Pecularities of calculation of throughput capacity and energy consumption of oil pipeline at parallel operation of pumping units

M.D. Serediuk*

Ivano-Frankivsk National Technical University of Oil and Gas;
15, Karpatska Str., Ivano-Frankivsk, 76019, Ukraine

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Abstract

The peculiarities of hydrodynamic processes in the case of parallel operation of centrifugal pumps on the pipeline are established. The method and software for determining the throughput capacity and energy efficiency of the main oil pipeline for the use of multi-type pumps operating at oil pumping stations are developed. It has been proved by calculations that, under certain conditions, a parallel operation of the pumps can have advantages over the traditional sequential scheme of their operation.

Keywords: *main oil pipeline, parallel operation of the pumps, sequential operation of the pumps, specific costs of electricity, technological limitations of regime parameters, throughput capacity.*

As noted in [1–3], the throughput capacity and energy consumption of a main pipeline depends on a dozen of factors, the main place among which is played by the characteristics and schemes of the joint operation of pumping units at oil pumping stations. Pumping units of main oil pipelines and petroleum product pipelines can be operated both in a consistent manner and in parallel schemes. At domestic main oil pipelines until now, a sequential scheme of operation of main pumps was usually used. At the same time, in the main gas transport a parallel scheme of operation of full-pressure centrifugal superchargers has been given an advantage for the past 20 years. This allows us to adjust the throughput capacity of a gas pipeline in a wide range without using the throttling process. It is obvious that for the main oil pipelines and petroleum product pipelines, in some cases, the transition to a parallel scheme of pumps at the oil pumping station will prevent forced throttling and thus increase the energy efficiency of transportation of oil or petroleum products.

It should be noted that the transition to the parallel operation of pumping units provides significant oil consumption in the pipeline at significantly lower operating pressures. This is very important for domestic pipelines with long term operation, since it reduces the probability of an accident and improves the reliability of oil supply.

Determination of the throughput capacity and energy consumption of the main oil pipeline in case of parallel operation of pumps has some pecularities, which must be considered in this paper.

* Corresponding author:
tzng@nung.edu.ua

If pumping units of one trademark with the same rotors are being operated simultaneously at an oil pumping station, then the calculation of parameters of their joint operation does not create additional difficulties in determining the throughput capacity and energy consumption of the main pipeline. At oil pumping stations of national oil pipelines, pump units with basic and and variable rotors are used, which are often sharpened to a certain value. Parallel operation of centrifugal pumps with different rotors requires a separate study.

We accept that the main pipeline (site) has *n* of oil pumping stations. At the i-oil pumping station of the oil pipeline, k_i of pumps with different rotors operate in parallel. Under the parallel scheme of work, depending on the loading of the oil pipeline, pumps can work for different work feeds. Therefore, for a mathematical description of the pressure characteristics of a pump in a wide range of feedings, we don't use a non-common binary but a polynomial model

$$H_{ij} = a0_{ij} + al_{ij} Q_{ij} + ak_{ij} Q_{ij}^2 , \qquad (1)$$

where $a0_{ij}, al_{ij}, ak_{ij}$ are coefficients of the mathematical model of the pressure characteristic of j main pump at i-oil pumping station; Q_{ij} is supply of j-main pump at i-oil pumping station.

A similar expression is used to describe the dependence of the efficiency of the main pump upon its supply

$$\eta_{ij} = c0_{ij} + cl_{ij} Q_{ij} + ck_{ij} Q_{ij}^2 , \qquad (2)$$

where $c0_{ij}, cl_{ij}, ck_{ij}$ are the coefficients of the mathematical model of the curve of the efficiency of the j-main pump at i-oil pumping station.

For the joint operation of centrifugal multi-type pumps, the important task is to find a working pressure range and supply for each of the oil pumping stations.

The maximum value of the operating pressure of the pumps of the i -oil pumping station is equal to the minimum value of the coefficient in the mathematical model of the pressure characteristic

$$H_{\max_i} = \min_j(a0_{ij}) . \quad (3)$$

We compare the maximum values of the pressure of the oil pumping station pumps and find the least value. This will be the maximum oil pumping station pressure for the oil pipeline

$$H_{\max_{gen}} = \min_i(H_{\max_i}) . \quad (4)$$

The maximum value of the oil pumping station pressure corresponds to the minimum working flow of the pump, which is found by solving the square equation, taking into account the formulas (3) and (4)

$$Q_{\mathrm{mi}_{ij}} = \frac{-al_{ij} + \sqrt{\left(al_{ij}\right)^2 - 4ak_{ij}(a0_{ij} - H_{\max_{gen}})}}{2ak_{ij}} . \quad (5)$$

The minimum working flow of pumps of the i -oil pumping station is equal to

$$Q_{\min_i} = \sum_{j=1}^{j=k_i} Q_{\mathrm{mi}_{ij}} .$$

We compare the minimum values of the total working flow of pumps of all oil pumping stations and find the maximum value. This will be the minimum value of working oil consumption for the oil pipeline

$$Q_{\min_{gen}} = \max_i(Q_{\min_i}) .$$

We analyze the minimum values taken from the passport characteristics of the pumps of the same oil pumping station and find the greatest value

$$H_{\min_i} = \max_j(H_{\mathrm{mi}_{ij}}) .$$

The minimum value of the oil pumping station operating pressure for the pipeline section is equal to

$$H_{\min_{gen}} = \max_i(H_{\min_i}) .$$

The minimum value of the oil pumping station pressure corresponds to the maximum working flow of each pump $Q_{\mathrm{ma}_{ij}}$, which can be found by solving the square equation of the form (5). The maximum working flow of pumps of the i -oil pumping station equals

$$Q_{\max_i} = \sum_{j=1}^{j=k_i} Q_{\mathrm{ma}_{ij}} .$$

We compare the maximum values of the working flow of pumps of all oil pumping stations and find the least value. This will be the maximum value of oil consumption for the oil pipeline section in terms of the possibility of parallel operation of the pumps

$$Q_{\max_{gen}} = \min_i(Q_{\max_i}) .$$

The above formulas enable us to determine the technological limitations on pressure (oil pumping station pressure) and oil consumption due to the application of a parallel scheme of operation of the oil pumping station pumps with different rotors.

The throughput capacity of the main oil pipeline is usually found by the iteration of the working oil consumption [4]. In the case of the use of a parallel scheme of work of various types of pumps on the oil pumping station, it is expedient to apply the iteration method for the working pressure (pressure) created by the pumps of the oil pumping station.

Applying the approach outlined in [4–6], we have developed a method, computational algorithm and software for determining the pipeline throughput capacity and specific energy consumption for oil transportation in the case of application of a parallel scheme of pumps operation on the oil pumping station.

The computer program includes the following elements:

the block of mathematical modeling of pump characteristics for a parallel scheme of work at an oil pumping station according to formulas (1) and (2);

the block of determination of technological limitations of operating pressure of pumps and oil consumption in the oil pipeline in accordance with the formulas given above;

the block for calculating the pressure and energy parameters of each pump and the oil pumping station in general for the constant and variable speed of the shaft;

the block of hydraulic calculation of the linear part of the oil pipeline section;

the block of taking into account the technological limitations of pressure and oil consumption at the inlet and outlet of the oil pumping station, as well as at an arbitrary point of the pipeline.

The calculation of the change in the rotating frequency of the pump shaft is based on the method suggested in [6]. Hydraulic calculation of the linear part of the oil pipeline section involves applying for the hydraulic resistance coefficient of the universal modified Kolbruk formula [4, 6].

According to the graphic characteristics of the pumps, the coefficients of the mathematical models for the pressure dependences and the efficiency of the supply in formulas (1) and (2) are calculated. They are adjusted if the rotational frequency of the shaft of the pump differs from the nominal value.

The above formulas determine the maximum and minimum values of the operating pressure of the pumps of each oil pumping station, the system as a whole and the maximum and minimum value of the working oil consumption in the oil pipeline.

As the first approximation, the minimum value of the working oil consumption for the oil pipeline section is set as

$$Q = Q_{\min_{gen}} .$$

For each oil pumping station the following value of working pressure is taken

$$H_i = H_{\max_i} .$$

Since in the parallel scheme of the work, the pressure created by the oil pumping station pumps will be the same, then using the equations of form (5), we calculate the supply of each pump and find the total oil consumption for the main oil pumping station Q_{GOIS} .

If the following condition is fulfilled

$$Q_{GOIS} < Q ,$$

then the pressure of the main oil pumping station is reduced.

As a result, they find the pressure of the pumps of the main oil pumping station, which corresponds to the first approximation of the working flow of oil in the oil pipeline.

From the pressure we proceed to the pressure of oil at the outlet of pumps of the main oil pumping station. The performance of the technological pressure limitation for the strength of the pipe is checked and the oil pressure after the regulators of the main oil pumping station is determined.

A hydraulic calculation of the adjacent section of the oil pipeline is performed and the oil pressure at the inlet to the oil pumping station, net on the route is determined.

Provided that the main-pump operation is carried out without cavitation, the calculations are repeated similarly for all subsequent oil pumping stations and corresponding sections of the oil pipeline.

If the oil pressure at the end of the oil pipeline exceeds the technologically necessary value and at the same time ensures the fulfillment of the abovementioned technological limitations of pressure and oil consumption, then the working pressure of the main oil pumping station is reduced with a certain step and the calculations are repeated until the necessary accuracy of the calculations has been achieved.

If for a certain value of the pressure of the main oil pumping station, the pressure at the inlet of any oil pumping station reaches the minimum allowable value of the condition of non-cavitation operation of main pumps, this indicates the finding of the pipeline throughput capacity for a specific parallel scheme of pumps.

After determining the throughput capacity of the oil pipeline, the efficiency and power consumption of each operating pump unit is calculated. The computational procedure is completed by finding specific energy consumption for oil transportation by oil pipeline. They characterize the energy efficiency of operation of the oil pipeline for a specific scheme of pumps operation.

In order to test the developed method and software, the throughput capacity and energy consumption of oil transportation by the main oil pipeline, on which there are two oil pumping stations, are determined. The inside diameter of the pipeline is 0.702 m, the length of the sections between the oil pumping stations is 40 and 60 km, respectively. Estimated oil density is 850 kg/m^3 and kinematic viscosity is 10 cSt. The oil pumping stations are equipped with pumps of the brand NM 3600–230 with variable rotor at 0.5 nominal feed, while the impellers of some pumps are sharpened.

Initially, a case was considered, in which at the first oil pumping station there is a parallel pump without turning off and a pump with trim impregnated with a three-speed impeller. At the second oil pumping station there is a parallel pump without turning off and a pump with a five percent trim impeller. As a result of the calculations according to the developed method and program it was obtained that the pipeline throughput capacity will be 2789 m^3/h, there will be no forced throttling, the specific electricity consumption for oil transportation will be 19.35 kWh / (ths. tons · km).

Similar calculations were made for the case of a sequence of operation of the oil pumping station of the above pumps. Given the technological limitations for pumps for maximum oil supply, the capacity of the pipeline will be 2000 m^3/h, the forced throttling will exceed 16 bar, the specific electricity consumption for oil transportation will be 31.16 kWh / (ths. tons · km).

Thus, for the conditions under consideration, the parallel scheme of pumps operation on the oil pumping station is characterized by better performance both in terms of transport capability and in terms of electricity consumption for oil pipelines through the main pipeline.

Conclusions

In the oil and gas pipeline transport there is a tendency towards the use of full-spin centrifugal machines that operate under a parallel scheme. In case of oil pipelines, the transition to a parallel scheme of pump units ensures significant oil consumption in the pipeline at lower operating pressures. This increases the reliability of pipeline transportation of oil.

Calculation of the mode of joint operation of different types of pumps in a parallel scheme has the features that need to be taken into account in the technological calculations of oil pipelines. The main difference between calculations is the need for a preliminary determination of the characteristics of the pumps range of operating pressures and costs, which provide effective parallel operation of the pumps.

The method and software for determination of oil pipeline throughput capacity and specific energy consumption for oil transportation in the case of parallel operation of various types of pumps on oil pumping stations are developed.

The method is tested by performing calculations for the conditions of the main oil pipeline. It is shown that the transition from a series to a parallel circuit of pumps can not only increase the volume of pumping, but also significantly increase the energy efficiency of pipeline transportation of oil.

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Особливості розрахунку пропускної здатності та енерговитратності нафтопроводу за паралельної роботи насосних агрегатів

М.Д. Середюк

Івано-Франківський національний технічний університет нафти і газу;
вул. Карпатська, 15, м. Івано-Франківськ, 76019, Україна

Встановлено особливості гідродинамічних процесів у разі паралельної роботи відцентрових насосів на трубопровід. Розроблено метод та програмне забезпечення для визначення пропускної здатності та енергоефективності магістрального нафтопроводу за використання на нафтоперекачувальних станціях паралельної схеми роботи різнотипних насосів. Розрахунками доведено, що за певних умов паралельна схема роботи насосів може мати переваги перед традиційної послідовною.

Ключові слова: *магістральний нафтопровід, паралельна робота насосів, питомі витрати електроенергії, послідовна робота насосів, пропускна здатність, технологічні обмеження режимних параметрів.*