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HYDRAULIC ANALYSIS OF A RECYCLED TECHNOLOGICAL WATER SUPPLY NETWORK

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ABSTRACT

Modern industry uses large quantities of water for production processes and requirement to water quality is higher and higher. Technological water supply of few industrial enterprises often put complicated issues in terms of consumption to users. In this paper a hydraulic analysis model of a recycled technological water supply network is developed. Based on this model a computerprogramwas elaborated, which is expected tobeimplemented in a computer control and monitoring centralised system.The results of this program are used to taking decisions that ensure optimal operation of the network with a high reliability of service and with low energy consumption. The numerical results of a practical application for studied issue show the operational efficacy of proposed computational model.

Keywords: water supplies, industrial enterprise, self-supply network, recirculation, hydraulic analysis, computational model, operational optimisation.

1. INTRODUCTION

Water supply in industrial sector is an important task of the national economies, because modern industry uses large quantities of water for production processes and requirement to water quality is higher and higher.

It is estimated that 22% of worldwide water is used in industry. Major industrial users include hydro-electric dams, thermoelectric power plants, refineries, manufacturing plants, and other chemical plants. In these industrial sectors, large volumes of treated water are involved in the production process. Industry requires pure water for many applications and utilises a variety of treatment techniques both in water supply and discharge [1, 2]. Diminishing quality water supplies, increasing water purchase costs, and strict environmental effluent standards are forcing industries to target increased water-efficiency and reuse. These factors, in combination with an estimated fivefold increase in worldwide manufacturing water use by 2030, will contribute to growing industrial water/related expenses in the near future [3]. In 1995, the estimated water use for all domestic industries was 117×10^6 m^3/day, and currently the global annual cost to purify industrial-use water and wastewater exceeds $ 350 billion [4, 5]. Water for industrial use may be delivered from a public supplier or be self-supplied.

For establishing water supply system in industry and the network scheme [6, 7] is necessary to take into account the conditions of uninterrupted users supply with minimum energy consumption. These are necessary for achieving planned production, and for avoid equipments damage. Thus, within many industrial enterprises is adopted technological water supply self-system with recirculation. The captured water temperature is increased because it is used in the process of cooling equipments and aggregates. That is why water is passed through cooling systems, which cause the decrease of the temperature and allow be used again to cool the aggregates. From water source is captured only the flow rate lost through the cooling facilities or in the distribution network and addition water required when there is a marked mineralisation of water in the cycles of cooling-heating-cooling. In this case the water supply network forms an open system. In cold weather, however, recycled water is discharged directly into the suction tank of the pump station, achieving a closed system.

The real operation of such distribution (supply) and recirculation (return) networks may be different from nominal operation due to causes such as: design for a perspective stage, develop in time of water consumption, change of user facilities and the pump station characteristics compared to the original stipulations.

In this situation is necessary both systematic analysis of the flow and pressure distribution in the network and optimisation of the user water consumption [8, 9, 10] by a computer control and monitoring centralised system. Thus, it should be possible to restore perpetually the hydrodynamic balance of network through automatic control valves or at least manual adjustment valves. The pressure drop across the control valve varies between a maximum, when it is controlled, and a minimum, when the valve is near full open. Typical control valve flow characteristics are shown in [11].

In [12] is presented a numerical simulation model of technological water consumption foran enterprise in chemical sector with self-supply system. In this paper is developed a hydraulic analysis model of a recycled technological water supply network. Based on this model a computer program was elaborated, which is expected to be implemented in a computer control and monitoring centralised system. The results of this program are used to taking decisions that ensure optimal operation of the network with a high reliability of service and with low energy consumption.

2. MATHEMATICAL MODEL

For formulation of proposed computational model are considered as known following basic data: the network topology; the length, diameter, and local friction factor of the pipes; initial pipe roughness and operating duration; increase rate of pipe roughness; mean water temperatures in supply pipes and return pipes; the geodesic head, necessary pressures, necessary discharges, and consumed discharges in each consumption point; the elevation head at pump station.

Knowing the pressure drop at each consumption node is simulated each user by one fictitious pipe, carrying the required discharge of the considered user. This fictitious pipe has a diameter equal to that of the pipe which supplies the user and an equivalent length determined to introduce a head loss equal to the pressure drop in the user's facility. Minor loss coefficient for fictitious pipe is considered zero.

Supply network pipes are numbered so that the end node of a pipe is considered identical to its serial number. Considering each branch is assigned a number for node and for upstream pipe only after having exhausted all feed-water branches. Then numbering is continued arbitrary for return network node and pipes beginning from the first pipe of supply network. Thus, each pipe has a serial number and is defined by an initial node and a final node.

Taking into account the required discharges QN_n and consumed discharges QC_n at the consumption node n, in regular operation of users, could be determined discharge Q_i for each pipe i and then is calculated adequate head loss h_i:

$$h_i = \frac{8}{\pi^2 g}\left(\lambda_i \frac{L_i}{D_i} + \zeta_i\right)\frac{Q_i^2}{D_i^4} \quad (1)$$

in which: L_i, $D_i$are the length and diameter of pipe i; λ_i is the Darcy-Weisbach friction factor of pipe i; ζ_i is the sum of minor loss coefficients of pipe i; g is the gravitational acceleration.

The friction factor $\lambda_i$can be calculated using the Colebrook–White formula [7] or the explicit equation proposed by Arsenie [13] for the transitory turbulence flow, in which:

$$\Delta = \Delta_0 + a\tau \quad (2)$$

$$\nu = \frac{1.79 \cdot 10^{-6}}{1 + 0.0337t + 0.00022t^2} \quad (3)$$

where: Δ is the pipe roughness at age τ [14, 15]; Δ_0 is the pipe roughness when pipe was new (τ=0); a is the rate of roughness change; τ is the pipeline age; ν is the kinematic viscosity of water; t is the water temperature.

Water flow velocity V_i is given by equation:

$$V_i = \frac{4Q_i}{\pi D_i^2} \quad (4)$$

The average head pump H_p is determined as maximum from average values of pump head for each considered path j, beginning from the pump station PS to the final node N and passing through by one critical point C (Figure-1), in which is located a user:

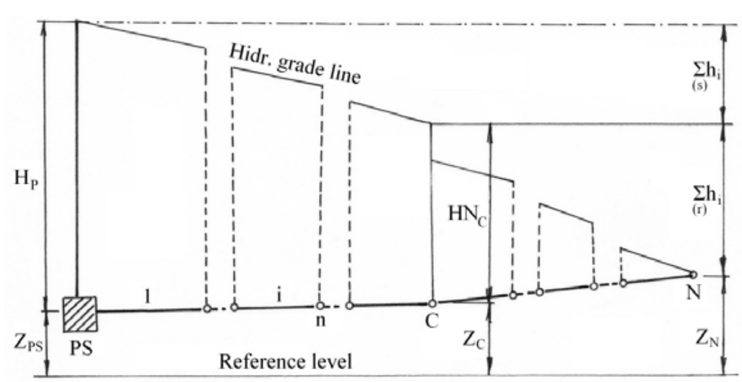

Figure-1. Schematic of a pipe path PS–C–N.

–if $Z_N - Z_{PS} + \sum_{(r)} h_i \le Z_C - Z_{PS} + HN_C$:

$$H_{p,j} = Z_C - Z_{PS} + HN_C + \sum_{(s)} h_i \quad (5)$$

–if $Z_N - Z_{PS} + \sum_{(r)} h_i > Z_C - Z_{PS} + HN_C$:

$$H_{p,j} = Z_N - Z_{PS} + \sum_{(s)} h_i + \sum_{(r)} h_i \quad (6)$$

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in which: $\sum_{(s)} h_i$, $\sum_{(r)} h_i$ are the sums of head losses in supply and return pipes, respectively, which to belong to path j; Z_N, Z_C are the elevation heads at node N and at critical point C, respectively; Z_{PS} is the elevation head at pump station.
Therefore:

$$H_p = \max(H_{p,j}) \tag{7}$$

Hydrodynamic stability coefficient of network in a consumption node (critical point) C is given by equation:

$$\sigma_C = \frac{HN_C}{H_p} \tag{8}$$

Knowing pump head could be determined the available pressure $H_n$in each node n of a path j:

$$H_n = H_p - \left(Z_n - Z_{PS} + \sum_{(n)} h_i \right) \tag{9}$$

which in consumption nodes C must verify condition:

$$\left| H_C - HN_C \right| = \varepsilon \tag{10}$$

where $\sum_{(n)} h_i$ is the head losses sum up to considered node and ε is the admissible error (10‒50 mm).

To ensure regular operation of the users, the hydrodynamic balance of network is performed. Thus, if it is not satisfied equation (10) shall be reduced available pressure at the consumption nodes by operating the control valve from the line which supplies the user in question. Then if the available pressures at the intersection points of the return ramifications computed on different path do not satisfy the same condition (10), proceed analogous step by step.

To ascertain the percent opening of the control valves that provide network hydrodynamic balance is computed every time the minor loss coefficients ζ'_{vi} for control valves:

$$\zeta'_{vi} = \frac{\pi^2 g H_i}{8} \frac{D_i^4}{Q_i^2} - \lambda_i \frac{L_i}{D_i} - (\zeta_i - \zeta_{vi}) \tag{11}$$

in which

$$H_i = h_i + (H_n - H'_n) \tag{12}$$

where: ζ_i is the minor head loss coefficient on pipe$i$ in absence of hydrodynamic balance;$\zeta_{vi}$is the minor loss coefficient forcontrol valve on pipe i before the balance; H_n is the available pressure at a consumption node, or at a node n of the return network placed on a path j; H'_n is the necessary pressure at a consumption node or the available pressure at a node n but computed on another path j'.

Most valve manufacturers can provide a chart of percent opening versus valve coefficient C_v, which can be related to the minor loss coefficient ζ'_{vi} by using equation [7]:

$$C_{vi} = D_i^2 \sqrt{\frac{12.1}{\zeta'_{vi}}} \tag{13}$$

If one or more users are decommissioned, a hydraulic unbalance y_{CP} is produced to every user C remained in operation, and is given by equation (14). Supply discharges Q_C of remaining users in operation increase according to the equation (15):

$$y_C = \sqrt{\frac{H_C}{HN_C}} \tag{14}$$

$$Q_C = y_C QN_C \tag{15}$$

where: H_C is the available pressure in critical point C, determined in previously mentioned operating mode; QN_C is the necessary discharge of user located in critical point C.

Damage to a pipe is simulated considering all downstream users of this pipeline and supplied it as decommissioned (required and consumed discharges null).

If for one or more user increases their supply discharge, result a pump head $H_p$greater than pump head H_{p0} in regular operation mode of users. In order not to modify the characteristic parameters of the regular operation it should either to replace the pumps or to add other units grouped in series or in parallel at existing pumps, or to modify the existing pump rotational speed from valueω_0 to value ω, given by the equation:

$$\omega = \omega_0 \sqrt{\frac{H_p}{H_{p0}}} \tag{16}$$

Using this computational model can easily determine network discharge redistribution in case of decommissioning of any user or user group and may verify the hydrodynamic stability of the network.

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3. COMPUTER PROGRAM OPREATER

Practical resolution of discussed problem is lightened by computer use. Based on the computational model developed above acomputer program OPREATER was elaborated in FORTRAN programming language for personal computer (PC) compatible microsystems. This program operates sequentially by calling three subroutines and haves flow chart in Figure-2. As input parameters are introduced general data, pipe characteristics, node characteristics, branch matrix, path matrix, and critical points.

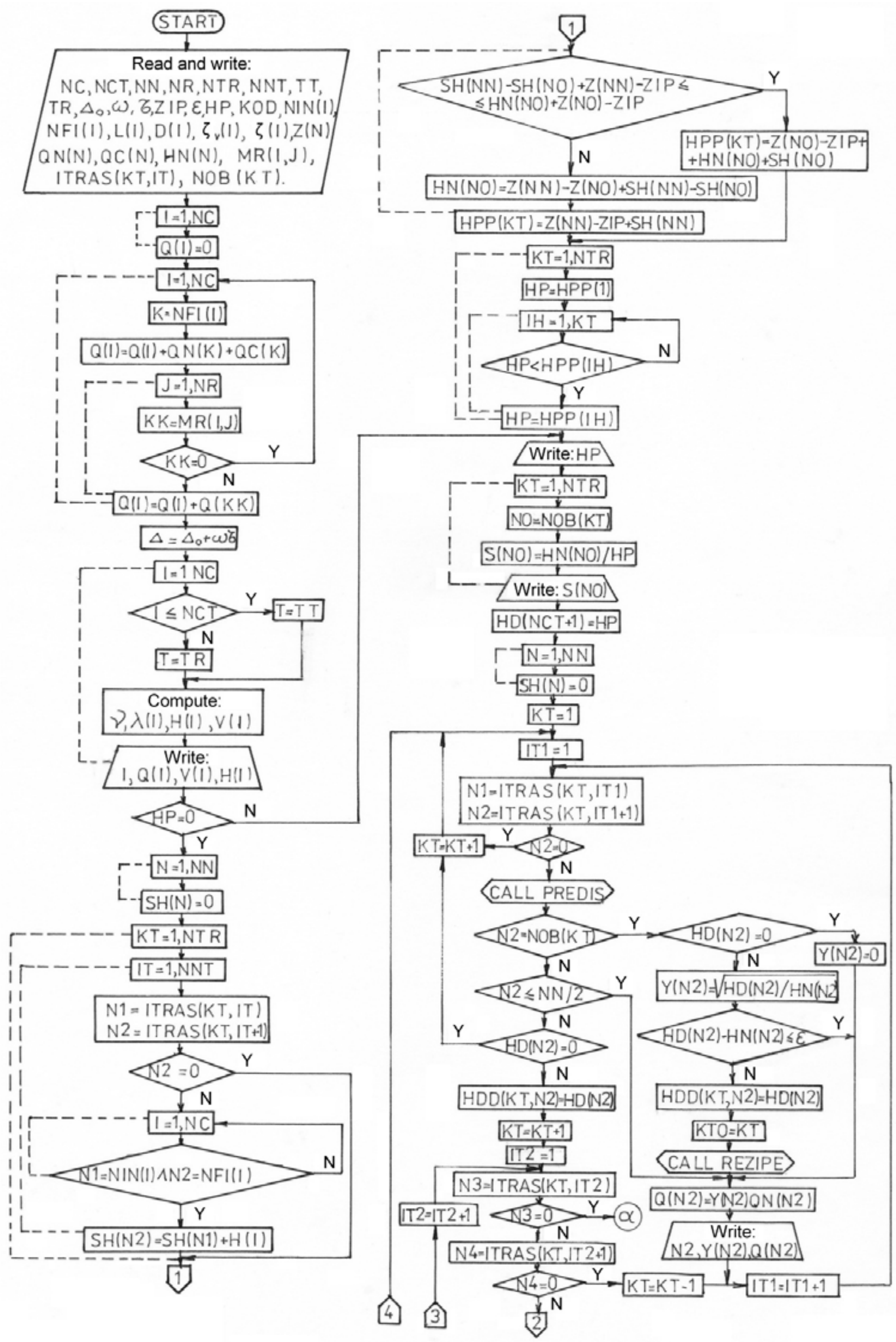

Figure-2. Flow chart of computer program OPREATER.

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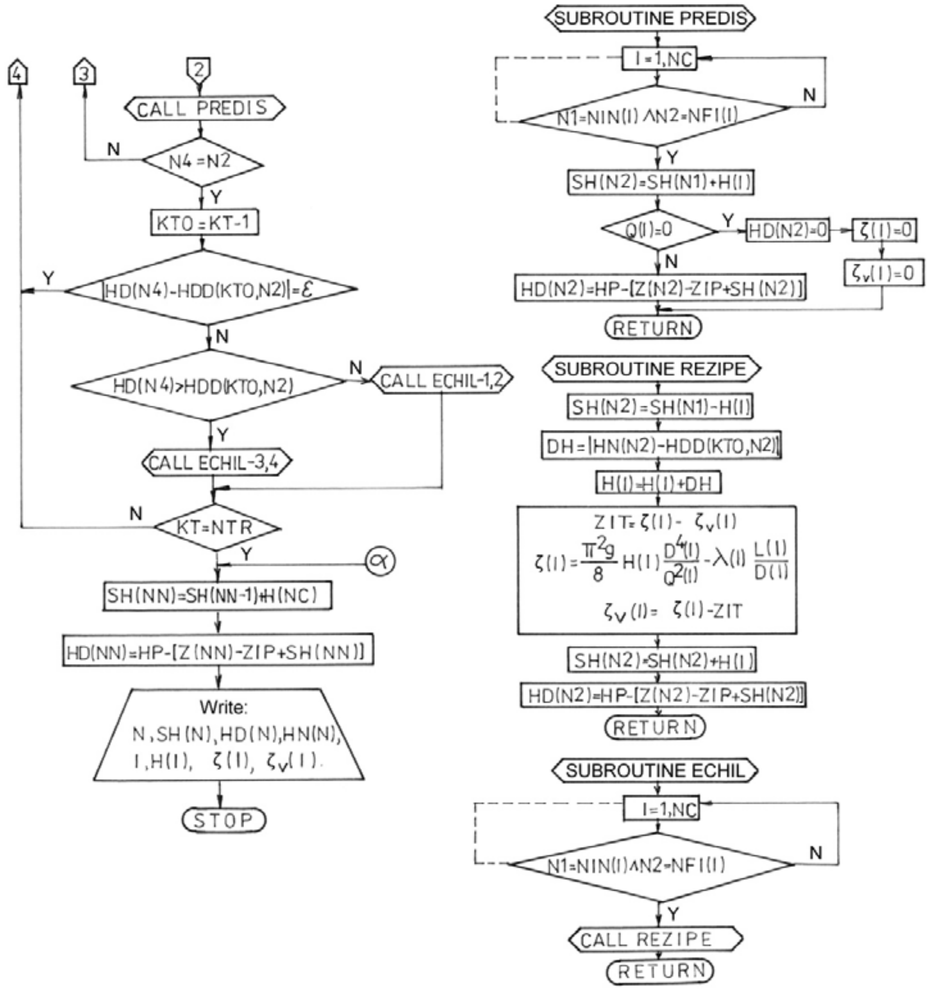

Figure-2. Flow chart of computer program OPREATER (continuation).

In case that the pump head is not known, for identifier HP is assigned to the value 0 and if not the effective value. For KOD identifier of the user operating status is assigned the value 0 when all users are active, and otherwise to critical point number in which is located the user removed from service. For necessary pressure is considered value 0 in nodes in which there are not users supplied directly. It is the possible to study the variants in which water outflow is made by means of cooling towers or directly into the pump suction tank.

For a correct network hydrodynamic balance it is necessary to know precisely all the functional parameters of users in regular operation mode.

4. NUMERICAL APPLICATION

For the network of Figure-3 are known lengths and diameters of the pipes, regular operation characteristic parameters summarised in Table-1, and the other parameters: Δ_0=0.10 mm, τ=15 years, a=0.10 mm/year, t_s=20 °C, t_r=33 °C. Using OPREATER computer program have been studied four significant operational variants that may occur in its operation. Also, both the assumption of water outflow by means of cooling towers, as well as the assumption of direct discharge to suction tank pump station PS has been considered.

The study variants and the results are presented succinctly as follows:

a) Variant I consider that all users are active in regular operation mode. Finally, there was obtained head pump H_p=49.2 m and the percent opening of the control valve on each line, in order to achieve the network balance that leads to available pressure at nodes at least equal to the necessary pressure of the users.
b) Variant II presume the decommissioning of user from critical point 4. Pressure provided by the pump station remaining unchanged from the previous variant, is needed the network hydrodynamic rebalance, according to the results of the computer program to avoid disturbances of users remained in operation.

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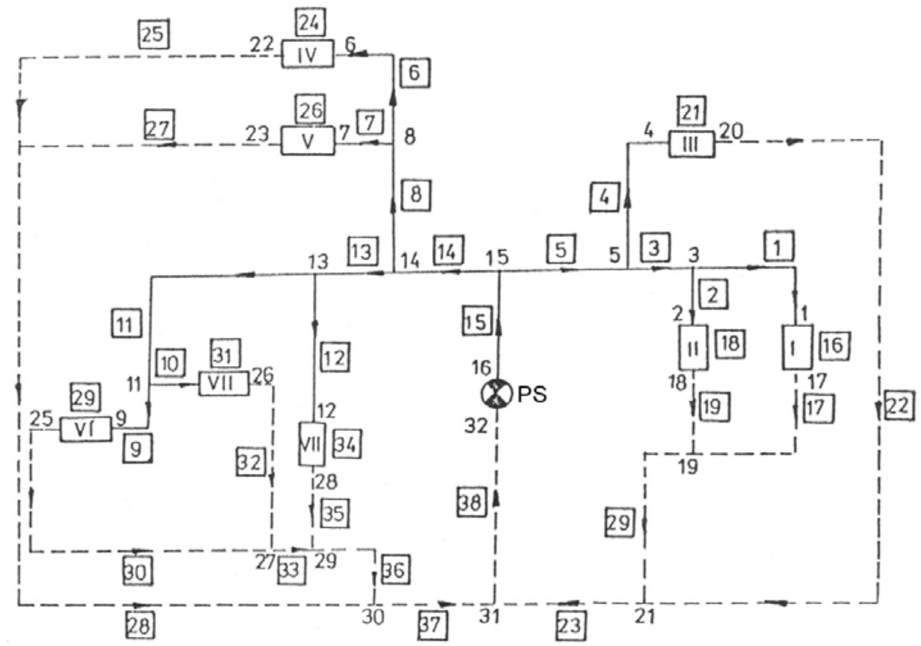

Figure-3. Schematic of analysed network.

Table-1. Characteristic parameters for normal operation of network.

User	Node (*n*)	Z_n[m]	H_n[m]	QN_n[m^3/s]	QC_n[m^3/s]
0	1	2	3	4	5
I	1	105	25	0.0417	–
	17	101	–	–	–0.0021
II	2	110	23	1.3889	–
	18	110	–	–	–0.0694
III	4	120	23	0.0500	–
	20	120	–	–	–0.0025
IV	6	115	25	0.5000	–
	22	115	–	–	–0.0250
V	7	105	25	0.0694	–
	23	105	–	–	–0.0035
VI	9	105	23	0.0417	–
	25	105	–	–	–0.0021
VII	10	115	23	0.0972	–
	6	115	–	–	–0.0049
VIII	12	115	23	0.1250	–
	28	115	–	–	–0.0063

c) Variant III considers that necessary discharge to user in critical point 4 increases by 20% and those of user from critical point 12 increases by 30%. Consequently, in order to ensure the regular operating parameters of all users it is necessary that pump station have other operating characteristics. Therefore must be achieved either the rotational speed change of existing aggregates

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or the aggregates change with other having parameters resulted from the computer program (H_p=51.6 m).

d) Variant IV considers same necessary discharges for users from critical points 4 and 12 as in variant III, but maintaining pressure provided by pump station in regular state. In this case, the available pressures at consumption nodes are reduced below the pressures necessary for the regular operation. This leads to the hydraulic disturbance and to the malfunction of users.

5. CONCLUSIONS

The proposed analysis model offers the advantage of an operative computation being programmable on PC microsystems. With it could take into account the influence of pipe network ageing on pressure losses and the significant changes of water temperature in supply and return pipes that may occur during a year of network operation.

To avoid the hydraulic disturbances at users during network operation when appear the change of some functional parameters is needed a systematic analysis of flow and pressure distribution in network through a computer control and monitoring centralisedsystem. In this system's frame could be implemented the elaborated computer program.

This system can be optimises the water supply of technological facilities, eliminating water losses, increasing reliability, reducing reagent consumption fees for water treatment and saving electric energy.

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