Energy efficiency of functioning of water reservoir wells and collecting conduit

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Abstract. Maintaining the stable operational mode of groundwater intakes and increasing their operation period is an urgent task of urban water pipelines operating. The problem of the water supply to consumers can be solved in the process of managing the operation modes of water intakes. We consider the negative developments in the functioning of groundwater intakes.
The purpose of this research is to improve the existing schemes of water supply in Pure Water Reservoir through pressure pipelines of groundwater abstraction and increase the productivity of submersible pumps. Inside the wells various pumps can be installed, characterized by the pressure and performance. Submersible pumps at nominal flow supply have maximum efficiency, so the most favorable for the pump is work to a tank of clean water. The layout of wells and common culvert is shown.
Monitoring of water intakes allows setting technical parameters for selecting an independent scheme, choosing the right equipment, taking into account the joint operation of the well system - submersible pump - prefabricated water conduit - Pure Water Reservoir. Based on the results of theoretical and practical studies, a mathematical model of the energy efficiency of the system operation is proposed: a water well - Submersible Pump - collecting conduit. Reviewed the mutual influence of the operating mode of individual wells and precast culvert under various schemes of connection of pressure. Most preferred is a diagram of feed water in the basin with clean water by a separate pressure lines, in this scheme ruled out mutual influence of the operating mode of individual wells.
Energy-efficient operation of the water intake with separate pressure lines must be assessed by comparing the total energy consumption in the system.
Key words: water intake, water supply, water well, pump, collecting conduit

1. Introduction

Maintaining the stable operational mode of groundwater intakes and increasing their operation period is an urgent task of urban water pipelines operating. The problem of the consumers water supply can be solved in the process of managing the operation modes of water intakes. [1-5, 10, 13].

The main condition for efficient and reliable operation of submersible pumps is their coordinated work in the well system - submersible pump - prefabricated waterway. Therefore, such a system should be considered as a single one, and the choice of submersible pumps and schemes for the supply of water to the CWT (clean water tank) should be decided on the basis of the calculation of the joint operation of the elements of the system.

The purpose of this work is to improve the existing schemes [1-2, 6] of water supply to CWT through pressure pipelines of groundwater abstraction and increase the productivity of submersible pumps. Based on the results of theoretical [1, 3-5, 7-20] and practical studies, a mathematical model of the energy efficiency of the well system functioning is proposed - submersible pump - prefabricated water conduit.

The general scheme of location of structures at the water intake of groundwater [2, 6] is shown in Fig. 1 and is the most common in the practice of construction and operation. Water from the aquifer enters wells 1, from where it is fed by means of submersible pumps through pressure pipelines 2 to the collecting waterway 3. Next, water is sent to the CWT 6 via the main water pipeline.

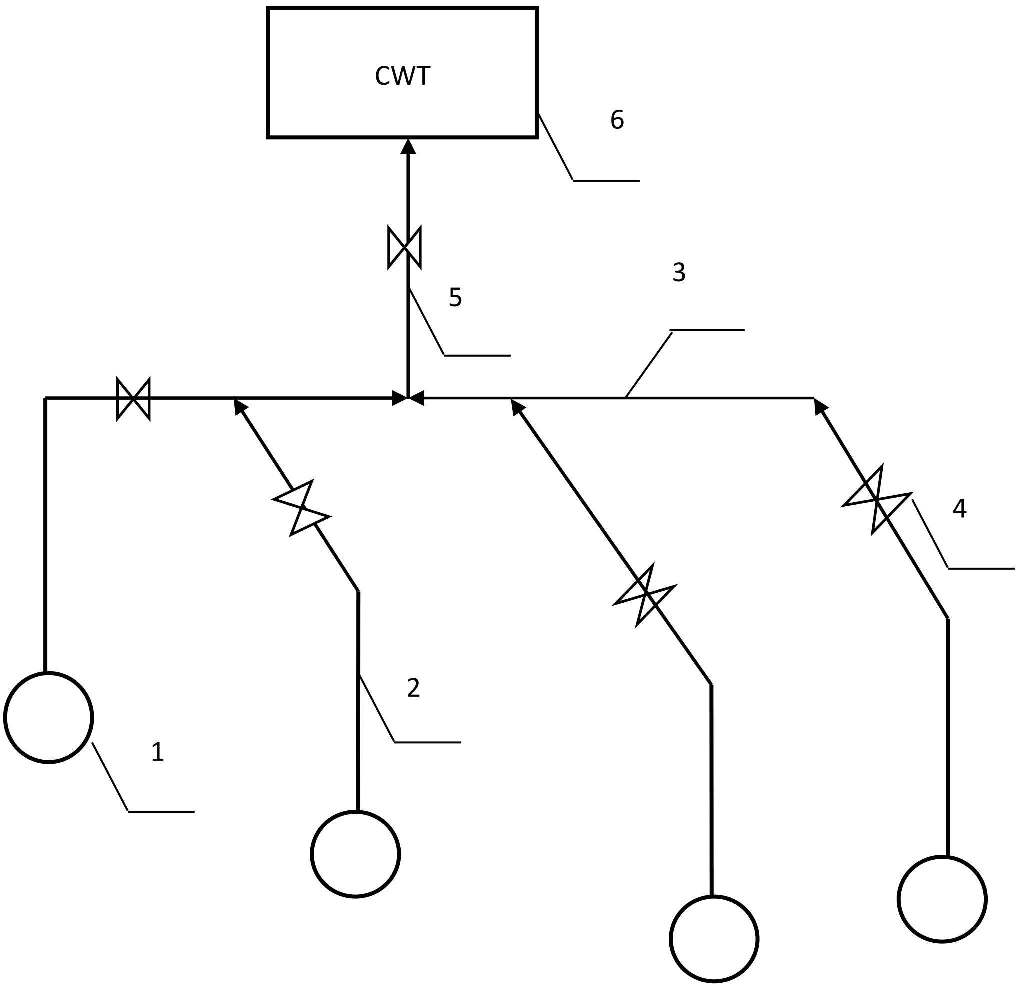

Figure 1. Scheme of location of water intake facilities: 1 - wells with submersible pumps; 2 - pressure pipeline; 3 - prefabricated water conduit; 4 - shut-off and control valves (controlled throttles); 5 - main water conduit; 6 - clean water tank (CWT)

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2. Methods

For the analytical solution of the problem of the joint operation of the well - submersible pump - prefabricated waterway - CWT system, a linear flow distribution model [10, 12] is developed for the disturbed state, since such a system has certain forms of boundary conditions, which allows obtaining an unambiguous solution for the problem.

The control model for the functioning of the water intake is made for a one-dimensional quasistationary flow of a viscous incompressible fluid in pipes. It includes the Bernoulli system of equations with a certain right-hand side, in the form of chain equations for a system of linearly independent chains, where the first Kirgof law is applied as functional constraints in the form of nodal balance equations for a set of nodes with undefined potential [10]:

$$\sum_{j\in J_p}\sum_{j\in J_\gamma}\operatorname{sgn}\Delta P_{ij}=\sum_{j\in J_p}\sum_{j\in J_\gamma}\operatorname{sgn}S_{ij}Q_{ij}^2=\sum_{j\in J_p}\left[(Z+H)_N-Z_R\right]_j\ , \tag{1}$$

$$\sum_{j\in J_\mu}\left(\sum_{j\in J_\varepsilon}\operatorname{sgn}Q_{ij}+q_j^z\right)=0\,, \tag{2}$$

where:

J_P, J_γ – is the set of independent chains, the set of segments in the composition of the independent chain j, respectively;

S_{ij}, Q_{ij} – coefficient of hydraulic resistance and design flow rate of pressure pipeline i in circuit j;

J_μ, J_ε – is the set of nodes with an unspecified potential, the set of sites incident to node j, respectively;

q_j^z – concentrated preset selection (inflow) from node j;

$(Z+H)_N$ – is the geodetic level of the pump and the head generated by the submerged pump as part of the circuit j;

Z_R– is the geodetic level of the position of the CWT in the circuit j.

The rule for assigning positive signs to the terms (1), (2): $sgn\Delta P_{ij} = +\Delta P_{ij}$ - in case of coincidence of the flow direction in the section i with positive orientation along the chain j; $sgn\Delta Q_{ij} = +\Delta Q_{ij}$ - in the case of inflow of the local flow to node j. Negative signs are assigned in opposite cases. The term q_j^z is assigned (+) in case of water inflow to node j from the source, negative - in case of drain from node to consumer.

For the formation of feedback, realizing the mode of water supply from wells, set by the user, additional (redundant in relation to equations (1), (2)), analytical connections are necessary. To this end, it is proposed to use the surrogate (not based on physical laws) Legendre-Gauss principle, known as the method of least squares (LSM).

A quadratic functional constructed on the basis of LSM represents the residual function F compiled by comparing the supply of water coming from the well according to the computer version and the user version forming the set of the water supply mode in the CWT.

$$F=\sum_{i\in I_\pi}\left(Q_i^{\pi z}-Q_i^{\pi}\right)^2+\lambda\left(\sum_{i\in I_\pi}Q_i^{\pi z}-\sum_{i\in I_R}Q_i^{\eta}\right), \tag{3}$$

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where:

$Q_i^{\pi z}$, Q_i^{π} - the estimated flow rate of the pressure pipe i, which supplies water from the well according to the user version and computer version, respectively;

Q_i^{η} – estimated discharge of the collected water conduit i, which supplies water to the CWT;

I_π – a number of sections (pressure pipelines) supplying water from submersible pumps;

I_R – the set of receiving CWT (prefabricated water conduit);

λ - is the indefinite Lagrange multiplier.

The second group of terms (3) reflects the continuity of the water flows in conditions of arbitrarily set values of the design flow rate of the pressure pipe supplying water from the well (according to the user version), which must be limited by this condition of continuity.

In contrast to LSM, operating with various measurement errors of the magnitude, the values of the weight function W_k in the composition of the objective functional (3) are assumed to be the same and do not affect the position of the extremum (3).

Model of water intake functioning management:

$$\left[\frac{C_{n1\times P}}{C_{n1D\times P}}\right]^t \times \left[\frac{h_{n1\times 1}}{h_{n1D\times 1}}\right] = \left[M_{p\times g}\right]\times\left[\widehat{H}_{g\times 1}\right], \tag{4}$$

$$\left[\frac{\grave{A}_{n1\times\mu}}{\grave{A}_{n1D\times\mu}}\right]^t \times \left[\frac{Q_{n1\times 1}}{Q_{n1D\times 1}}\right] = [0], \tag{5}$$

$$\left[\frac{E_{n1\times(e-1)}}{0_{n1D\times(e-1)}}\right]^t \times \left[\frac{Q^{\pi}{}_{n1\times 1}}{Q_{n1D\times 1}}\right] = \left[\frac{E_{n1\times(e-1)}}{0_{n1D\times(e-1)}}\right]^t \times \left[\frac{Q^{\pi z}{}_{n1\times 1}}{Q_{n1D\times 1}}\right], \tag{6}$$

where:

[C], [A], [M], [E] – matrix of a system of independent water intake circuits, an incidence matrix for in-feed-back nodes with undefined potential; matrix of contiguity of sections connecting prefabricated units; matrix of normal equations composed of single elements, respectively;

n1 – the number of water intake sites, excluding areas with associated controlled throttles;

n1D – the same for areas with connected controllable throttles;

p = (g - 1) – number of independent chains in the water intake system;

g=(e+1) – the number of nodes with a fixed potential in the water intake); hi - loss of pressure of the pressure pipe i;

$\widehat{H}_j = Z_j + H_j^z$ - fixed potential of the borehole j; where H_j^z - fixed potential of the borehole;

μ - number of water intake points with undefined potential;

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Q_i^{π} $Q_i^{\pi z}$ - calculated flow rate of the pressure pipe i, which supplies water from the submersible pump, according to the computer version;

$Q_i^{\pi z}$ - the same, according to the user's version;

t – is the sign of transposition.

The model of water intake operation allows to monitor the transition of the well system - submersible pump - prefabricated waterway - CWT to a new state and change of parameters along separate lines within this transition.

One of the main reasons for the reduction of the energy efficiency of the water intake operation is the way water is supplied from the wells to the collecting water conduit (Figure 1).

Water intakes of underground waters work according to the scheme of connection of pressure well pipelines to assembled units and further supply of water to the assembled water conduit, which is connected with all wells and is the transmitting link of regime disturbances of one group of wells to others.

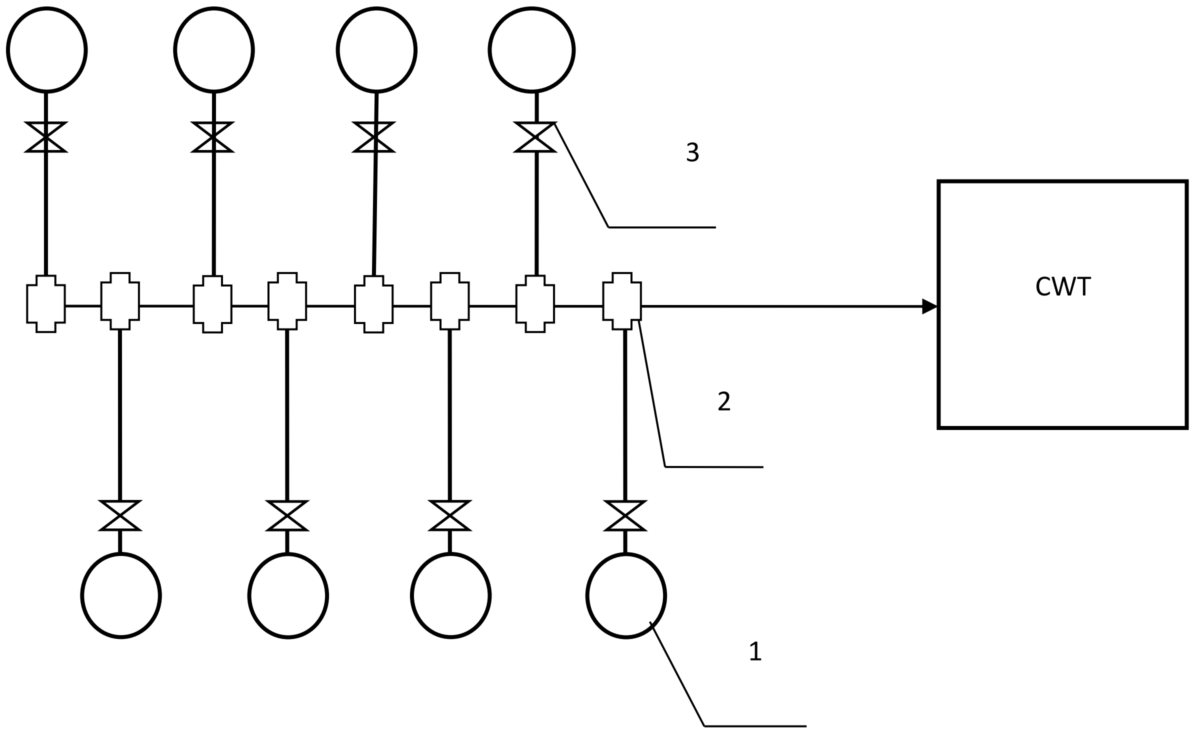

Figure 2. Scheme of connection of pressure pipelines to separate assemblies of the assembled water conduit: 1 - wells with submersible pumps; 2- assembled units; 3 - shut-off and control valves

3. Results

With a significant difference in the brands of submersible pumps, it is possible to increase the flow resistance in a prefabricated water conduit and to reduce the supply of water from individual wells. The total supply of water by all submersible pumps operating on a single conduit is much lower than the calculated pump-specific data. The flow of water through such schemes results in a decrease in the head and the amount of incoming water in the CWT compared to the expected values in the new state, with some pumps deviating from the optimum operating conditions.

Most preferable is the scheme for supplying water to CWT along separate pressure lines (Figure 3), in which the mutual influence of the operating mode of individual wells is excluded. Submersible pumps in the system can be tuned to their own energetically optimal mode of water intake operation.

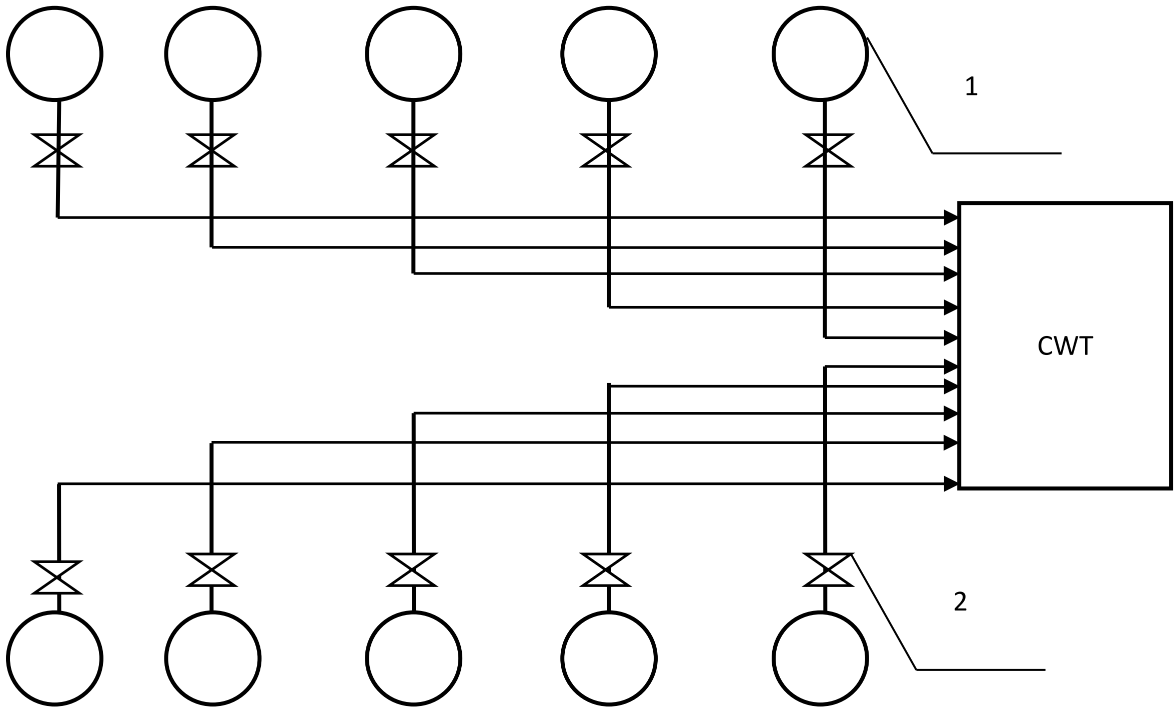

Figure 3. Scheme of water supply to CWT along separate pressure lines:
1 - wells with submersible pumps; 2 - shut-off and control valves

The economic analysis of the scheme for supplying water to RFW via separate pressure lines can be done by the ratio of the volume of construction work and the cost of pipes in comparison with the schemes discussed above. Thus, the design of the water intake is carried out with the obligatory construction and analysis of the characteristics of the combined operation of pumps and a combined water conduit. When reconstructing existing water intakes, it should be borne in mind that such a scheme will require large capital expenditures for laying pressure pipelines. It is necessary to determine the boundaries of the most effective use of pumping units and, accordingly, the choice of pipe diameters [13, 15-16, 19].

4. Conclusions

Monitoring of groundwater intakes allows establishing technical indicators for choosing an independent scheme, to properly select equipment, taking into account the joint operation of the well system - submersible pump - prefabricated waterway - CWT.

Energy efficient operation of water intake with separate pressure lines for water supply to CWT should be assessed basing on a comparison of the total electricity consumption in the system, taking into account the cost of separate pressure lines.

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