Optimization of Technological Water Consumption for an Industrial Enterprise with Self-Supply System

Ioan Sarbu, Gabriel Ostafe and Emilian Stefan Valea

***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 article is developed a numerical simulation model of technological water consumption for an enterprise in chemical sector with self-supply system. Based on this simulation model a computer program was elaborated in FORTRAN programming language, which is expected to be implemented in a computer control and monitoring centralized system. The results of this program are used to taking decisions that ensure optimal operation of the system with a high reliability and with low energy consumption, taking into account the operation dynamics of enterprise water users. The numerical results of a practical application for studied issue show the operational efficacy of proposed simulation model.**

***Index Terms*—water supply, industrial enterprise, technological consumption, numerical simulation model, computer program.**

I. 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 hydroelectric 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 utilizes 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] 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.

Since technological water supply of such industrial enterprises often put complicated issues in terms of consumption to users, so it is necessary both systematic analysis of the flow and pressure distribution in system and optimization [7]-[9] of the users water consumption by a computer control and monitoring centralized system.

In [10] is presented a computational model for the analysis and operation optimization of a recycled technological water network. In this article is developed a numerical simulation model of technological water consumption for an enterprise in chemical sector with self-supply system. Based on this simulation model a computer program was elaborated, which is expected to be implemented in a computer control and monitoring centralized system. The results of this program are used to taking decisions that ensure optimal operation of the system with a high reliability and with low energy consumption, taking into account the operation dynamics of enterprise water users.

II. Numerical Simulation Model of Technological Water Consumption

It is considered the self-system of an industrial enterprise supplied with natural water from surface source. The principle scheme of the system is shown in Figure 1. Within of this system are the following quality categories of technological water: filtered (decanted) water; chilled filtered water which is recycled; softened water; demineralized water. Also, the system comprises the following user categories: direct users, those who consume filtered water, indirect users, those who use water either after additional treatment or through recirculation. In Figure 2 is shown a scheme of water ensuring to users, which includes pumping

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stations corresponding to each step of the system. The coefficients k_p and k_s takes into account the water losses in system and respectively the system self-consumption.

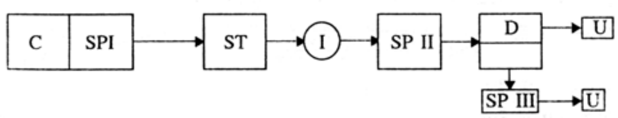

Fig. 1 Scheme of technological water supply system
C – water catching; SPI, SPII, SPIII – I, II, III stage pumping station; ST – natural water treatment station; I – storage; D – distribution network; U – user

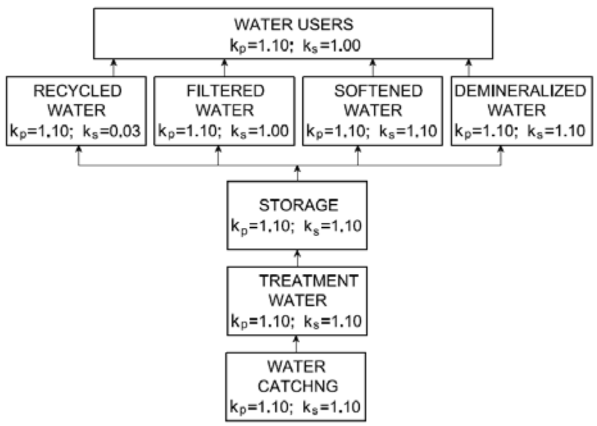

Fig. 2 Scheme of water supply to users

Proposed numerical model for computer-aided simulation of technological water consumption involve the establishment of technological water quantities in system significant sections. These sections represent users, storage, treatment plant and catching. There are considered known following basic data: hourly production and specific consumption per unit of product, on water quality categories, for each user; duration of daily production for each user; volume and restoration time of intangible fire reserve; maximum capacity of treatment plant.

Water demand of users represents the water quantity to be provided at use points, so that technological processes to be efficient satisfied. This is determined on basis of adopted production technologies, depending on the hourly production and the specific discharge per product unit, for each quality category of water.

Water requirement of users represents the water quantity to be taken from the source to satisfy efficient the water demand, water losses in the system and its domestic consumption, with optimal reuse or recirculation without diminish production. Water requirement is determined per hours and for water quality categories, as follows:

$$Q_{f\,i,j} = k_p k_s q_{f\,j} P_j t_{i,j} \tag{1}$$

$$Q_{m\,i,j} = k_p k_s q_{mj} P_j t_{i,j} \tag{2}$$

$$Q_{d\,i,j} = k_p k_s q_{d\,j} P_j t_{i,j} \tag{3}$$

$$Q_{r\,i,j} = k_p k_s q_{rj} \frac{\Delta t_{0\,j}}{\Delta t_j} P_j t_{i,j} \tag{4}$$

$$Q_{i,j} = Q_{f\,i,j} + Q_{m\,i,j} + Q_{d\,i,j} + Q_{r\,i,j} \tag{5}$$

$$Q_{fu\,j} = \sum_{i=1}^{24} Q_{f\,i,j} \tag{6}$$

$$Q_{mu\,j} = \sum_{i=1}^{24} Q_{m\,i,j} \tag{7}$$

$$Q_{du\,j} = \sum_{i=1}^{24} Q_{d\,i,j} \tag{8}$$

$$Q_{ru\,j} = \sum_{i=1}^{24} Q_{r\,i,j} \tag{9}$$

$$Q_{u\,j} = Q_{fu\,j} + Q_{mu\,j} + Q_{du\,j} + Q_{ru\,j} \tag{10}$$

$$Q_{fo\,i} = \sum_{j=1}^{NU} Q_{f\,i,j} \tag{11}$$

$$Q_{mo\,i} = \sum_{j=1}^{NU} Q_{m\,i,j} \tag{12}$$

$$Q_{do\,i} = \sum_{j=1}^{NU} Q_{d\,i,j} \tag{13}$$

$$Q_{ro\,i} = \sum_{j=1}^{NU} Q_{r\,i,j} \tag{14}$$

$$Q_{o\,i} = Q_{fo\,i} + Q_{mo\,i} + Q_{do\,i} + Q_{ro\,i} \tag{15}$$

where: k_p is the coefficient of water losses in system, k_s – coefficient that takes into account the self-consumption of system; $q_{f\,j}$, $q_{m\,j}$, $q_{d\,j}$, $q_{r\,j}$ – specific consumption for user j of filtered, demineralized, softened and recycled water, P_j – hourly production of user j; $\tau_{i,j}$ – time variable with the value 0 or 1 as in the hour i a given user j consumes water or not; Δt_{0j}, Δt_j – nominal and real temperature difference of recycled water to user j; $Q_{f\ i,j}$, $Q_{m\ i,j}$, $Q_{d\ i,j}$, $Q_{r\ i,j}$, $Q_{i,j}$ – respectively, the filtered, demineralized, softened, recycled and fully treated water quantity, requested at hour i by user j; $Q_{fu\ j}$, $Q_{mu\ j}$, $Q_{du\ j}$, $Q_{ru\ j}$, $Q_{u\ j}$ – respectively, the filtered, demineralized, softened, recycled and fully treated water quantity, requested by the user j; $Q_{fo\ i}$, $Q_{mo\ i}$, $Q_{do\ i}$, $Q_{ro\ i}$, $Q_{o\ i}$ – respectively, the filtered, demineralized, softened, recycled and fully treated water quantity, requested at hour i by the users.

The determination of water consumption on hours and users offer the possibility know it for each user both on technological water quality categories and global. It is possible also to know consumption daily variation, on quality categories and global, allowing calculation of the hourly variations percentage of consumption:

$$k_{0i} = 100 \frac{Q_{o\,i}}{\sum_{i=1}^{24} Q_{o\,i}} \tag{16}$$

and of the natural water discharge necessary to be captured from source:

$$Q_c = k_s \sum_{j=1}^{NU} Q_{u\,j}, \tag{17}$$

This, if simulation is performed for a fire case, gets the form:

$$Q_c = k_s \sum_{j=1}^{NU} Q_{u\,j} + 24\frac{V_i}{T_r} \qquad (18)$$

where: NU is the number of water users; V_i – water volume of fire intangible reserve; T_r – fire water reserve recovery time.

Since the technological water demand in system is supplied through storage tanks which are serviced by pumping stations, is determined their fluctuant volume for a period of one day (24 hours), using the cumulated differences analytical method [6].

The value of required useful volume for storage tanks is given by equation:

$$V_u = V_f + V_{nt} \qquad (19)$$

in which $V_{nt} = 0.1Q_c$ represents water volume for technologic needs of the system.

Assuming normal operation of the enterprise supply system, useful volume V_u needed for storage is equal to the existing useful volume V_0 achieved by storage building. Also, maximum capacity Q_{MAX} of the treatment plant at a given turbidity of natural water is at least equal to captured water discharge, which determines the volumeV_0.

When in supply system operation there are deviations from the normal water discharges, appear two running distinct situations for storage tanks:

a) When $V_u < V_0$:

– if $Q_c \le Q_{MAX}$, (20)

beginning with start time of water storage in the tank, it could be reduced captured natural water discharge by value:

$$\Delta Q_c = \frac{V_0 - V_u}{T} \qquad (21)$$

in which: T is period of time since water accumulation in storage tanks until reaching the fluctuant volume;

– if $Q_c > Q_{MAX}$, (22)

are introduced constraints to users, their needed reduction of water consumption ΔQ_{UT} is given by:

$$\Delta Q_{UT} = \frac{Q_c - Q_{MAX}}{k_s} \qquad (23)$$

b) When $V_u > V_0$:

– if is accomplished condition (20), storage tanks operate only as suction basin of water pumping station in the distribution network;

– if is verified inequality (22), is necessary introduction of constraints to users, initial reduction of their water consumption:

$$\Delta Q_{UT} = \frac{V_u - V_0}{2}, \qquad (24)$$

being determined through successive approximations so achieving the condition:

$$\left|V_u - V_0\right| \le \varepsilon \qquad (25)$$

in which ε (0.5…2 m^3) is the admissible error in useful volume calculation

If inequality (22) is still maintained are introduced more severe restrictions, reducing water consumption of the users with the value given by relation (23).

For each user j to which is allowed hourly production diminishing ($\psi_j = 0$), it is necessary to reduce its technological water consumption with:

$$\Delta Q_{u\,j} = \frac{Q_{u\,j}}{\sum_{j=1}^{NU} Q_{u\,j} - \sum_{j=1}^{NUR} Q_{u\,j}} \Delta Q_{UT} \qquad (26)$$

Corresponding hourly production becomes:

$$P'_j = \psi_j P_j \qquad (27)$$

where:

$$\psi_j = 1 - \frac{\Delta Q_{u\,j}}{Q_{u\,j}}, \qquad (28)$$

and NUR represent water user's number which not allow supply constraints.

It is regenerated calculation of hourly water consumption for users under the created constraints.

III. Computer Program SIOCATEH

Based on the computational model developed above a computer program SIOCATEH was elaborated in FORTRAN programming language for PC compatible microsystems. This program operates sequentially by calling six subroutines and haves flow chart in Figure 3.

As input parameters are introduced: general data: NU, V_0, Q_{MAX}, k_p, k_s, ε; V_i, T_r; consumption times for each user during the day τ(I,J); characteristics of water users: $P(J)$, $q_f(J)$, $q_m(J)$, $q_d(J)$, $q_r(J)$, $\Delta t_0(J)$, Δt(J), $\psi(J)$.

For the identifier $\psi(J)$ is assigned initial value 0 or 1 as J user is allowed or not to decrease the production.

Accuracy of achieved results is a function of the input data accuracy, as the hourly production and specific water discharge per product unit (pu).

IV. Numerical Application

For example are presented four significant assumptions which may occur in the operation of a water supply system for six technological users with continuous operation during the day and with the characteristics provided in Table I. These hypotheses are the following:

TABLE I
CWater Users' Characteristics

User	P_j [pu]	$q_{f\,j}$ [m^3/h·pu]	$q_{m\,j}$ [m^3/h·pu]	$q_{d\,j}$ m^3/h·pu]	$q_{r\,j}$ [m^3/h·pu]	Δt_{0j} [K]	Δt_j [K]	Ψ_j
1	300	1.05	0	0	0.95	5	6	0
2	307	1.00	0	0	0.65	5	6	0
3	400	1.25	0.75	0	0.85	4	6	1
4	200	0	1.00	0	0	0	0	1
5	185	0	0	0.90	0	0	0	0
6	350	0	0.55	0	0.75	4	6	0

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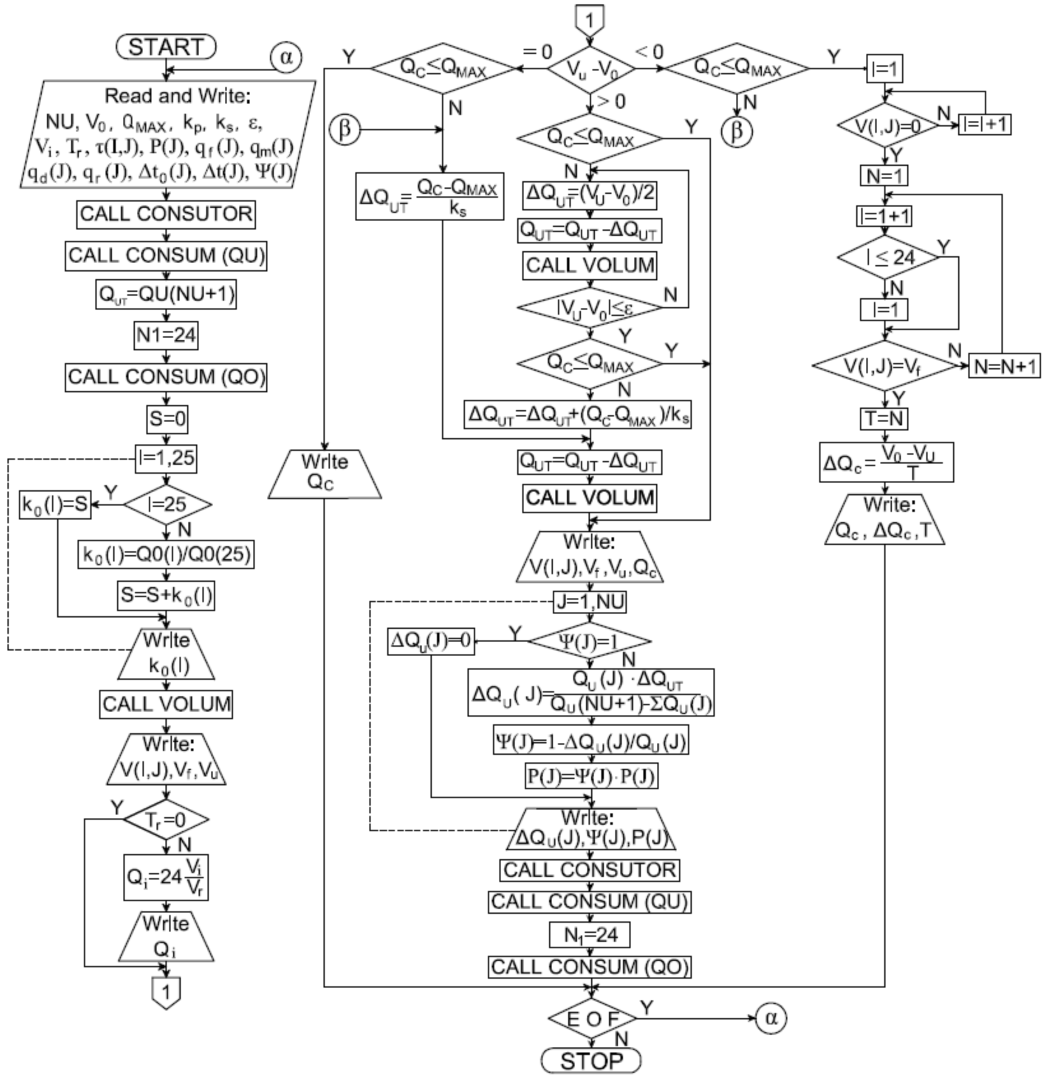

Fig. 3 Flow chart of computer program SIOCATEH

– i) Considering V_0 = 11000 m^3 and Q_{MAX} = 57700 m^3/day, was obtained a required useful volume of storage V_u=11001 m^3, from a total users consumption of treated water Q_u = 52385.5 m^3/day. So, it results a reduction ΔQ_{UT} = .2818.6 m^3/day of user consumption, which leads to decrease of their hourly production in proportion indicated by coefficients ψ_j. In this situation it is necessary to capture the natural water discharge Q_c = 57624.1 m^3/day.

– ii) The values V_0 = 12500 m^3 and Q_{MAX} = 62000 m^3/day are assumed. Since has resulted V_u = 11592.8 m^3 < V_0, beginning on moment that water is stored in tanks, it could be reduced captured water discharge Q_c = 60724.5 m^3/day with value ΔQc = 37.8 m^3/h on a period T = 24 hours, obtaining Q_0 = 59817.3 m^3/day without affecting nominal production of users.

– iii) It are considered values V_0 = 11000 m^3 and Q_{MAX} = 62000 m^3/day, and has resulted V_u = 11592.8 m^3 > V_0, being so possible the catchment of necessary natural water discharge Q_c = 60724.5 m^3/day < Q_{MAX}, without introducing constraints at users.

– iiii) Assuming values V_i = 2000 m^3 and T_r = 24 hours, along parameters of hypothesis (i), it was determined technological water consumption after a fire and have resulted as necessary the following values: V_u = 10563.6 m^3, Q_c = 55700 m^3/day, ΔQ_{UT} = 4567.5 m^3/day. Consequently, there is need of more stringent constraints at users than for hypothesis (i), because of necessity catch an additional natural water discharge for the recovery of fire intangible reserve.

The computation was performed within the limits of precision ε = 0.5 m^3. Table II summarizes the final results obtained only for the total treated water consumption, for each user, corresponding of each considered hypothesis.

V. Conclusion

The storage operation depends on daily water consumption and is determined by hourly variation of it. Based on the difference between real and calculated useful volume is optimized operation of technological water supply system. Difference of useful volume remained in the storage tank can be valued by reducing water discharge captured over a corresponding period. In this way it is saved electricity and reagents for the treatment plant.

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TABLE II
TOTAL TREATED WATER CONSUMPTION FOR EACH USER

User	Hypothesis					
	(i)		(ii)	(iii)	(iiii)	
	$Q_{u\,j}$ [m^3/day]	ψ_j	$Q_{u\,j}$ [m^3/day]	$Q_{u\,j}$ [m^3/day]	$Q_{u\,j}$ [m^3/day]	ψ_j
1	7966.2	0.937	8504.1	8504.1	7632.4	0.897
2	7715.5	0.937	8236.5	8236.5	7392.2	0.897
3	20694.2	0.937	22091.5	22091.5	19827.0	0.897
4	5808.0	1.000	5808.0	5808.0	5808.0	1.000
5	4835.2	1.000	4835.2	4835.2	4835.2	1.000
6	5366.4	0.937	5728.8	5728.8	5141.6	0.897
Total	52385.5	-	55204.1	55204.1	50636.3	-
Q_c [m^3/day]	57624.1		59817.3	60724.5	55700.0	
V_u [m^3]	11001.0		11592.8	11592.8	10563.6	

Global technological water consumption of enterprise is limited by the maximum treatment capacity of related facilities. This is a function of available water turbidity in source.

After any eventual water consumption for fire, the source ensure water discharge necessary for the recovery of fire reserve, imposing in most cases constraints for water-users.

The proposed numerical simulation model offers the advantage of an operational calculus, is programmable on microsystems, has a high degree of generality, and can be applied to various industrial enterprises with technological water self-supply system. Computer program SIOCATEH is very suitable to be implemented in a centralized monitoring and control system of technological water consumption. This system could be optimized water supply for technological facilities, eliminating water wastage, increasing reliability, reducing reagent consumption fees for water treatment and saving electric energy.

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