640-651. https://doi.org/10.28999/2541-9595-2019-9-6-640-651

Zhumagulov, B. T., Smagulov, S. S., Evseeva, A. U., & Nesterenkova, L. A. (2002). Pipeline transportation of high-viscosity and highly solidifying oils. Gylym. © 2021 The Author(s). This open access article is distributed under a Creative Commons Attribution (CC-BY) 4.0 license.

You are free to:
Share — copy and redistribute the material in any medium or format.
Adapt — remix, transform, and build upon the material for any purpose, even commercially.
The licensor cannot revoke these freedoms as long as you follow the license terms.
Under the following terms:
Attribution — You must give appropriate credit, provide a link to the license, and indicate if changes were made.
You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use.
No additional restrictions
You may not apply legal terms or technological measures that legally restrict others from doing anything the license permits.