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Monitoring of Pumping Unit Operation in Indicators of Energy Efficiency of Its Work

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Abstract. The influence of pumping unit elements on the overall energy efficiency of its work is viewed in the article. The areas of pumping unit operation effectiveness are identified and evaluated within the field of his QH characteristics and efficiency of its use in real technological process. The methodology of pumping unit operation evaluation in different modes through indicators of unit electrical energy consumption is developed.

Introduction

Today there is no single worldwide generally accepted definition for energy efficiency. Standards of different countries interpret this concept in different ways [1]. The term, that defines the energy consumption, which provided the technological process of the liquid pumping at its predetermined parameters, is the most appropriate definition of the concept of energy efficiency of pumping stations (or pump units) operation.

The most commonly used measure of the operating process efficiency today is the efficiency coefficient. Its determination regarding complex branched hydraulic systems of water supply and wastewater system is a time consuming process that does not always permit to consider the impact of all elements of the water supply system on the general index of the efficiency of system operation.

Typically, manufactures and processes are equipped with counters of primary energy (electricity consumed by electric motors), meters of the final product quantity (volume of pumped fluid) and manometers. Taking into account the difficulty of the analyzes of the impact of separate elements of the unit on the general efficiency of the process and the presence of accounting device in enterprises, it would be practice to introduce an index that could be measured with the existing meters without additional tools. The value of this index could serve as the criterion of the operation efficiency of electric pump unit and the system of water supply as a whole, as well as the need for technical measures to restore the pump unit or its redesign.

So scientifically based energy intensity per unit of product, which in water supply system is determined by the specific indicator of power consumption for pumping of liquid volume unit, is to be used as a measure of energy efficiency. In conditions of the actual production, this indicator may be determined by the data of meters at any given time.

Materials and Results of Research

Considering the water supply system, several main components can be defined: electrical network, electric drive of pumps (synchronous or asynchronous electric motors), tank and waterways of water supply system to the pumping station, valves from the suction side, pump units of pump station with control system, stop valve after pump units on charging, waterways of the system supplying water to the consumer, water consumer and its system of regulation and accumulation.

The maximum energy efficiency of the system, so securing the requirements of the production process in the water consumer with minimal consumption of electricity from the electrical network, is possible only if all elements of the system.

Quantity of consuming electric energy and other costs depend on the design features of pump units and elements of system, as well as the mode of system operation. All these factors are interrelated.

Energy efficiency operation of the system is largely determined by the right choice of pump by parameters of consumption and pressure that provides the pump operation within the operating range with maximum efficiency coefficient.

Let's consider the main element of the system - a pump. The optimal parameters of the pump (consumption Q_{opt}, pressure H_{opt}) are specified in his passport. However, depending on the scope of the pump usage, its operating parameters in the operating conditions may vary over a wide range. This range mainly is (0.5 - 102) Q_{opt} of the pump. If you change the characteristics of the network the pump operations in a mode, that differs from the optimal one. In this case, its efficiency is reduced. Moreover, when working in a mode that are more than nominal (optimal), the pump does not create a necessary pressure in the system, and while working in a mode that is smaller than nominal (optimal) it is necessary to constrict the overpressure that results in additional charges. Operation of pump in modes (0.3 – 0.5) Q_{opt} leads to a number of problems associated with the increase of pump vibration, occurrence of unsteady axial and radial forces.

Evaluation of technical level (in terms of energy use in the workflow) of pump units is made in terms of the efficiency coefficient (efficiency coefficient according to the passport) in operation (optimal) mode of pump operation. Researches and conclusions of experts show that when pumps are operated in systems with variable over time hydraulic resistance, they work only from 10% to 25% of the time with the parameters corresponding to the optimal (nominal) efficiency coefficient [2].

So declared a high nominal efficiency coefficient of pumps may be offset by the additional energy losses caused by mismatch between the consumption of pump unit and immediate need of the network.

Electric pump unit includes a pump, couplings and drive motor. Its lifting characteristics depend on the type of pump, dimensions ratio of its main parts and components, which are design parameters, as well as on a number of indicators of operating mode, which constitute the regime parameters.

Operating capacity N_i of aligned pump in mode i of its operation having losses Q_i is calculated from the formula [3]:

$$N_i = \rho g H_i Q_i / 1000 \eta_{pump.i} \quad (1)$$

where ρ is liquid density pumped over by the pump;

g is gravity acceleration,

H_i is pump head,

$\eta_{pump.i}$ is pump efficiency coefficient in mode i.

Drive motors of electric pump units affect the energy efficiency of the process because of the energy loss in the electromagnetic and mechanical processes that occur during their operation. These losses depend on the workload of motors, which quantitatively characterized by the load factor k_3. The latter is the ratio of the actual operating capacity of the motor P_m to its nameplate nominal power P_{nom}:

$$k_3 = P_m / P_{nom} . \quad (2)$$

The actual value of the efficiency coefficient of the electric motor depends on the actual load P_m and corresponds to a specific value of the load factor k_3. Generalized dependence of the efficiency coefficient of the electric motor from the load factor [4] is showed in Fig. 1.

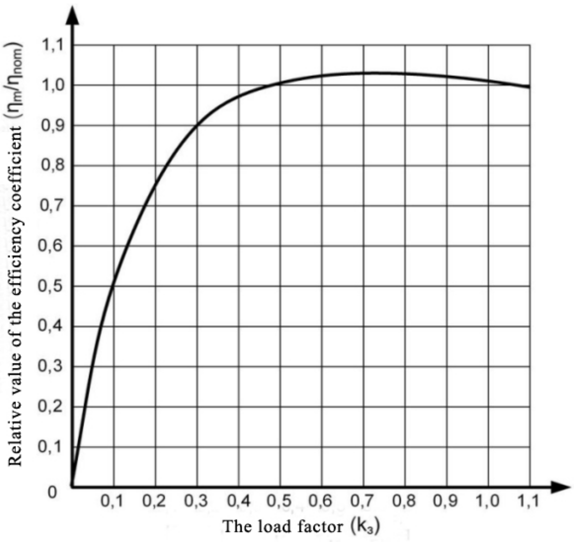

Fig. 1. Generalized dependence of the electric motor efficiency coefficient from the load factor

Fig. 1 and [4] show that the electric motor efficiency coefficient is down from its maximum value by 1% within the variation $k_з$:

$$0{,}5 < k_3 < 1{,}05\,. \tag{3}$$

Therefore, in view of rational energy use by electric pump units, it is advisable to apply the drive motors within the specified range of their load (Eq. 3). The decision to use the drive motor out-of-range (Eq. 3) should be based on a comprehensive analysis and calculation of the energy performance of the whole water supply system.

The foregoing in the article research results are obtained in the study of the workflow of D pump units, one of which is pump D6300-80-2.

The results of the workflow research of pumps D6300 -80-2 at different values of consumption Q_i within range $0{,}3\,Q_{opt} < Q_i < 1{,}2\,Q_{opt}$, ($Q_{opt}$ - pump consumption while work at the point with $\eta_{pump\max}$) received due to conduction of numeric experiments, confirm the possibility of pump operation within the specified range of consumption using the original (initial) impeller with outside diameter D_2= 1020mm , with a decrease diameter by 21%. Field of $Q-H$ parameters change for each variant of D_2 , which are considered, within the possible decrease of its efficiency coefficient from its maximum value by 5% ($0.95\,\eta_{pump\max}$), are shown in Fig. 2.

In Fig. 3 the areas of $Q-H$ characteristic within the range of changes of the efficiency coefficient to 3% and 5 % of its maximum values $\eta_{pump\max}$ for the defined D_2 are also marked out. Current practice indicates for the appropriateness of the pump operation in this variation range of the efficiency coefficient [5]. Reducing the diameter up to 865 mm (on 15% from the initial) results in a reduction in pump efficiency at the optimal consumption point Q_{opt} for about 5%. Further reduction in diameter D_2 results in additional energy losses in the impeller and outlet, which reduces the pump efficiency coefficient on 12% if D_2= 805 mm. However, vibroacoustic condition of the worker operating in this mode of the pump is satisfactory.

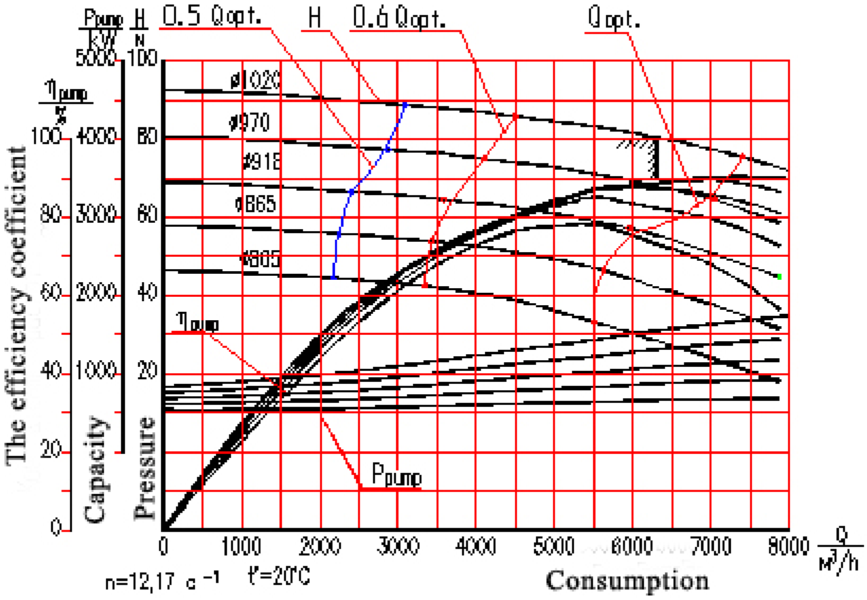

Fig. 2. Variation range of $Q-H$ characteristics of pump D6300-80-22 while reduction of its outside diameter D_2 within the range 1020 … 805 mm

The results of numeric experiments and conducted field tests on operating site confirm the possibility of stable operation of the said pumps in mode of consumption from 0.6 Q_{opt} to 1.2 Q_{opt}, but in this case the change in the pump efficiency coefficient is beyond the value $\eta_{pump\max}$ - 5%.

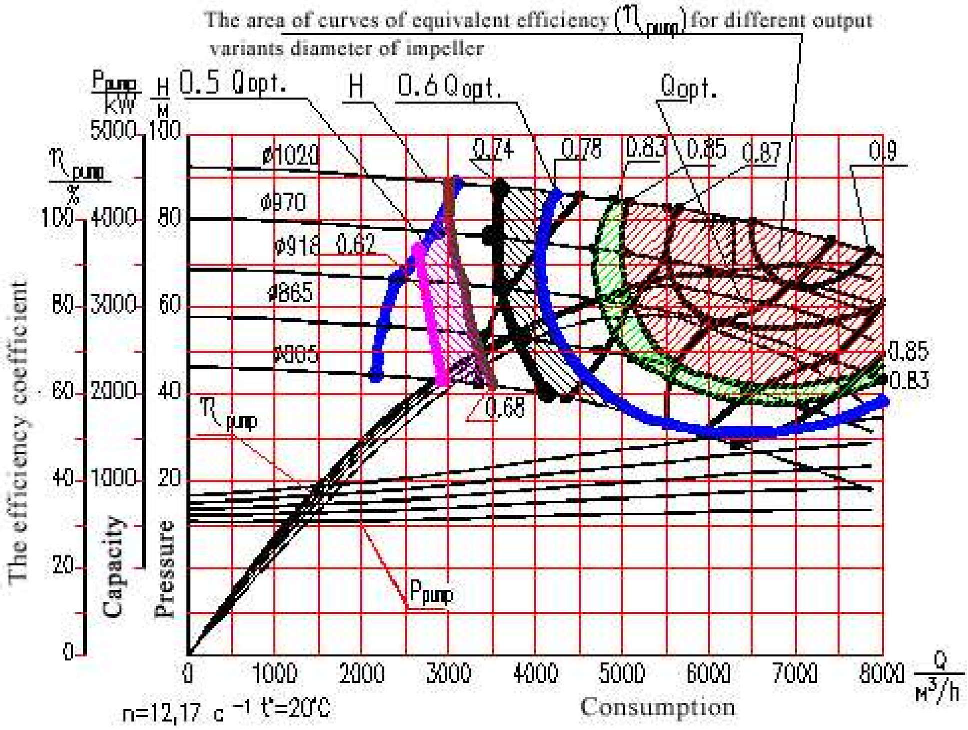

Fig. 3. Changes in pump D6300-80-2 efficiency coefficient within the range of changes of consumption Q_i from 0.6 Q_{opt} to 1.2 Q_{opt}

Due to accepted limits of variation of motor load factor (Eq. 3), we consider the range of pump operation. Limit on a previously defined (Fig. 2) part of the working area of $Q-H$ characteristics of the pump the area of «problem" use (Fig. 4) of drive motors, pump units D6300-80-2 are equipped with (i.e., the area of electric motor load, which reduces the motor efficiency coefficient by more than 1% of efficiency coefficient in P_{nom} point).

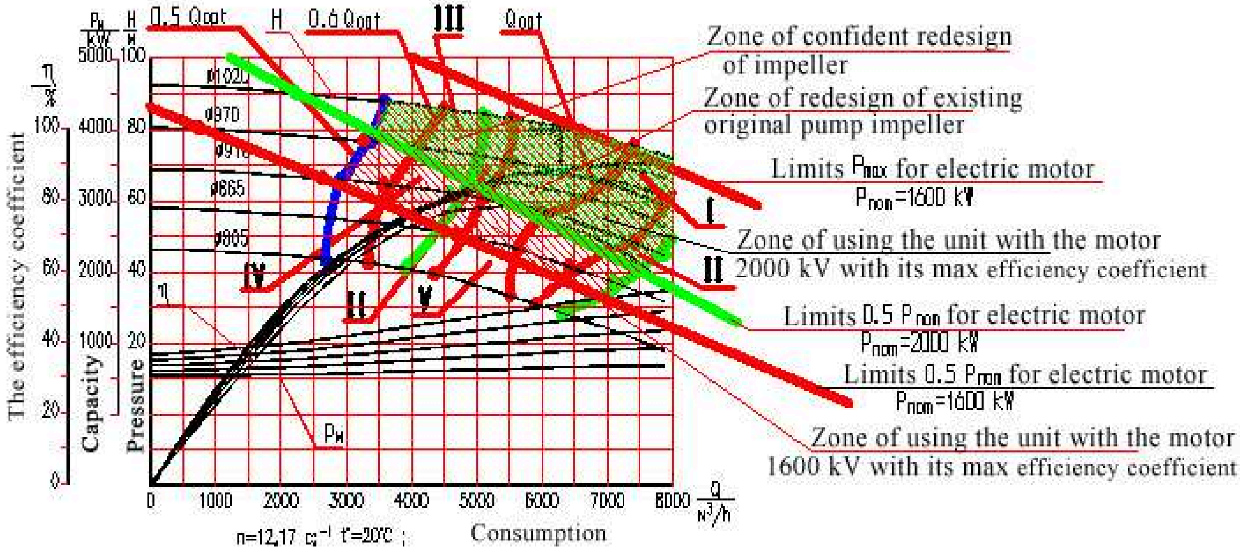

Fig. 4. Limits of the area of *Q-H* characteristics based on energy efficiency use of drive motor

Based on the criterion of marginal changes in the pump efficiency ($\eta_{pump\max}$ -5%) and restrictions for motor efficiency reduction by 1% from $\eta_{el\max}$, that is shown in Fig. 4, the field $Q-H$ will be divided into zones:

I - zone of possible redesign of existing original pump impeller without motor replacing;

II – zone of primary possible upgrading of existing original pump impeller without motor replacing;

III - zone of possible pump redesign by replacing the original impeller on the impeller of new design required for necessary parameters without electric motor replacing;

IV - zone of possible redesign of the electric pump unit by replacing the original impeller on the impeller of new design required for necessary parameters and electric motor;

V - zone of possible redesign of electric pump unit by redesign of the existing original impeller with obviously significantly reduced indexes of energy efficiency of the unit, as well as through the work of the electric motor in modes with a low load factor k_z.

Based on the above considerations and calculations, while the application of an electric motor SDN2-17-44-8UZ, the area of $Q-H$ characteristics of electric pump unit D6300-80-2, if it is subject to the effective operation, takes the form shown in Fig. 5

$$\eta_{agr.i} = \eta_{pump.i} \cdot \eta_{muft.i.} \cdot \eta_{e.d.i} \cdot \eta_{reg.i} \quad (4)$$

The overall efficiency of the unit $\eta_{agr.i}$ while any consumption Q_i is determined by the expression where:

$\eta_{pump.i}$ is the pump efficiency while its work on i mode with consumption Q_i;

$\eta_{muft.i}$ is the efficiency of couplings;

$\eta_{e.d.i}$ is the efficiency of the drive motor while operation of the unit in mode i;

$\eta_{reg.i}$ is the efficiency of the regulatory system of the drive motor.

To assess the efficiency of pump unit in the mode i by determining its efficiency by the expression (Eq. 4) it is necessary to have numeric values of the efficiency of pump and electric motor in the mode i with consumption Q_i. This information is shown in the passport of the unit, but it is mostly calculated on the basis of results obtained under the conditions of test benches while new product testing. In actual service conditions of pump stations, there is mainly the meter of consumed electric energy by drive motor, manometers and meter of pumped water. In addition, the indexes of technical condition of the pump unit (excluding vibroacoustic) are defined in the repair and disassembling. Therefore, the determination of the pump unit running efficiency during its operation through the efficiency coefficient is a hard work.

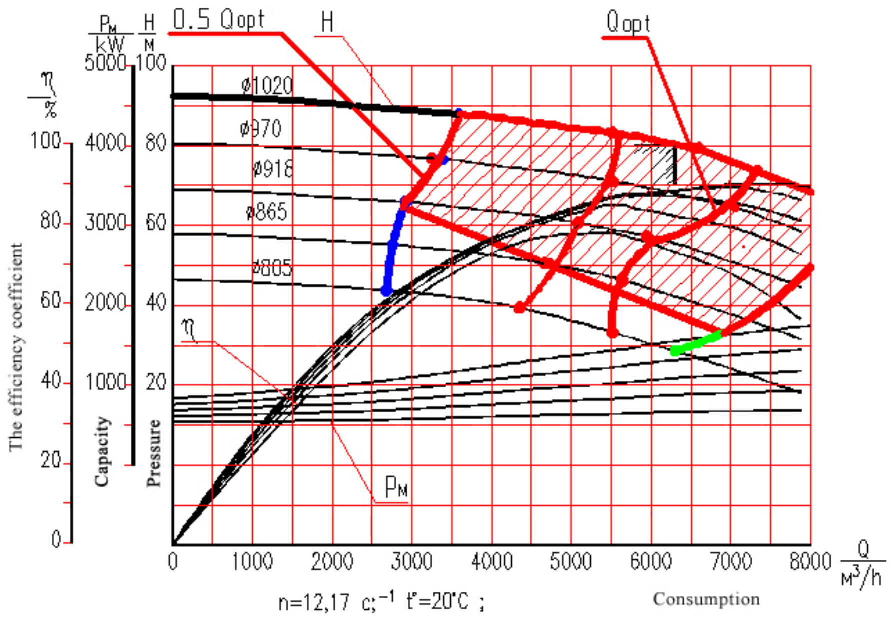

Fig. 5. Limits of the area of *Q-H* characteristics of the electric pump unit D6300-80-2 while using electric motor SDN2-17-44-8US

Evaluation of energy efficiency of electrical pump units, pump station is generally proposed to perform by indexes of specific electricity consumption for pumping of one cubic meter of liquid while operation in mode i (with consumption Q_i)[6]. This index ρ_i is calculated according to the formula:

$$\rho_i = A_i / t_i Q_i , \tag{5}$$

where A_i is the amount of electricity consumed by electric pump unit in mode i (kW/h);

t_i is the period of operation in mode i (h);

Q_i is the consumption of the pump for t_i (m $м^3$/h).

Specific power consumption indexes ρ_i are also determined by calculation using the results of the research of pump work process, specifications and characteristics of drive motors. In (Eq. 5) A_i / t_i - unit operating power is N_i while its work in the mode i,

$$\rho_i = N_i / Q_i , \tag{6}$$

so in turn, operating power N_i of electric pump unit is determined by the operating capacity of the pump $N_{pump.i}$ as:

$$N_i = N_{pump.i} / \eta_{e.d.i} , \tag{7}$$

operating capacity of the pump $N_{pump.i}$ while its work in the mode i determined by (Eq. 1) using (Eq. 1), (Eq. 7) takes the form:

$$N_i = (\rho g H_i Q_i / 1000\eta_{pump.i}) / \eta_{e.d.i} \,. \tag{8}$$

That is why according to (Eq. 6), using (Eq. 8):

$$\rho_i = \rho g H_i / 1000\eta_{pump.i}\eta_{e.d.i} \tag{9}$$

If the energy loss in the couplings is to be considered by 1%, the expression (Eq. 9) takes the following form:

$$\rho_i = \rho g H_i / 990\eta_{pump.i}\eta_{e.d.i} \tag{10}$$

The results of the research of the work process of several sizes of D type pumps, using the formula (Eq. 10), the indexes of specific power consumption ρ_i for pumping of one cubic meter of liquid during operation of the unit in the range of consumption Q_i from $0.5Q_{opt}$ to $1.2Q_{opt}$ are calculated. In Fig. 6 the variation area of calculated index of specific power consumption ρ_i for pumping of one cubic meter of liquid by pump unit D6300-80-2 is shown.

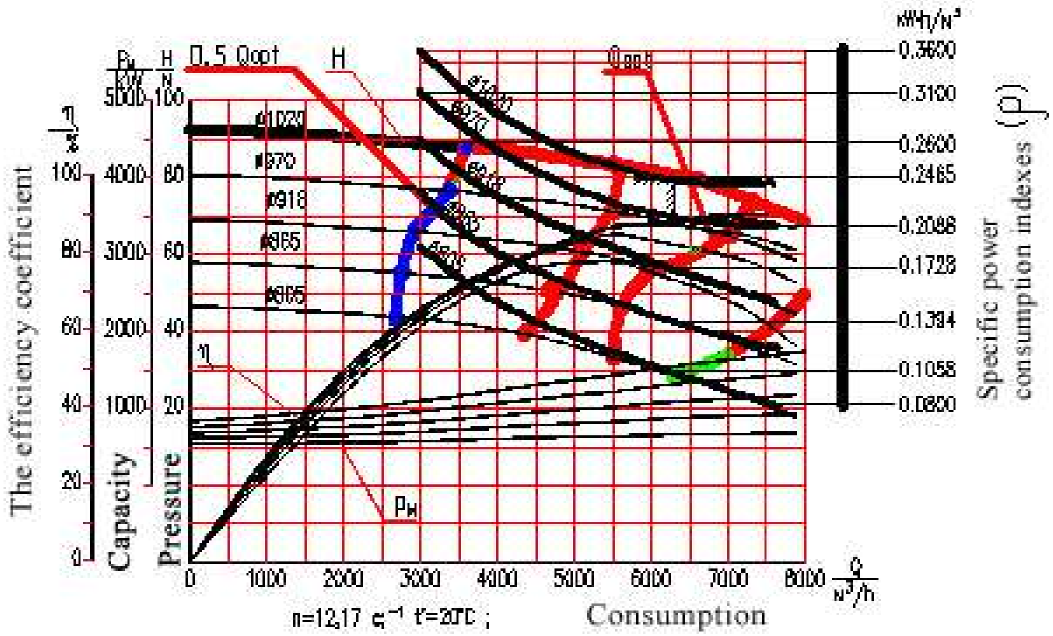

Fig. 6. Variation area of calculated index ρ_i of pump unit D6300-80-2

To determine the actual index $\rho_{f.i}$ while pump unit operation in mode i with consumption Q_i it is necessary to use electricity and water meters, taking their measures for a certain period of time t_i, and use the (Eq. 5) for the calculation of this index.

The difference $\Delta\rho$ between the calculated ρ_i and actual $\rho_{f.i}$:

$$\Delta\rho = \rho_i - \rho_{f.i} \tag{11}$$

is an indicative index of the need for technical measures to restore the pump unit or its redesign. The above difference (Eq. 11) is the basis for evaluating the efficiency of the use of the pump unit in the technological process of water supply and evaluation of changes of technical parameters of pumping equipment and systems in general.

Summary

According to the results of the research it was prompted the zoning of area of *Q-H* characteristics of electric pump units having the aim to determine the limits of possible energy efficiency of their operation, the volume of possible redesign for increasing the energy efficiency of their work, and the impact of losses in electric drive motor on the efficiency of the unit use while different operation modes. Within the area of *Q-H* characteristics of electric pump units of D type it was calculated and designed the variation areas of specific power consumption for the pumping of unit volume of fluid that allows to determine the calculated indexes values of unit energy efficiency according to the predetermined parameters (consumption and pressure) of the operation of water supply system and serves as the basis for establishing a system of monitoring the operation efficiency of pumping units

Suggested approach for determination of the operation efficiency of pumping units is based on the definition of the indexes of specific power consumption for pumping of one cubic meter of liquid, which is an integral criterion of the energy efficiency of water supply systems functioning.

Obtaining the necessary input data for its calculation requires no additional tools besides meters of electric energy consumed by drive motors, meters of pumped liquid and manometers, which water supply system are usually equipped with.

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