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OPTIMALNI PARAMETRI NAFTOVODA, INVESTICIONA ULAGANJA I TROŠKOVI

OPTIMAL PARAMETERS OF OIL PIPELINE, INVESTMENTS AND COSTS

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U radu su razmatrani optimalni parametari naftovoda kao što su: trasa naftovoda i prečnik cevovoda. Kod izračunavanja cene transporta naftovodom, kao i kod izbora optimalnih parametara sa kriterijumom minimalnih troškova, osnovu proračuna čine godišnji troškovi. Amortizacioni vek cevovoda iznosi od 15 do 20 godina. Pumpne stanice imaju amortizacioni vek 10 do 15 godina. Troškovi održavanja naftovoda obuhvataju troškove održavanja i funkcionisanja naftovoda. Investicije za pumpnu stanici iznose oko 1100 $ / kW. Investicije za gradnju cevovoda prečnika 323 - 710 mm, kreću se u opsegu 160 340 - 330 050 $ / km. Izbor optimalnog prečnika u odnosu na godišnje troškove predstavlja upoređenje troškova cevovoda i troškova pumpnih stanica u varijantama sa različitim prečnicima cevovoda. U ovom radu razmatran je magistralni naftovod, dužine l = 91000 m i kapaciteta 500 - 700 m^3/h. Dobijen je optimalni prečnik cevovoda D = 457 mm. Pad pritiska Δp je opsegu 30 - 40 bar. Za transport nafte, izbor snage pumpnih agregata ima veliki značaj. Prema ukupnom padu pritiska, planira se raspored i broj pumpnih stanica na trasi naftovoda. Usvajanjem pumpi sa većim pritiskom, smanjuje se broj pumpnih stanica i obrnuto.

Ključne reči: *naftovod; optimalni parametri; prečnik naftovoda; trasa naftovoda; izgradnja i projektovanje; investicije*

The paper discussed the optimal parameters of the oil pipeline, such as: the route of the oil pipeline and the diameter of the pipeline. When calculating the price of transportation by oil pipeline, as well as when choosing optimal parameters with the criterion of minimum costs, annual costs are the basis of the calculation. The amortization life of the pipeline is from 15 to 20 years. Pumping stations have an amortization life of 10 to 15 years. Oil pipeline maintenance costs include oil pipeline maintenance and operation costs. Investments for the pumping station amount to about 1100 $ / kW. Investments for the construction of pipelines with a diameter of 323 - 710 mm are in the range of 160 340 - 330 050 $ / km. The choice of the optimal diameter in relation to annual costs is a comparison of pipeline costs and pump station costs in variants with different pipeline diameters. In this paper, a main oil pipeline with a length of l = 91000 m and a capacity of 500 - 700 m^3/h was considered. The optimal pipeline diameter D = 457 mm was obtained. The pressure drop Δp is in the range of 30 - 40 bar. For the transportation of oil, the choice of the power of the pumping units is of great importance. According to the total pressure drop, the layout and number of pumping stations

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on the pipeline route are planned. By adopting pumps with higher pressure, the number of pumping stations is reduced and vice versa.

Key words: *oil pipeline; optimal parameters; pipeline diameter; pipeline route; construction and designing; investments*

1. Introduction

The criterion of minimum annual costs is usually applied, ie. selection of the optimal oil pipeline route, which has minimum annual costs. The criterion can be the smallest investments, construction time and reliability of the constructed pipeline. For example, the goal is to determine the oil pipeline route with the lowest annual costs and the shortest construction time, [1].

Annual pipeline costs consist of amortisation, interest on invested capital, insurance and pipeline maintenance costs. The amortization life of pipelines ranges from 15 to 20 years. However, when calculating amortization, the amortization life of individual pipeline components must be taken into account. Thus, for automation, measurement and regulation, the amortization life is from 5 to 10 years. Pumping stations have an amortization life of 10 to 15 years. At pumping stations, the amortization life of individual components should be taken into account.

Buildings have a amortization life of 20-25 years, [2]. Oil pipeline maintenance costs include the costs of maintenance and operation of oil pipelines (pipelines, pumping stations and supporting facilities). This includes the salaries of the employed staff, the costs of procuring repro materials, spare parts, equipment servicing, repair of breakdowns, driving energy (electricity, fuel, lubricant) and others.

1.1. Investments in the pumping station

According to the data [3], [4], [5], the price of pumping stations in (dollars) per unit of power in (kW) is given. For example, investments in electric drive amount to 1088 $ / kW. In Table 1, is given review of investments in the pumping station.

Table 1. Investments in the pumping station

Pump power (kW)	*Investments ($/kW) Electric drive*	*Investments ($/kW) Gas drive*	*Investments ($/kW) Diesel drive*
200	3535	4216	4550
500	1224	2108	3060
1000	1088	1836	2380
2000	1054	1734	2176
3000	986	1632	2060

According to the literature [3], [6, 7], a significant part of the price of pipeline construction has the value of pipelines and pipeline equipment and amounts to about 60% of the total value of the pipeline system. The price of the pump also occupies a very significant part in the construction of the oil pipeline.

1.2. Price of pipeline construction

According to the literature [3], the price of pipeline construction is given depending on the diameter. For example, for a 323 - 710 mm pipeline diameter, the cost of building the pipeline is $

160 340 - $ 330 050 / km. The given data can be useful for an approximate estimate of the necessary investments for the construction of the pipeline. The cost of building the pipeline is given in Table 2. Price of pipeline construction.

Table 2. Price of pipeline construction

Pipeline diameter (inch)	*(m)*	*The cost of building a pipeline ($/km)*	*Unit price ($/m - diameter) / (m - length)*
12	0,323	160 340	496
14	0,355	177 350	500
16	0,400	202 765	506
18	0,457	223 985	490
29	0,508	245 200	482
22	0,559	266 420	477
24	0,609	287 640	472
26	0,660	308 750	468
28	0,710	330 050	464

Steel pipelines are exposed to corrosion. Since the value of the pipeline is about 60% of the value of the entire pipeline system of the pipeline, it is necessary to provide adequate protection against corrosion, in order to prevent rapid decay of the pipeline. In this regard, cathodic protection of pipelines is used. Metal corrosion processes are electrochemical reactions, which are related to the anode and cathode process. Corrosion protection with cathodic protection is based on bringing steel pipes to a potential where no corrosion process occurs.

3. Material and method

3.1. Optimal pipeline diameter

The choice of the optimal diameter in relation to annual costs is a comparison of pipeline costs (C_2) and pumping station costs (C_1) in variants with different pipeline diameters, according to equation (1). In the consideration of the variants, with the reduction of the diameter, the costs of pipelines decrease, while the costs of pumping stations increase, [8].

With smaller pipeline diameters, larger pressure drops are obtained, and thus higher pump power. As power increases, pumping costs also increase. By reducing the diameter of the pipeline, the cost of building the pipeline decreases, but due to the increase in pressure drop, the cost of the pumping station increases. Taking into account the relevant parameters, power, flow, pressure drop and costs of the oil pipeline, a well-known relation is used to determine the optimal diameter of the pipeline, [3]:

$$D = \left(4,05696 \cdot 10^{-3} \cdot Q^3 \cdot \lambda \cdot \rho \cdot \frac{C_1}{\eta_p \cdot C_2} \right)^{0,16666} \qquad (1)$$

where:

D – the inner diameter of the pipeline (m)
Q – flow (m^3/s)
ρ – oil density (kg/m^3)
λ – coefficient of friction
η_p – efficiency of pump
C_1 – total annual costs of pumping stations ($ / kW)
C_2 – annual pipeline costs in $ per meter of diameter and meter of pipeline length (costs depending on the diameter of the pipe).

The main oil pipeline plant characteristics are given in Figure 1 and in Table 3.

Table 3. Characteristics of the main oil pipeline system

Pump 2	*Pump 4*	*Reservoir 1*
Q = 350 m^3/h - flow	Q = 900 m^3/h - flow	V = 15000 m^3 - volume
H = 75 m – pump head	H = 335 m – pump head	
N =110 kW – pump power	N = 1000 kW – pump power	
η_p = 0,70 – efficiency of pump	η_p = 0,80 – efficiency of pump	
NPSH = 25 kPa	NPSH = 300 kPa	
Pipeline (3) length *l* = 1550 m	Pipeline (5) lenght *l* = 91000m	

According to the scheme of the experimental plant in Figure 1, using the main oil pipeline (5), crude oil is transported with a flow rate in the working range (500 – 700) m^3/h. The speed of the flow was in the range 1 – 1,35 m/s. Pumps (2) provide a pressure at the inlet to pump (4) of about 5 bar. The length of the main oil pipeline is *l* = 91000 m. The density of oil is ρ = 875 (kg/m^3). The coefficient of friction is λ = 0,028 and efficiency of pump is η_p= 0,80. The total annual costs of the pumping station amount to C_1 = 600 ($ / kW), and annual pipeline costs are C_2 = 98 ($ / m/m), [3], [9].

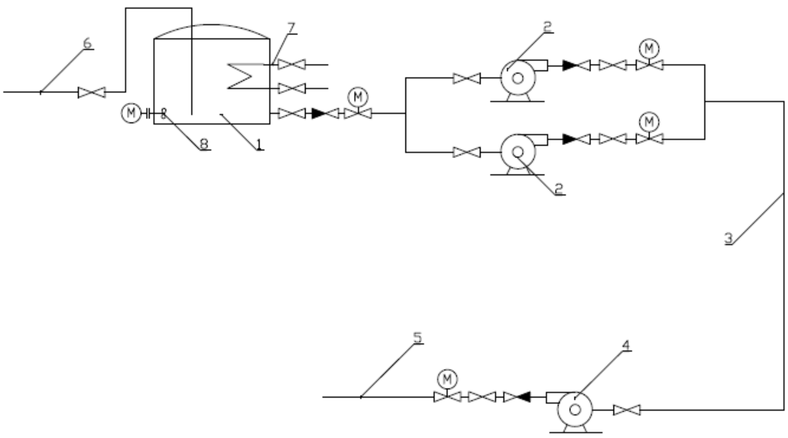

Figure 1. Scheme of the experimental plant, 1-reservoir, 2-centrifugal pump, 3-oil pipeline, 4-centrifugal pump, 5-the main oil pipeline, 6-crude oil supply, 7-heater, 8-mixer

In Figure 2, the characteristics of the pump (4) are given.

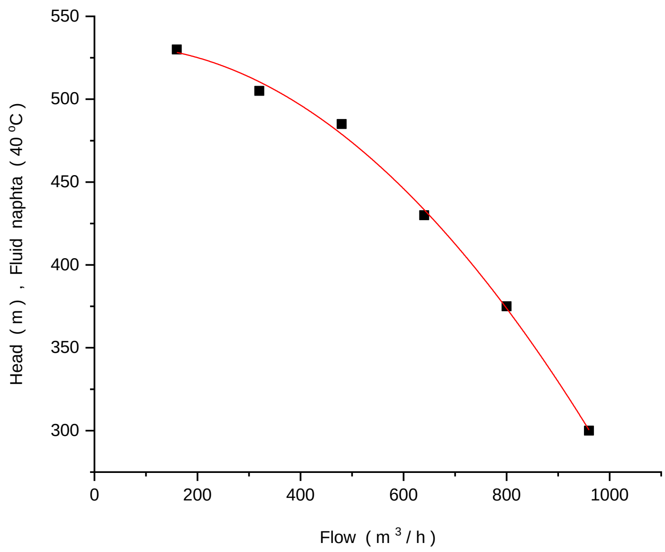

Figure 2. Characteristics of the pump (4), operating flow range 550 – 700 m³/h, power 665 – 835 kW, the efficiency of the pump is about 0,8

4. Research results and discussion

In comparison with different modes of transportation, the transportation of oil through pipelines is the most economical. It is the most obvious when analyzing the supplying of refineries with crude oil [10, 11].

Based on the research for the main oil pipeline (5) diameter D = 457 mm, length l = 91000 m, capacity 500 - 700 m^3/h, pressure drop is obtained Δp = 30 - 40 bar. The initial temperature of the oil is t_1 = 40 ^oC, and the density of crude oil is 875 kg/m^3.

According to [3, 4], for the transportation of heated oil using a pipeline with a diameter of 400 mm and length 90 000 m, for transport capacity 347 m^3/h, (330 t/h), pressure drop is Δp = 21 bar. The oil temperature is t = 50 ^oC and density of crude oil is 950 kg/m^3.

Based on the results of the research, the pressure drop was approximately twice as high as the results according to [3, 12], given that the transport capacity is also approximately twice as high. Based on the flow variation in the optimal operating range, the optimal pipeline diameters were obtained, the results are given in Table 4.

Table 4. Optimal pipeline diameter

Flow Q (m^3/h) (m^3/s)	500 0,139	560 0,155	600 0,167	640 0,177	700 0,194
Pipeline diameter D (m)	0,365	0,386	0,400	0,412	0,432

For maximum flow value 700 m^3/h, the optimal diameter of the pipeline was obtained D=432 mm, which corresponds to the standard pipeline diameter D = 18" i.e. (457 / 428,4) mm. The pressure drop (Δp) on the section of the oil pipeline is a key parameter for the pump power calculation. For the transportation of oil and oil derivatives, the choice of power of pumping units is of great importance.

According to the total pressure drop, the layout and number of pumping stations on the pipeline route are planned. By adopting pumps with higher pressure, the number of pumping stations is reduced and vice versa. When transporting by pipeline, the same working pressure and capacity for all pumps has its advantage. This achieves the same flow speed and object safety [3].

Figure 3 shows the results of the research, which show the mutual dependencies of pump power (N), flow rate (q), initial temperature (t) in the range 20 – 50 °C and corresponding crude oil viscosities (ν). When transporting crude oil with a higher viscosity, there is a greater pressure drop through the pipeline, so a pump with a higher power is needed in order to achieve the necessary transport, Figure 3.

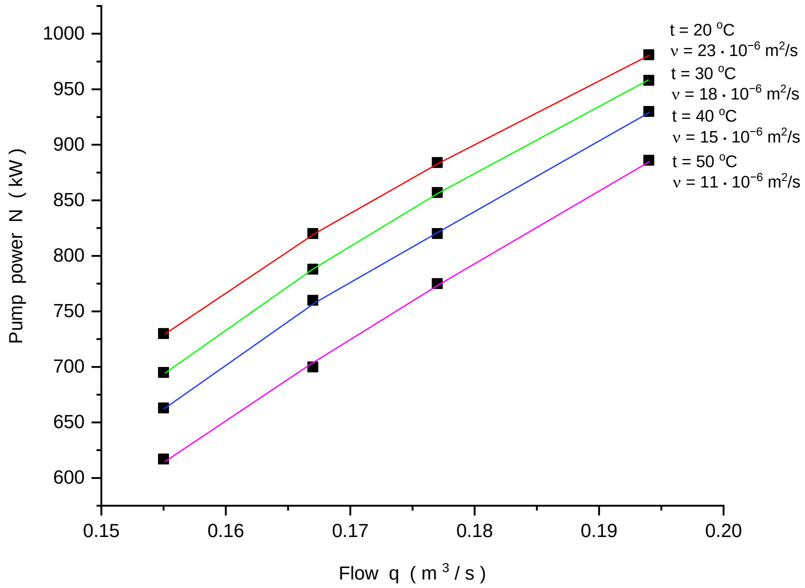

Figure 3. Dependence of pump power and flow

Figure 4 shows the pressure drop due to friction depending on the amount of crude oil flow through the pipeline (5), for the initial oil temperature t = 40 °C .

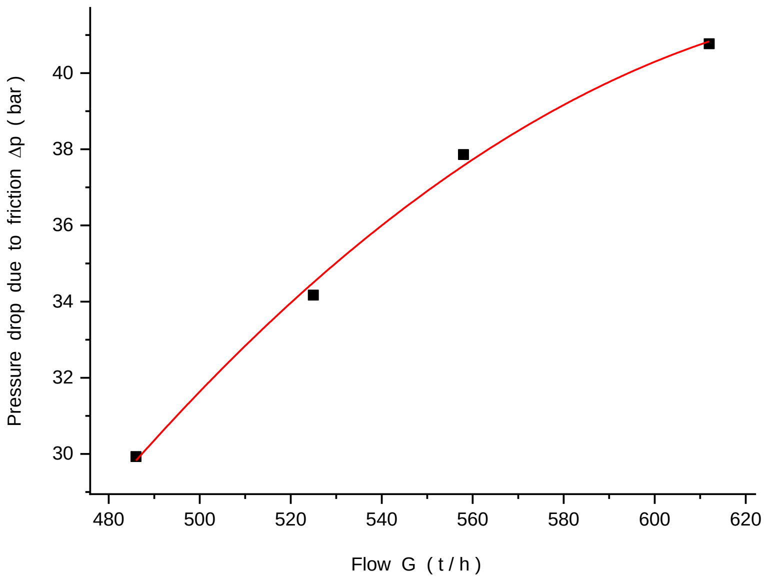

Figure 4. Pressure drop due to friction depending on the amount of crude oil flow through the pipeline (5)

With a decrease in temperature by Δt = 10 ºC and an increase in viscosity, there is a noticeable increase in pump power by 3 to 4%, Figure 3. By heating crude oil before introducing it into the pipeline, optimal transport conditions are ensured in terms of reducing pressure drop and pump power.

5. Conclusion

The optimal parameters of the oil pipeline, considered in this paper, are the route and diameter of the pipeline. When choosing the optimal parameters of the oil pipeline with the criterion of minimum costs, annual costs are the basis of the calculation. Oil pipeline maintenance costs include oil pipeline maintenance and operation costs. Investments for the pumping station amount to approx 1100 $ / kW. Investments for the construction of pipelines of diameter 323 - 710 mm, move in the range $ 160 340 - $ 330 050 / km. The amortization life of the pipeline is from 15 to 20 years. Pump stations have an amortization life of 10 to 15 years. For main oil pipeline length l = 91000 m and capacity 500 - 700 m^3/h, the optimal diameter of the pipeline was obtained D = 457 mm. The pressure drop ranged 30 - 40 bar. With a decrease in temperature by Δt = 10 ºC and an increase in viscosity, there is a noticeable increase in pump power by 3 to 4%. According to the total pressure drop, the layout and number of pumping stations on the pipeline route are planned. By adopting pumps with higher pressure, the number of pumping stations is reduced and vice versa.

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