ANALIZA PARAMETARA TRANSPORTA SIROVE NAFTE PRI IZOTERMNOM SRUJANJU

ANALYSIS OF CRUDE OIL TRANSPORT PARAMETERS IN ISOTHERMAL FLOW

Jasna TOLMAČ*[1], Slavica PRVULOVIĆ[1], Saša JOVANOVIĆ[1], Marija NEDIĆ[2], Aleksandra ALEKSIĆ[3], Dragiša TOLMAČ[4]

[1] University of Novi Sad, Technical faculty „Mihajlo Pupin“, Zrenjanin, Serbia

[2] PETKUS Engineering d.o.o., Serbia

[3] NIS Gazprom Neft, Novi Sad, Serbia

[4] University of Nikola Tesla, Belgrade, Faculty of Management, Sremski Karlovci, Serbia

https://doi.org/10.24094/ptk.021.34.1.157

U radu su prikazani rezultati eksperimentalnog istraživanja i simulacije parametara transporta sirove nafte cevima. Sadržaj parafina u nafti ima dominantan uticaj na svojstva parafinskih nafti, a posebno ima uticaj na smanjenje protočnih svojstava nafte. Zagrevanjem nafte poboljšavaju se protočna svojstva, smanjuje se viskoznost, kao i gubici pritiska na trenje pri transportu cevima. Fizičke osobine sirove nafte se modifikuju zagrevanjem kako bi se sprečio nastanak voska unutar naftovoda. Na osnovu eksperimentalnih i teorijskih istraživanja na realnom naftovodu prečnika 323 mm i dužine 1550 m, simulacijom pomoću softvera Origin, analiziran je uticaj promene temperature zagrevanja sirove nafte, viskoznosti i protoka, na pad pritiska i snagu pumpe. U zavisnosti od sadržaja parafina, nafta se zagreva na odgovarajuću temperaturu pre uvođenja u cevovod. Polazna temperatura nafte zavisi od sadržaja parafina i tačke tečenja. Razmatran je slučaj zagrevanja nafte na temperaturu 20 – 50 °C. Brzina hlađenja pri transportu nafte iznosi (0,52 – 0,55) °C/h. Pri transportu domaće parafinske nafte, vreme zastoja nebi trebalo da bude duže od 24 h, jer bi usled stajanja i hlađenja došlo do pojave čvrstih čestica parafina, a potom i do geliranja nafte u cevovodu. Sa smanjenjem temperature Δt =10 °C i posledično porastom viskoznosti, primetno je povećanje pada pritiska za 3 – 4 % i za toliko je potrebna i veća snaga pumpe.

Ključne reči: *transport; sirova nafta; pad pritiska; snaga pumpe*

The paper presents the results of experimental research and simulation of the parameters of crude oil transport of pipes. The content of paraffin in oil has a dominant influence on the properties of paraffin oil, and in particular has an impact on the reduction of the flow properties of the oil. Oil heating improves the flow properties, reduces the viscosity, as well as the losses of pressure on the friction when transporting pipes. The physical properties of crude oil are modified by heating to prevent the formation of wax inside the oil pipeline. Based on experimental and theoretical research on the real oil pipeline, simulation using the Origin software, the influence of the change in the temperature of heating crude oil, viscosity and flow, pressure drop and pump power was analyzed. Depending on the paraffin content, the oil is heated to the appropriate temperature before being introduced into the pipeline. The starting temperature of the oil depends on the paraffin content and the pour point. The case of heating oil to a temperature of 20 – 50 °C was considered. The cooling rate during oil transport is (0,52 – 0,55) °C / h. When transporting domestic paraffin oil, the downtime should not be longer than 24 hours, because due to standing and cooling, solid paraffin particles would appear, and then the oil would gelation in the pipeline. With a decrease in temperature Δt = 10 °C and a consequent increase in viscosity, there is a noticeable increase in pressure drop by 3 – 4% and that requires more pump power.

Key words: *transport; crude oil; pressure drop; pump power*

* Corresponding author, e-mail: jasnatolmac@yahoo.com

1 Introduction

An analysis of the economy of the transport of crude oil and its products by various modes of transport shows that the transport of these raw materials with pipelines is most economical. This is particularly noticeable when analyzing the supply of crude oil refineries [1], [12]. The pipelines are most often buried in the ground at a depth of (1 – 1,5) m, measured from the ground surface to the upper edge of the pipeline. At certain places there are pressure pumping stations (50 - 60) bar. Sometimes the main pipelines are laid above the ground on the columns of height (0,50 – 0,75) m, [1], [15].

The basic technical parameters of the oil pipeline subject to the optimization process are: technical characteristics of the pipeline, pipeline route, operating pressure of the pipeline, the number of pumping stations, power, types of pumps and the quality of the pipeline equipment, [2], [18]. The problem of pipeline transport of paraffin oil was the subject of a certain number of scientific researches.

When a pipeline transport of paraffin crude oil breaks down the flow and cooling of the oil below the flow temperature, there is a gelation of the entire transported mass of oil. For these reasons it is necessary to design such operating conditions of oil pipelines, that the oil temperature is above the flow temperature. There are several technical solutions for the transportation of crude oil, and one of the common solutions is the transport of heated crude oil [3], [16].

In liquid, dynamic viscosity decreases with increasing temperature. For this reason, viscous liquids such as crude oil and the like. heated before transport by pipelines to reduce their viscosity. This reduces the pressure drop due to friction losses, as well as the power of the pump. The content of paraffin in petroleum has a dominant influence on the properties of high paraffinic oils, especially the flow temperature [4], [19].

Crude oil containing more than 15% paraffin oil are paraffinic naphtha. Such oil has high flow temperatures and unfavorable characteristics for transporting pipes. When the oil is heated above the paraffin melting point, then the paraffins are liquid. By cooling crude oil to the temperature of pouring, solid particles of paraffin appear, and then to the oil gelation. Depending on the type of crude oil, [5], [9], the paraffin pour point moves to a wider range of 18 to 36 ^oC [5], [12].

The problem of precipitated paraffin may occur after starting the pump for transport after the repair or failure. The problems of starting the pump are particularly pronounced in the winter period [10]. If there is a delay in the transport of crude oil at a temperature below the melting point, then the appearance of the gelation occurs, and the re-establishment of the flow will require significantly higher pumping pressure, [6], [17].

Based on given data on the behavior of paraffin oil, one can gain insight into the complexity of the problem of the transport of crude oil by pipes. It is difficult to find two oil of the same composition. Based on this, for each type of crude oil, flow properties are determined and identified appropriate transport solutions.

The paper presents the results of a research on a real pipeline of 323 mm in diameter and 1550 m, in length. The oil pipeline is isolated and it is possible to heat pipelines on the entire length. On the basis of this, the conditions are ensured that the flow of oil at constant temperature, i.e., isothermal.

2 Material and methods

Experimental research and measurements were carried out on a real facility for the storage and transport of crude oil. The scheme of the experimental plant is shown in Figure 1. Crude oil is shipped from several oil fields to the refinery. Each oil field gives oil certain characteristics, density and viscosity. Crude oil is stored in a section of technology reservoirs. The transport of oil to the main oil pipeline (5) is carried out from the tank (1). Crude oil from the tank (1) is transported by means of pumps (2), and oil pipelines (3), to the pump (4). Using the pump (4) and the main oil pipeline (5), the oil is pumped to the measuring station (6), and the tank (7). In the reservoir (1), the pre-heating of crude oil is carried out at an appropriate temperature (20 – 50) ^oC, depending on the contents of the paraffin and the pour point. Heating is done by heaters (9), the heating fluid is a water vapor pressure of 4 bar, and a temperature of 160 ^oC. The thermal power of the heater is 9300 kW.

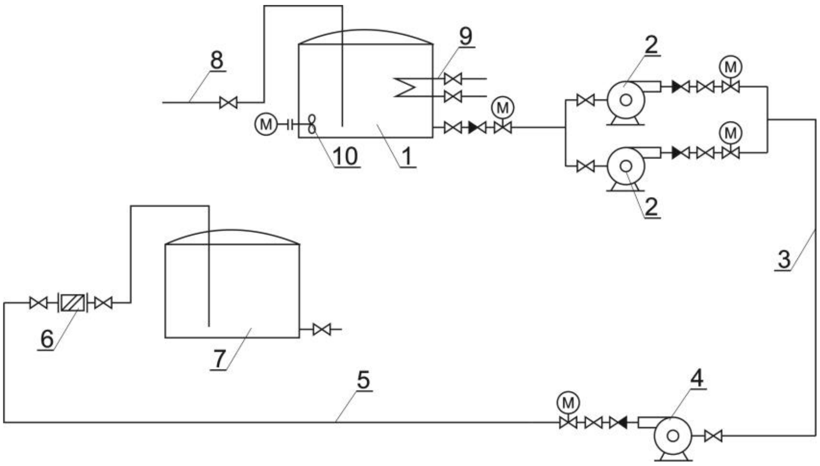

Figure 1. Scheme of the experimental plant, 1-tank, 2-centrifugal pump, 3-oil pipeline, 4-centrifugal pump, 5-the main oil pipeline, 6-flow meter, 7-tank, 8-input crude oil, 9-heater, 10-mixer

At a maximum filling height of 10 m, the tank contains 12560 m^3 of oil, corresponding to a mass of 10990 t. The characteristics of crude oil for transport do not exceed the limit values given in Table 1, according to [11], [12].

Table 1. Characteristics of crude oil

Property	Unit of measure	Value
Density at 15 ^oC	[kg/m^3]	875
viscosity at +20 ^oC max. viscosity at +30 ^oC max. viscosity at +40 ^oC max. viscosity at +50 ^oC max.	[m^2/s]	$23 \cdot 10^{-6}$ $18 \cdot 10^{-6}$ $15 \cdot 10^{-6}$ $11 \cdot 10^{-6}$
Pour point	[^oC]	+ 8 max. +26
Vapor pressure fluid - Reid pressure steam max.	[bar]	0,5

The pumps (2) are connected in parallel. During the transport, both pumps are running simultaneously and provide a pressure at the pump inlet (4), in the amount (4 – 5) bar. The heating of the oil pipeline (3), the outer diameter D_n = 323 mm, is carried out using two pipelines of the inner diameter D_p = 25 mm, through which water pressure pairs p = 12 bar, temperature t = 200 ^oC, Figure 2.

The oil pipeline (3) is isolated, so the temperature drop along the pipeline is insignificant. For these reasons, conditions are provided for the flow of oil to be isothermal [13]. The pipeline is laid over the ground on pillars of height of 0,75 m. Table 2, gives basic data for the pipeline (3).

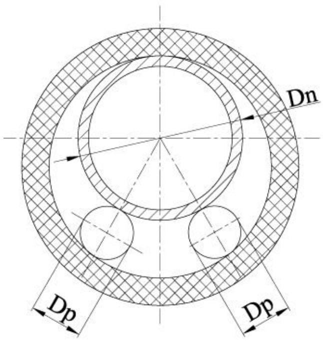

Figure 2. Oil pipeline heating scheme (3)

Table 2. Characteristics of oil pipeline (3), diameter of 323 mm

Pump 2		Oil pipeline D_{ca} = 323 mm		Tank 1	
Q = 350 m^3/h	Flow	D_{ci} = 301,7 mm	The inside diameter of the pipeline	40 m	Diameter
H = 75 m	Head	δ_c =11,1 mm	Pipeline wall thickness	12,7 m	High
N = 132 kW	Pump power	l = 1550 m	Oil pipeline length	15000 m^3	Volume
η_p = 0,70	Pump efficiency	s = 100 mm	Thickness of isolation	s =100 mm	Thickness of isolation
NPSH=25 kPa	Net positive section head				
n=2950 min^{-1}	revolutions per minute				

By the main pipeline (5), oil transport is carried out with the pump (4), to the tank (7). The pipeline is buried in the ground at a depth of 1 m. Depending on the temperature and transport capacity, the pressure at the start of the pipeline is p_1 = (35 – 40) bar, and at the end of the pipeline is p_2 = (2 – 3) bar. The transport capacity is (486 – 612) t/h. Table 3 gives basic data for the main pipeline (5). During transportation, the oil is cooled, so the oil flow through the main pipeline (5) is non-isothermal.

Tabela 3. Characteristics of main oil pipeline (5), diameter 457mm

Pump 4		Oil pipeline D_{ca} = 457 mm	
Q = 900 m^3/h	Flow	D_{ci} = 428,4 mm	The inside diameter of the pipeline
H = 335 m	Head	δ_c =14,3 mm	Pipeline wall thickness
N = 1000 kW	Pump power	l = 91000 m	Oil pipeline length
η_p = 0,70	Pump efficiency	s = 100 mm	Thickness of isolation
NPSH = 300 kPa	Net positive section head		
n = 2960 min^{-1}	revolutions per minute		

3 Results and discussion

The minimum heating costs of crude oil will be when the oil is heated to an initial temperature of t_1 = 20 ^oC, these are oils with a pour point +8 ^oC and 3% paraffin. Significantly higher heating costs will be when crude oil is heated to an initial temperature of t_1 = 40 ^oC, these are oils with a pour point +26 ^oC and 15,3% paraffin. Oils with a pour point +18 ^oC and 10,5% of paraffin are heated to an initial temperature of 30 ^oC, while paraffin oils with a pour point of +36 ^oC and 29% paraffin are heated to an initial temperature of 50 ^oC. The temperature of crude oil at the end of the pipeline must be higher than the pour point, [8], [12].

For the flow range (550 – 660) m^3/h, the Reynolds number moves in the interval Re = (25625 – 75000), so the flow through the oil pipeline (3) is turbulent, since Re > 2320.

When operating the pump station, it is desirable that the operating point of the pump is in the area of optimal efficiency. When transporting crude oil, the characteristic of the pipeline is kept approximately constant, this is achieved by heating the crude oil.

By varying the parameters for the values of crude oil heating temperature in the range (20 – 50) ^oC, the optimal values of pressure drop due to friction losses, pump effort and pump power were obtained. The optimal heating temperature of crude oil is also influenced by the specific operating conditions of the pipeline, [9], [17]. Figure 3 shows the results of the research, which show the dependence of the change in pressure drop and flow for the pipeline (3).

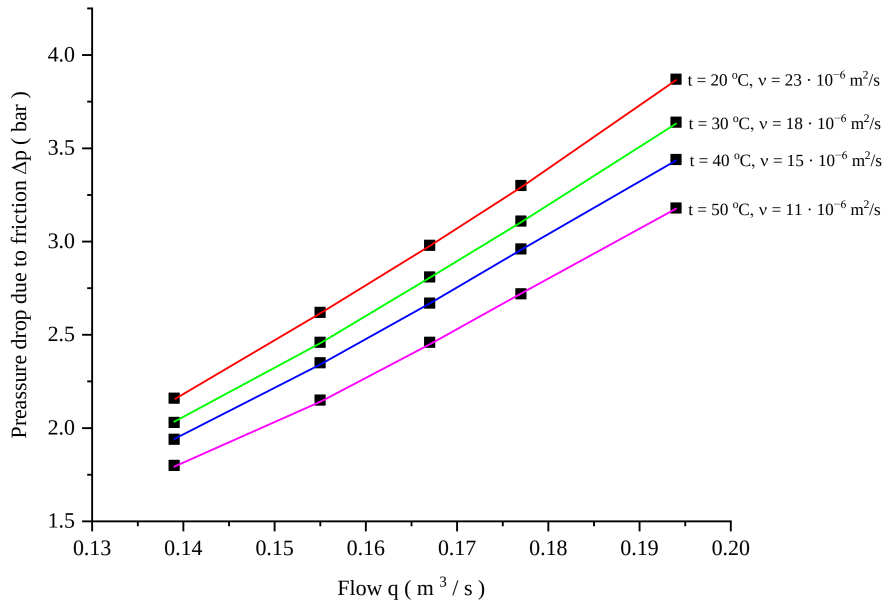

Figure 3. Pressure drop due to friction depending on the flow

Based on the results of research for the pipeline (3), diameter D_{ca} = 323 mm, length l = 1550 m, a pressure drop Δp = 3,87 bar was obtained, when the oil temperature is 20 °C, i.e., specific pressure drop $\Delta p/l$ = 0,25 bar/100 m. With a decrease in temperature by Δt = 10 °C and an increase in viscosity, an increase in pressure drop of 3 – 4% is noticeable, and a higher pump power is required for that much.

In the design phase of the pipeline for the transport of heated oil, it is necessary to consider the impact of changes in transport capacity and pressure drop on the operation of the pipeline. Figure 4 shows the results of the research, which show the dependence of the change in pump power and flow, for the temperature range of heated oil 20 – 50 °C.

The cooling rate during oil transport is (0,52 – 0,55) °C/h. When transporting domestic paraffin oil, the downtime should not be longer than 24 h, because due to standing and cooling, solid paraffin particles would appear, and then the oil would gel in the pipeline [12].

For the flow regime 0,075 – 0,092 m^3/s, (275 – 330 m^3/h), per pump (2), Figure 1, the pump power is in the range of 85 – 100 kW. The efficiency of the pump is about 0,70, Figures 4 and 5.

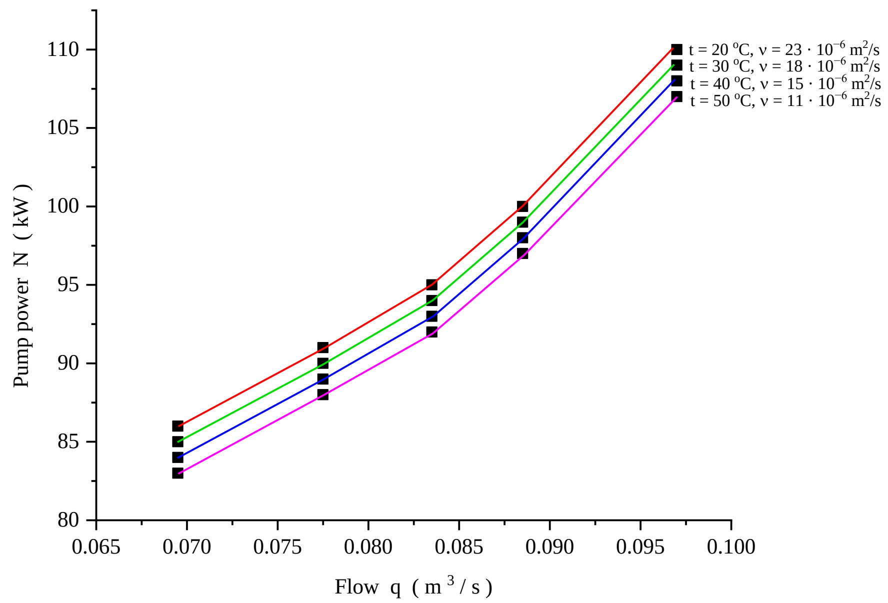

Figure 4. Dependence of pump power change and flow

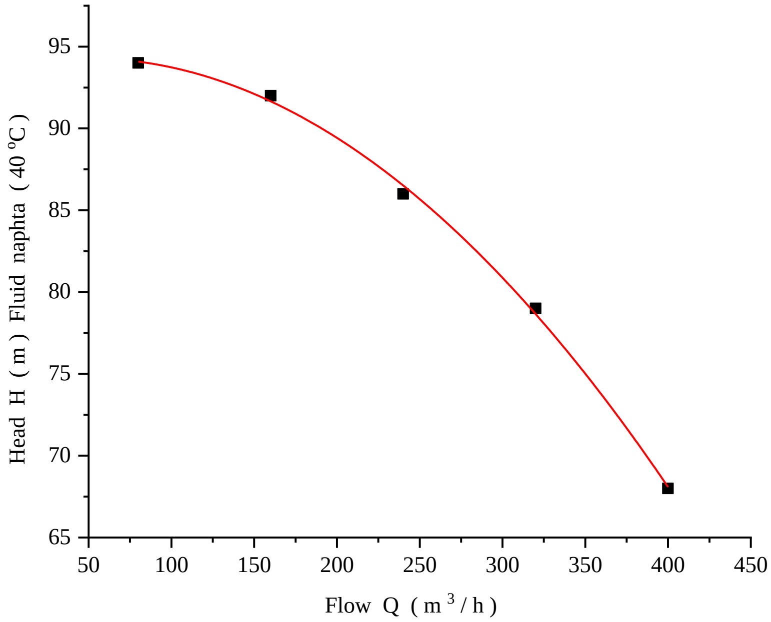

Figure 5. Characteristics of the pump (2), operating flow range 275 – 330 m^3/h, power 85 – 100 kW, the efficiency of the pump is about 0,7

When transporting paraffin oil, at a temperature below the flow point, higher pumping pressure is required. If it is ensured that the fluid is kept in motion, there will be no major problems or delays [13, 14].

4 Conclusion

For the transport of oil and oil products, the choice of pump power units is of great importance. According to the total pressure drop, i.e., repress power of pump, the layout and number of pumping stations on the pipeline route are planned. Adopting pumps with higher repress pressure reduces the number of pumping stations.

The paper presents the results of experimental and theoretical research of the parameters of crude oil pipeline transport. For different operating modes, curves and interdependencies of flow, pressure drop and pump power are determined.

It was found that:

- The pressure drop along the entire length of the oil pipeline is a key parameter for the calculation of the pump power. With a decrease in temperature by Δt = 10 °C and a consequent increase in viscosity, there is a noticeable increase in pressure drop by 3 – 4% and this requires more pump power.
- For optimal flow regime 0,075 – 0,092 m^3/s, (275 – 330 m^3/h), per pump (2), the pump power is in the range of 85 – 100 kW. The efficiency of the pump is about 0,70.
- The initial temperature of the oil depends on the paraffin content and the flow point. The temperature of the oil at the end of the pipeline should be higher than the melting temperature of the paraffin. The cooling rate during oil transport is (0,52 – 0,55) °C/h. When transporting domestic paraffin oil, the downtime should not be longer than 24 hours, because due to standing and cooling, solid paraffin particles would appear, and then the oil would gel in the pipeline.
- When transporting crude oil with a high paraffin content, at a temperature below the pour point, higher pumping pressure is required. There will be no major problems, if it is ensured that the fluid is kept in motion.
- The presented results can be useful for determining the optimal operating parameters of crude paraffin oil pipeline transport.

5 References

[1] **Rukthong, Wanwisa, Piumsomboon, Pornpote, Weerapakkaroon, Wichapun:** Computational Fluid Dynamics Simulation of a Crude Oil Transport Pipeline: Effect of Crude Oil Properties. Engineering journal, 2016; 70: 145-154.

[2] **Danilovic Dusan S., Karovic-Maricic Vesna D., Secerov-Sokolovic Radmila M., Ivezic Dejan D., Zivković Marija A.**: Laboratory testing and simulation of the paraffin deposition process in the oil field of the Turija field in Vojvodina. Chemical industry, 2011; 65: 249-256.

[3] **Skrbic, B.**: Transport of oil and gas, Faculty of Technology, Novi Sad, 2006.

[4] **Danilovic, D., Karovic-Maricic, V., Ivezic, D., Batalovic, V., Zivkovic, M., Lekovic, B., Crnogorac, M.**: Analysis of applied heating systems for heating well pumps for the transport of paraffin oil in the fields of oil industry of Serbia, Tehnika, 2012; 67: 919-923.

[5] **Secerov-Sokolovic, Radmila M., Bjelovic Zoran V., Sokolovic Srdjan S.:** Influence of solid paraffin content on the rheology of model oil, Chemical industry, 2006; 60: 10-14.

[6] **Ahmadpour, K. Sadeghy, S.-R. Maddah-Sadatieh.**: The effect of a variable plastic viscosity on the restart problem of pipelines filled with gelled waxy crude oils. J. Non-Newton, 2014; 205: 16–27.

[7] **Sun Guangyu, Zhang Jinjun, Me Chenbo.:** Start-up flow behavior of pipelines transporting waxy crude oil emulsion, Journal of petroleum science and engineering, 2016; 147: 746-755.

[8] **Cheng Qinglin, Pan Chenlin, Zhao Yan.:** Phenomenological study on heat and mass coupling mechanism of waxy crude oil pipeline transport process, Journal of dispersion science and technology, 2018; 123: 43-55.

[9] **Hussain H. Al-Kayiem, Wong Ning, Nassir Dhamin Mokhlif.:** Characterisation of paraffinic compositions in crude oils, International Journal of Oil, Gas and Coal Technology, 2017; 15 (2).

[10] **Davidson M.R., Nguyen Q.D., Chang C., Rningsen H.P.:** A model for restart of a pipeline with compressible gelled waxy crude oil, J. Non-Newton. Fluid Mech. 2004; 123 (2), 269–280.

[11] *** Rules of operation of the transport system for oil pipeline transportation, Transnafta, Pancevo, 2010.

[12] **Tolmac, J., Prvulovic, S., Nedic, M., Tolmac, D.**: Analysis of crude oil pipeline transport parameters, Chemical Industry, 2020; 74(2) 79-90.

[13] **Prstojevic, B.:** Pipeline transport of oil and gas, Faculty of Mining and Geology, Belgrade, 2012.

[14] **Tolmac, J., Tolmac, D., Prvulovic, S., Aleksic, A.:** Basic Elements of Crude Oil Pipeline Transport, All Russian Scientific Technical Conference: Problems of Geology, Hydrocarbons Exploitation and Transport, Technical University of Uhta, 2017.

[15] **Sasic, M.:** Transport of fluids and solid materials by pipes, Scientific book, Belgrade, 1980.

[16] **Prvulovic, S., Tolmac, D.:** Transport Sistems - a collection of solved tasks, Technical Faculty "M. Pupin", Zrenjanin, 2012.

[17] **Tanaskovic, P.:** Transportation of Crude Oil and Gas Part II, Faculty of Mining and Geology, Belgrade, 1998.

[18] **Prvulovic, S., Tolmac, D., Josimovic, Lj., Tolmac J.:** Remote monitoring and control of pumping stations in the water supply systems, Facta universitatis - Mechanical Engineering, 2013; 11: 113-121.

[19] **Tanaskovic, P.:** Transport of crude oil and gas I part. Faculty of Mining and Geology, Belgrade, 1998.

[20] **Tolmac, J., Prvulovic, S., Tolmac, D., Nedic, M.:** Oil products and pumping stations. VII International Conference Industrial Engineering and Environmental Protection, Proceedings 2017; 44-49.