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Optimization of hydraulic parameter control circuit of a pipeline using a variable-frequency drive

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Abstract. The performed studies in the area of petroleum engineering facilitate the shaping of a system of fundamental knowledge that allows the future specialist to scientifically analyze the issues in one's professional domain, implement the obtained basic knowledge in practice, and independently digest the new information encountered during one's industrial and scientific activity while employing modern methods of research. Controlling the pressure and flow of fluids in pipelines remains a highly important task. For this reason, further studies to find new designs and technological solutions to optimize these processes are promising and relevant, allowing to increase the technical and economic performance indicators of the processes of supplying pressurized fluid.

1. Introduction
Different technological processes in the oil and gas and petrochemical industry employ fluid supply under positive pressure above 0.5 Mpa [1]. The basic facilities to form such pressure are multistage centrifugal pumps of various designs. If there is no necessity to feed large volumes of fluid, then, instead of single pump units with a large number of impellers, it is practical to serially connect several units with a relatively low pump head [2]. In the case when it is also necessary to ensure smooth regulation of the pressure in the network, the optimal technique is controlling the speed of rotation of one of the units by means of a variable-frequency drive.

2. Materials and methods
The goal of this study is increasing the operation efficiency of multistage centrifugal pumps by replacing a single pump unit with a pumping station consisting of several serially connected centrifugal pumps with the equivalent flow but lesser pump head than in the replaced unit. It is known that when identical centrifugal pumps are installed serially, their pump heads sum up while the flow remains unchanged, as shown in Figure 1.
To regulate the hydraulic parameters of a network when using centrifugal pumps, the most economical and convenient technique is changing the speed of impeller rotation. In this case, the flow (feed) will be proportional to the rate of revolution of the centrifugal pump's impeller.

\[ Q \sim n \]  

(1)

The pump head (pressure) is proportional to the rate of revolution squared:

\[ H \sim n^2 \]  

(2)

The power consumed by the pump is proportional to the rate of revolution cubed:

\[ P \sim n^3 \]  

(3)

where \( Q \) is the fluid flow from the pump; 
\( H \) is the pump head; 
\( P \) is the power consumed by the pump; 
\( n \) is the rate of pump shaft revolution.

When changing the speed of rotation of a single pump unit, it is necessary to install a frequency converter with the maximum power equal to the pump's power. In this case, in the process of pressure regulation, power and flow will change accordingly [3]. For a serially connected pumping station, the operation mode is changed in the following way: one or several pumps work continuously, ensuring the flow of the main volume of the fluid at a small pressure. One of the pumps changes the impeller revolution rate depending on the readings of the pressure gauge installed in the pipeline.

This way, it is possible to use a low-power frequency converter while ensuring the accurate and timely pressure regulation depending on the change of the fluid volume consumed by the processing units [4].

For the purposes of the experimental study of pumping stations, a unit of two vertical multistage pumps (DPVF-15-7 and DPVF-15-11) was assembled and the hydraulic properties of the studied pumping station was compared with that of a TsNS-38-220 multistage centrifugal pump. The hydraulic characteristics of the pumps are presented in Table 1 and Figures 2 and 3.

![Figure 1. Hydraulic property of the combined action of two serially connected centrifugal pumps.](image-url)
The studies were carried out in factory conditions, the pumps were supplying water for spraying from the nozzles of reflux coolers with the flow of 6 tons per hour per one cooler.

**Table 1.** Main characteristics of pumps

| Name          | Power rating, kW | Maximum flow, m³/h | Maximum pump head, m |
|---------------|------------------|---------------------|----------------------|
| DPVF 15/7     | 7.5              | 22.5                | 102                  |
| DPVF 15/11    | 11               | 22.5                | 161                  |
| TsNS-38-220   | 45               | 38                  | 220                  |

The pumping station was equipped with vertical pumps to reduce head loss in the section of the pipeline between the pumps. Vertical pumps have flange connections on the suction and discharge parts located at the bottom of the casing from opposite sides, which simplifies the unit's installation and reduces the number of local hydraulic resistances. Only a small section of straight pipeline with a minimum number of isolation valves is located between the pumps of the first and the second stages.

The drive of the first stage (DPVF 15/7) with the power of 7.5 kW was controlled by an E2-8300-010N frequency converter that was working in automatic PID control mode responding to signals from a Metran-150 pressure gauge installed in the main collector of the water supply system before the reflux coolers.

![Figure 2. Hydraulic characteristics of TsNS-38 pumps.](image)

The required pressure was set by the personnel from the dispatch station based on the readings of remote recording instruments [10].
The use of this frequency converter offers an additional possibility to increase the electric motor shaft's revolution rate to 3600 rpm by increasing the frequency of the input alternating current to 60 Hz, which provides an additional reserve of pressure increase if required and allows to control the power consumed by the pump and give a timely signal about its unacceptable exceedance.

In the course of the tests, it was found that changing the revolution rate of the controlled drive within the range from 10 to 60 Hz results in a smooth change of the pump head provided by the station from 180 to 300 m with the flow up to 18 m$^3$/h, which allows to ensure the stable operation of three reflux coolers. At the same time, the power consumption decreased more than twice as compared with using a single TsNSG-38-220 pump unit.

This way, this study proves that replacing single pump units with pumping stations with serially connected centrifugal pumps is reasonable from the point of view of energy, while it is sufficient to install a variable-frequency drive on one of the connected pumps, which reduces equipment costs [9].

3. Conclusion
The results of the performed study are:
1. Serial connection of pumps in a pumping station provides stable hydraulic parameters of a pipeline in case of high pump heads and a relatively low flow.
2. A technical solution is offered that allows to replace single pump units with pumping stations to decrease specific power consumption.
3. The experimental studies carried out on the newly designed assembly have shown that changing the revolution rate of a variable-frequency drive in the range from 10 to 60 Hz allows to ensure the required mode of pipeline operation.
4. Using a frequency converter on the drive of one of the stages allows to ensure the automation of pressure control with lower power consumption and economic cost.

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