Selection of optimal operating modes for a block cluster pumping station

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Abstract. The article discusses a method for optimizing the model of a modular cluster pumping station using a variable frequency drive. Thanks to this technology, the energy consumption of the pumping units of the installation are sharply reduced. The equipment service life increases as a result of the application of this technology.

1. Introduction
At present, waterflooding is a well-established method of developing and enhancing oil recovery, applicable practically under all geological, physical and technical and technological conditions.

The use of waterflooding as the primary method is determined by the highest final oil recovery coefficient of the water-driven regime in comparison with others [1–6].

The main functions of the RPM system are as follows [7, 8]:
- preparation and provision of the required volume of water injection into the reservoir;
- control of the volume of injected water;
- reliable and economical operation throughout the entire life of the field.

Increasing the energy efficiency of the reservoir pressure maintenance system at the current high cost of electricity and the tendency to increase it against the background of a high percentage of water cut in good products means a decrease in current economic operating costs and an increase in the economic efficiency of the oil production process [9].

2. Materials and methods
Pumping units BKNS are the main energy-producing and at the same time energy-consuming elements of the pressure maintenance system. The type and number of installed pumping units determine the head and productivity of the BKNS [10, 11].

In the overwhelming majority, pumping units BKNS are represented by a group of multistage sectional centrifugal pumps of the type CNS 180, CNS 240, CNS 300, CNS 500 in an amount of 4 to 6 units.

The use of centrifugal sectional pumps is due to their significant advantages over other pumps [12, 13], the main of which are:
- relatively low cost, since the construction uses steel, cast iron and polymeric materials;
- ease of maintenance and operation;
- a wide range of performance regulation while maintaining a sufficiently high-efficiency value;
stable operation of pumps in sequential and parallel operation on a single pressure water conduit. The share of pumping units in the total balance of electricity consumption of the reservoir pressure maintenance system is 80–90%, and the cost of water injection in the cost of oil production is 26–35%.

The number of switching on-off per day of pumping units in the pumping station with tanks reaches 40-50 and in some cases 100. This number of switching-one for high-power units is unacceptable; therefore, in installations with units with a capacity of more than 150-250 kW, regulation of the operating mode of individual pumps is used, included in the BKNS.

An increase in the supply of the water supply network leads to an increase in the frequency of switching on the units and a decrease in the duration of pauses. The reason is that when the supply of the water supply network is increased, the volume of liquid in the tank is quickly triggered. In this case, the liquid level reaches the lower position more quickly, and as a result, additional pumping units are switched on more often [14].

The deliberate change in the flow and head of the pumps following the changing operating conditions of the system is called regulation.

Losses in pumps are associated with irrational operating modes of the system, which are characterized by a discrepancy between the parameters of the pump group and the parameters of the hydraulic network and the changing conditions of the oil field development technology [15].

Such modes of operation cause an increase in the share of non-productive losses of electricity in the technological system and increased specific consumption of energy parameters for water injection.

The reasons for the occurrence of electricity losses in the pumping units of the BKNS technological system of pressure maintenance can be conditionally divided into two groups [16]:

1) the first group – power losses determined by the type of pumping units in operation, individual characteristics of the hydraulic network and field equipment, adopted by the applied field development scheme.

Reducing these losses of the first group is possible:
- carrying out computational and technical developments to improve the flow path of the pumps, which will ensure high energy performance of the machine;
- improvement of materials and the inner surface of pipelines;
- improving the quality of calculations for the selection of technological equipment.

2) the second group – electricity losses determined by irrational operating modes of the pumping units of the BKNS, are considered as additional, which can be reduced by improving the existing approaches to the design of new and modernization of the operating RPM technological systems.

The reasons for the high share of electricity losses in the pumping units of the BKNS of the technological system are the low level of controllability of the electric drive of the pumps and the low adaptability of the BKNS to the changing conditions of the oil field development technology. The amount of power consumed by the pumping unit depends on its individual energy characteristics, which decrease during operation due to operational wear. The pump performance is also significantly influenced by the frequency, conditions and quality of repairs, which are not always carried out satisfactorily. Subsequently, this leads to a difference in hydraulic and energy characteristics of pumping units operating in parallel, which causes excessive energy consumption by pumping units with a lower capacity.

Pressure maintenance systems mainly operate on the principle of a centralized system, in which BKNS are united by one mode of water injection through high-pressure pipelines and water supply to injection well pads. The maximum head is determined from the condition of pumping the required volume of water into the wells with the highest injectivity.

The pressure in injection wells is controlled in the following ways:
1) fitting (flow limiter),
2) throttling with gate valves,
3) regulation of the pump flow, in which part of the liquid flow from the outlet of the BKNS is diverted to its inlet through the bypass, which is a special pipeline with a regulator valve.
4) step regulation of the pump flow, which is realized by inputting or outputting one or more pumps from the system.

The considered methods of flow control provide only technological parameters. They do not take into account energy parameters, which reduces the possibility of increasing the energy efficiency of the technological system for maintaining reservoir pressure.

Table 1. Comparative analysis of methods for regulating the performance of pumping units BKNS

| Regulation method                        | Energy loss level | Compliance with the injection plan | Efficiency | Depreciation of equipment | Notes                                                                 |
|------------------------------------------|-------------------|------------------------------------|------------|---------------------------|----------------------------------------------------------------------|
| Throttling on the pressure side of the pump unit | high              | high                               | low        | high                      | Wear of pumping equipment and valves. An inevitable increase in non-productive power losses |
| Installation of chokes at the injection wellhead | average           | low                                | high       | high                      |                                                                      |
| Bypass application                       | high              | low                                | high       | high                      | Wear of both pumping and electrical equipment. Limited number of communications in the absence of soft start systems. Reasonable in cases of pumping units operation for a long time in a constant flow mode |
| Step control: on / off pumping units     | high/average      | average                            | high       | high                      | Wide range of performance control of pumps, pumping units            |
| Changing the number of pump impellers (pumps) | low              | average                            | low        | low                       |                                                                      |
| Frequency-controlled electric drive      | low               | high                               | high       | low                       |                                                                      |

3. Results

The task of optimizing the control of the operating modes of the BKNS of the reservoir pressure maintenance system is associated with the need to take into account the many continuous technological, hydraulic and operating parameters of the elements of the entire system and can be implemented in two ways:

1) joint control of operating modes of pumps BKNS and hydraulic network,

2) increasing the level of controllability of the BKNS, i.e. more adaptive and operational behaviour of the system.

The optimization process consists of convergence of the hydraulic characteristics of the network and pumps of the BKNS while minimizing non-productive power losses. Each state of the hydraulic network and a set of planned tasks for injection into injection wells has its optimal mode of operation of the BKNS. That is, the position of the operating point on the flow-pressure characteristic of the hydraulic network, while the specific power consumption is minimal.

Optimization of regulation of operating modes of pumps BKNS is implemented in the following directions:

a) simultaneous control of the operating modes of the hydraulic system and pumps,
b) increasing the flexibility of regulating the parameters of the cluster pumping station.

The methods for converging the characteristics of the BKNS and the operating point of the hydraulic network are as follows:

a) change in the number of impellers in one or more pumps;
b) changing the characteristics of the hydraulic network;
c) the use of a frequency-controlled electric drive of pumping units BKNS. Frequency control provides the most significant operational regulating effect on pump performance, eliminating power losses. The figure shows the flow-pressure characteristic of the CNS 180-1900 and the characteristics of the hydraulic network, the optimal operating point on the graph is point A1, the flow rate is 180 m$^3$/h, the head is 1900 m.

In practice, when the pressure maintenance system is operating, a situation arises with a decrease in the supply of fluid from the hydraulic network. In this case, the BKNS operator regulates the fluid supply to the BKNS intake by closing the shut-off valve. As a result, the characteristics of the hydraulic network will change and point A1 will turn into point A2. However, the system will immediately experience energy losses (A2-A3) with an increase of 8.2% (1.55 MPa) since this action limited the capabilities of the hydraulic network. When using frequency control, for example, when the speed is reduced by 5%, point A1 will move to point A3 with a constant characteristic of the hydraulic network, which will not result in energy losses.

**Figure 1.** Flow-pressure characteristic of the CNS 180-1900: line 1 – the pressure characteristic of the pump at the rated speed, n = 3000 rpm; line 2 – pressure characteristic of the pump with a 5% reduced rotation frequency, n = 2850 rpm; line 3 – characteristic of the pipeline at the full opening of the gate; line 4 – characteristic of the pipeline with a 10% decrease in the degree of opening of the gate

4. **Conclusion**

The use of a frequency-controlled electric drive provides an increase in the efficiency of energy consumption of the technological system for maintaining reservoir pressure and the operability of the BKNS, which favourably affects the resource of the equipment.

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