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HYDRAULIC SYSTEM OPTIMIZATION FOR WATER SUPPLY UNDER PRESSURE

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Abstract

This paper proposes a solution of the problem of reducing production costs for supplied domestic water, which directly affects the reduction of the electric power consumption. The paper presents the methodology and the program of calculus for the transport's optimization of the water under pressure in the system of supply with water of Iasi city. The optimization calculation will use two target functions: total maximum efficiency and total electric power consumption required for transport of each cubic meter of supplied water, and cubic meter of sewage water, respectively. The mathematical methods may be improved by taking into account all active consumers in the network with simultaneous water requirements, at each moment of the day.

Key words: *adduction, pipe network, optimization, pumping station, tank*

1. INTRODUCTION

Taking in account the increasing of power tariffs and the limitations of the resources, a correct solving of the issue of developing water distribution networks in populated areas cannot be achieved without a systemic approach. This approach has to start from the long-term monitories strategically objectives which treat the water supply as an infrastructural basic system which operation has to be materialized through minimal/rational resource consumption.

Developed during the years according to the populaces' social and economic needs and according to the existing water resources, the water networks are complex systems which, apart the mains are including several storage tanks, main pumping/re pumping stations and auxiliary pumping stations.

Depending on their phased evolution, the hydro technical diagrams have, over several districts, several types of ring shaped networks. These networks are usually organized on height, depending on relief's profile and are also interconnected the way to circulate flows towards an area or another, gravidity or by pumping. Concerning the housings, the water supply towards tower blocks of flats is made in a centralized manner and through auxiliary pumps.

Priorities, in the different phases of construction of the existing water supply networks, lead to their mainly extensive development, which was exclusively trying to attempt the goal to satisfy the water needs, in terms of volumes.

These conditions are inducing, when operating water supply systems in great urban areas, the following shortcomings:

- Global water consumptions sensibly superior to the standard figures which are the basic parameters for sizing the systems' elements (mains, compensation tanks, pumping stations).
- Great hourly fluctuations of the water demand (greater than the one which is usual for this type of systems).
- Great pressure fluctuations, with great "falls" at peak hours, which disturb the supply conditions at the directly connected users and also at these fed by centralized systems with auxiliary pumps.
- Preferential flows, in total disproportion with the sources' capacities, appearing especially in the low areas.

All these are inducing the following effects:

- Low quality of the water supply conditions, especially because low pressures at the user and even because water cut-offs in certain areas.
- High specific power consumptions because the pumps' low efficiencies.

2. PROBLEM DEFINITION

The paper presents the authors efforts to find the optimum solutions to ensure proper servicing of consumers, 24 hours a day, and reduction of operation costs, proposing the following measures:

1. Rehabilitation of pumping stations, as the capacity of supply has to meet the requirements of the consumers and to take into account the present trend in domestic heating and hot water preparation by individual apartment heating units. The rehabilitation activity consists in replacing the present pumping devices with new ones that feature functional characteristics that correspond to the present and future requirements of the consumers. These new devices will exhibit technologies present today on the worldwide market.

2. Modernize the pumping station to ensure the increase of energy efficiency and economic efficiency of the domestic and industrial water supply activity, that is, introduce the process automation for a reduced specific consumption of electric energy and reduced operational workforce.

Profitability of water distribution activity depends largely on the relationships between operational capability and service costs, related to supplier’s performance, volume of distributed water and effective operating costs. The main variables that influence the total selling price are required investment value, specific consumption of electrical energy for pumping power, unit price of the electrical energy and total volume of monthly consumed water billed.

The selection of rehabilitation and modernization measures must rely on market studies results that appropriately establish the quantities of water that may be distributed and billed. Present and future water requirements will be determined based on the analysis of actual operation data and on estimation of future trends in water consumption on national and international levels.

Authors used original mathematical algorithms to develop original computer programs that calculate, at each moment in time, depending on the number of active consumers connected simultaneously to the network, the functional parameters of the ensemble pumping station – hydrophore – pipe distribution network, as well as the available consumer parameters. This may be done in the hypothesis of a minimum price of cubic meter of pumped water.

When the hydraulic energy is supplied by pumps, the operating regime is determined by the equivalent characteristic (at that moment) of the system represented by the network H_R and the active users and

by the equivalent characteristic (at the same moment) of the pumping systems H_{PS} , (p - pumps number; α - loading grade on network; H_D - load in pipes network origin; Q_D - debit in network origin; Q_R - network debit; H_{pf} - pump load; Q_{PS} - pumping station debit; K_{pf} - pumps resistance hydraulic modulus; M_{ro} - pipes network resistance hydraulic modulus):

$$H_{\mathrm{R}} = \frac{H_{\mathrm{D}} \cdot Q_{\mathrm{R}}^2}{\alpha^2 \cdot Q_{\mathrm{D}}^2};\ H_{\mathrm{PS}} = H_{\mathrm{pf}} - \frac{K_{\mathrm{pf}} + M_{\mathrm{ro}}}{p^2} \cdot Q_{\mathrm{PS}}^2 \ . \tag{1}$$

The resource consumptions depend on the features of the various operating conditions, which appear during operating but also by their change frequency within the analyzed period of time.

The equivalent characteristic of the network active users system is given by the hydraulic and geometric features of the constitutive elements of the network (on the route on which water flows) and also by the number of active users, their location within the network and their functional particularities.

Agreeing that each set of active users, defined by number, location within the network and functional characteristics defines an "operational configuration" of the network it is to observe the fact that to each of those corresponds a very well determined.

The great number of users connected to the network, together with the diversity of their functional features and the multitude of possibilities in terms of location at one moment within the network, determines, at least theoretically, an infinity of possible operating configurations for the network-users system, towards which shall correspond an infinity of (H, Q) characteristics on which can be defined the loads domains which ensure optimal service with a total probability between 0 and 100% of the total of active users, α.

The specific characteristics of load losses in the discharge pipes $h_{r\ Total}$ are established by summing up all the linear and local head losses, ($\lambda_{Dn,k}$ - Darcy coefficient of pipe k; ξ_j - local head losses coefficient; v_{Dn} – water speed on the pipe; g - gravitation acceleration):

$$h_{r\mathrm{Total}} = \sum_{Dn,k} h_{rDn;k} = \sum_{Dn,k} \left[\lambda_{Dn,k} \cdot \frac{L_{Dn,k}}{D_n} + \sum_j \zeta_{jDn,k} \right] \cdot \frac{v_{Dn}^2}{2.g} \tag{2}$$

The energy specific consumption produced by the water pumping e_s is established by the load H_R, the debit distributed by network $Q_{R,\,j}$, the debit of pumps $Q_{der,\,j}$, the pumping hydraulic outturn η_{pj} and the pumping mechanic outturn η_{mj}:

$$e_{\mathrm{s}} = 2,725.10^{-3} \cdot \frac{H_{\mathrm{R}}}{\eta_{\mathrm{pj}} \cdot \eta_{\mathrm{mj}}} \cdot \left(1 + \frac{Q_{\mathrm{der,\,j}}}{Q_{\mathrm{R,\,j}}} \right), [\mathrm{kWh/m^3}] \ . \tag{3}$$

Operational and energetically optimization of a water supply system has as goal to set the necessary structure of the mains and pumping plants, as well as to define the operational algorithm which should ensure all range of flows demanded by the users (within the capacity's limits and at an optimal service pressure), even in the most disadvantaged network areas, in the conditions in which the specifically power consumptions has to be minimized.

To solve the optimization problem, the authors developed a general mathematical model that will emphasize the importance of the relationship between energy side and technological side of the analyzed process.

The optimization calculation will use two target functions: total maximum efficiency and total electric power consumption required for transport of each cubic meter of supplied water, and cubic meter of sewage water, respectively.

The optimization problem consists in identification of the proper values for pumping station operational parameters that will determine the minimum specific consumption averaged on yearly basis, abiding by the operational and constructional restrictions as well as assuming normalized section dimensions; some of these variables (D - pipe's rated diameter; L - pipe length; n - pump rotational speed, n_o - pump nominal rotational speed; η - outturn) have direct or indirect influences on device's proper operation. The goal is to determine the values of the D, L, n parameters that minimize the economic target function $Z(D, n)$. This objective function is given by the equation, (a_p'' - yearly average expenses quota in pumping station; I_{po} - investment in pumping station; i_p - investment coefficient in constructions and installations; m - load loss parameter; k - economic coefficient; Q_M - maximum debit of pumping station in (O) section; L - pipe length; η_{PA} - overall outturn ensemble; n_N - upsetting pipe number; D - pipe's rated diameter; β, γ - constants of hydraulic slope; a_R'' - yearly average expenses quota in pipe; i_o - coefficient investment in pipe network; b, F - constant; W_o - water volume absorbed from sources; p_o - unitary average cost):

$$Z = a''_{\mathrm{p}} \cdot \left(I_{po} + i_p \cdot m \cdot \frac{k \cdot Q_M^{\gamma+1} \cdot L}{\eta_{PA} \cdot n_N^{\gamma} \cdot D^{\beta}} \right) + a''_{\mathrm{R}} \cdot n_N \cdot L \cdot \left(i_o + b \cdot D^{\alpha} \right) \cdot i_{\mathrm{o}} + \\ + \frac{k}{\eta_{PA}} \cdot m \cdot L \cdot \frac{Q_{\mathrm{M}}^{\gamma}}{D^{\beta} \cdot n_N^{\gamma}} \cdot F \cdot \frac{W_{\mathrm{o}}}{3600} \cdot p_{\mathrm{o}} \cdot \tag{4}$$

The calculation of the ensemble's overall outturn formed by the pumping station, the distribution network, consumers, loads into consideration the charge specific features which correspond to each ensemble's element, for the two work phases of hydrophore: fill up and emptying.

The total outturn of pumping aggregate – networks – hydrophore fill – up stage ensemble has the following mathematical relation:

$$\eta_{\mathrm{u,PA}} = \frac{N_{c,f}}{N_{\mathrm{a,f}}} = \eta_{\mathrm{p}} \cdot \eta_{\mathrm{m}} \cdot \frac{1}{1 + \frac{K_{\mathrm{pf}} + M_{\mathrm{ro}}}{p^2} \cdot \frac{Q^2_{\mathrm{PS\text{-}R\text{-}H,u}}}{H_{\mathrm{(O),PS\text{-}R\text{-}H,u}}}} . \tag{5}$$

The overall outturn of the pumping station – networks – hydrophore emptying stage ensemble, in (O) section has the following mathematical relation:

$$\eta_{\mathrm{g,PA}} = \frac{N_{\mathrm{c,g}}}{N_{\mathrm{a,g}}} = \frac{\eta_{\mathrm{m}} \cdot \eta_{\mathrm{p}}}{\left(1 - \frac{Q_{\mathrm{H,g}}}{Q_{\mathrm{(O),PS\text{-}R\text{-}H,g}}} \right)} \cdot \frac{1}{\left[1 + \frac{k}{p^2 \cdot H_{\mathrm{(O),PS\text{-}R\text{-}H,g}}} \cdot \left(Q_{\mathrm{PS\text{-}R\text{-}H,g}} - Q_{\mathrm{H,g}} \right)^2 \right]} \tag{6}$$

The automatic calculation program defines the exploitations regimes for the overall output's installation to be maximum and the total typical energy consumed to be minimum on the work cycle ensemble.

Calculations are made with dedicated software which usually performs the following:

1. Setting the parameters of the hydraulic model the way to recreate the real system (in this phase it is possible to check the data of the network's operators, data which are not always properly recorded).

2. Objectively knowledge of the network's operation, separating areas with the most numerous shortcomings, quantitatively characterized by the "connection" situations in which the ratio "real value/nominal value" for the supplied flow is less than one (respectively of the service pressures p/p_n).

The logical scheme of the programme is shown in the *figure 1*. The programme calculates the functional parameters of the ensemble pumping station – hydrophore – pipe distribution network. This may be accomplished at each moment in time, depending on the number of active consumers simultaneously connected to the supply network, in the hypothesis of a minimum price of cubic meter of pumped water.

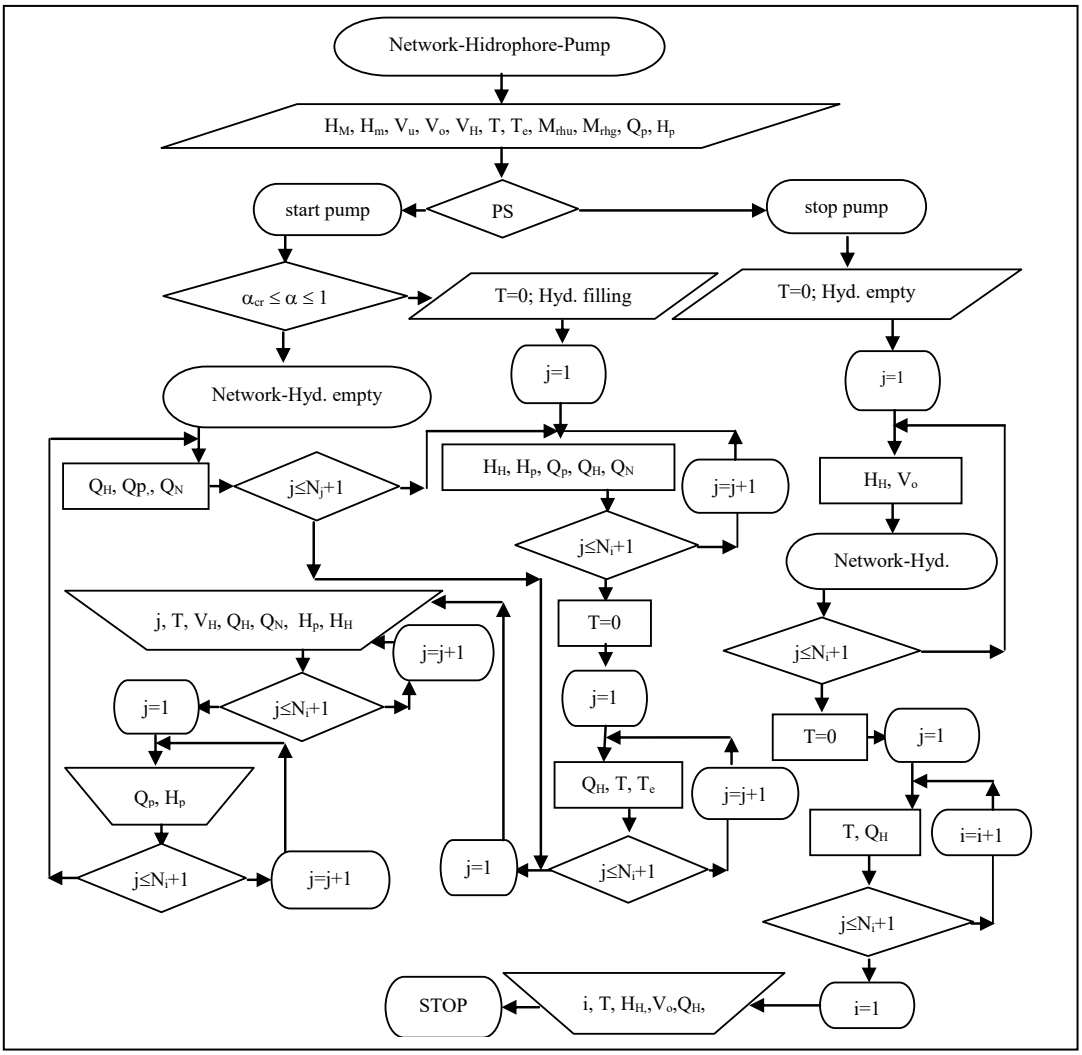


Figure 1. Logical scheme of the programme that calculates the functional parameters of the ensemble pumping station – hydrophore – pipe distribution network.

3. EXPERIMENTAL STUDY

Using several original mathematical algorithms, authors developed a computer program that calculates the functional parameters of the ensemble pumping station – hydrophore – pipe distribution network, as well as the available consumer parameters. This may be accomplished at each moment in time, depending on the number of active consumers simultaneously connected to the supply network, in the hypothesis of a minimum price of cubic meter of pumped water.

The optimization method is applied in the pumping complex system for drinkable water from Iasi city, (*figure 2*). This hydraulic system is composed of three pumping stations: Tutora, Chirita and I. Creanga. All these pumping stations are modernised through the usage of the optimization method.

This connection assessment brings information about the networks "health condition" and about the shortcomings that may occur, but no information about the corrective measures to be undertaken.

Their nature can be detected by investigation means that lead to a global description of the network:

- The load characteristics (*H, Q*) of "frontal" supplying plant (storage tanks and/or pumping stations) shown within plan (*Q, H*) as a set of curves corresponding to the various operational configurations.
- The load characteristics $(H, Q)_p$, corresponding to the various service qualities ensured by the network.
- The hyetograph of the real distributed flows in the studied network.

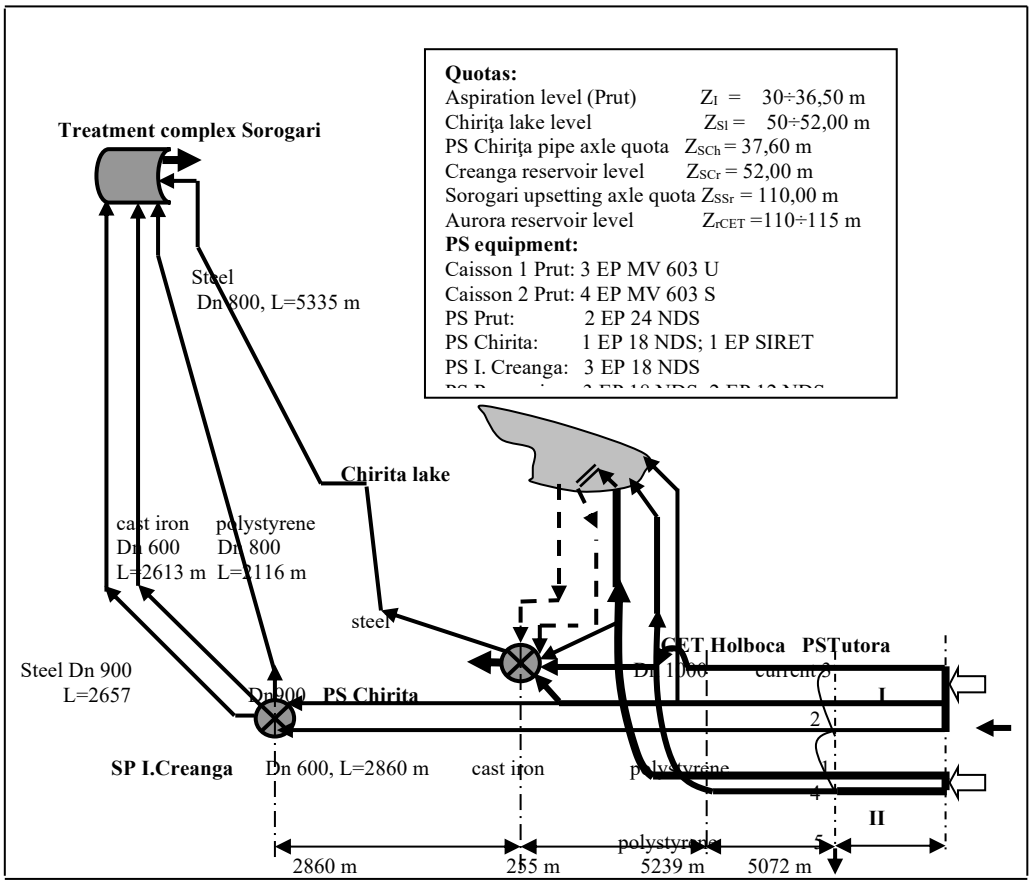


Figure 2. Adduction scheme for water supply from Iasi city.

4. RESULTS AND DISCUSSION

The maximum outturn for the best pumps depends on the pump rotation speed *n* and on the storied number *z*. The *figure 3* show the variation of outturn for the best pumps depend on the pump rotation speed *n* (*n* = 1500; 3000 rpm) and on the storied number *z.* The optimum pump is established for the debit $Q = 2{,}95\ m^3/s$, the load $H = 40$ m, the pump rotation speed $n = 3000$ rpm, the storied number $z = 4 \div 6$ and the outturn $\eta = 68\%$.

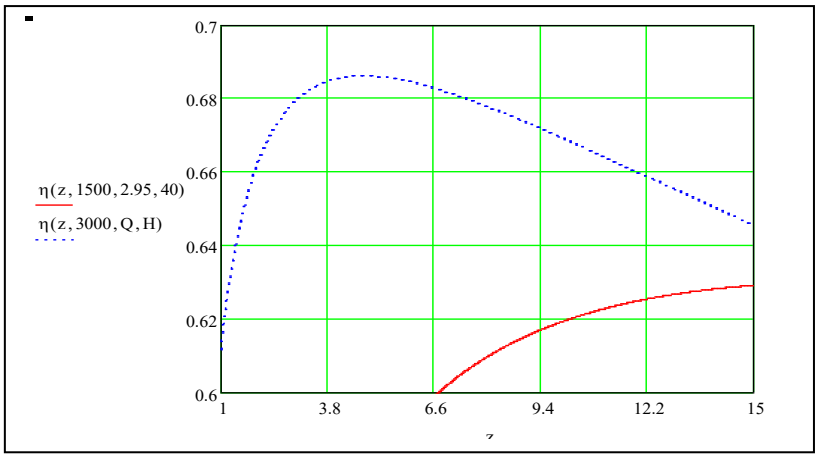


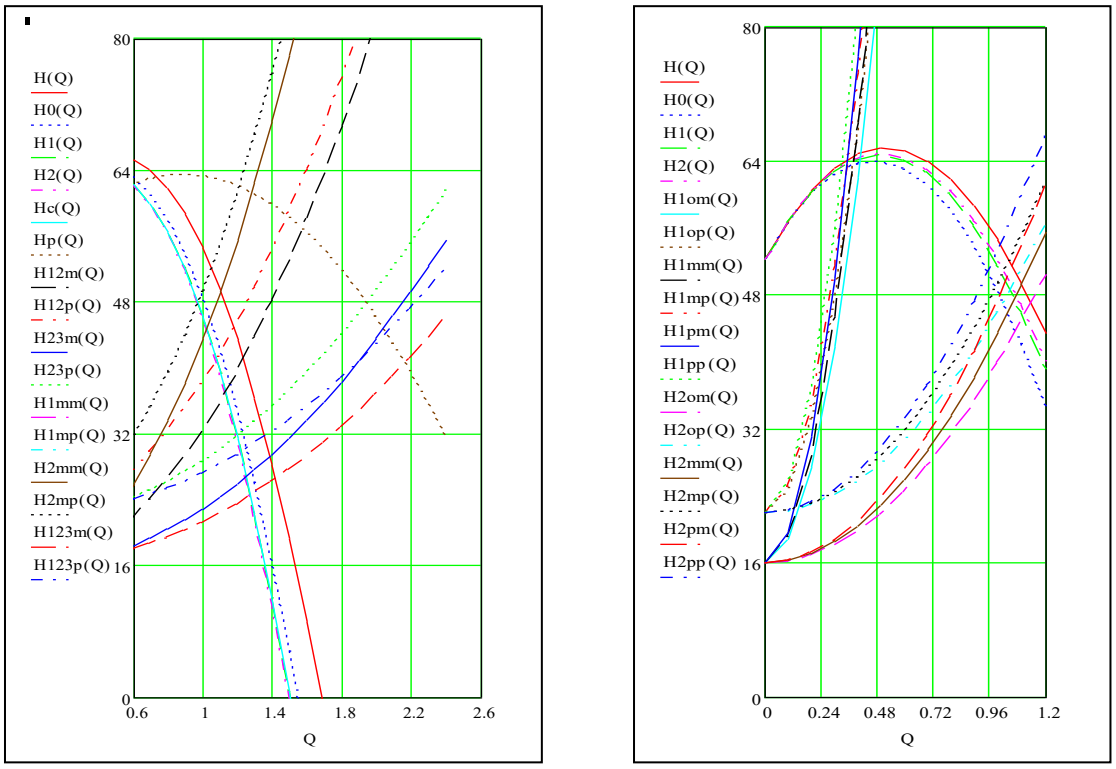
Figure 3. Maximum outturns for the optimum pump choice depend on the pump rotation speed *n* and on the storied number *z*, PS Tutora.

Figures 4 to *6* show the values of loads determined using the optimization method at pumping station Tutora, caisson I and II. In these figures are presented the specific features of head losses for pressurized networks for different static loads (minimum $H_{gs\ min}$ and maximum $H_{gs\ max}$), different roughnesses (minimum, average and maximum) and different operational configurations. The load specific features for the pipes network use the following notations: *Hcxy* – load specific feature of pipes networks, (*c* – represents number of current; *x* – roughness value: "o" for minimum roughness, "m" for average roughness and "p" for maximum roughness; *y* – static load: "m" for $H_{gs\ min}$ and "p" for $H_{gs\ max}$). *H(Q)* represents the load specific feature for one pump. The reduced specific features for pumps load are drown allowancing pumps number: *H0(Q)* for one pump on one current, *H1(Q)* for two pumps on currents, *H2(Q)* for three pumps on two currents. The influence of each consumer, on entire period of pump operation, supplied with industrial water from the network – hydrophore ensemble in 24 hours was considered. The reduced resultant specific features at collector/working parallel are noted thus: *Hc(Q)* for two pumps and *Hp(Q)* for three pumps, (*figures 4.a, 6.a*).

Figure 6.a presents the optimum specific features of working pumps coupled parallel; it uses following notations: *Hg1* – for two identical 24 NDS pumps; *Hg2* – for one MV603 pump and one 24NDS pump; *Hg3* – for three pump: two identical MV603 pumps and one 24NDS pump; *Hg4* - for three pump: one MV603 pump and two identical 24NDS pumps; *Hg5* – for four pumps: two identical MV603 pumps and two identical 24NDS pumps.

5. CONCLUSIONS

The replacement of the existent equipment, that is obsolete from physical and technological point of view, must be done with new equipments with performances that will meet the requirements of an optimum operation from both energetic and economic perspectives. The water transport and distribution network must have the capability to meet the requirements of the consumers. The various phases of the analysis allows to set the water transportation capacities on various routes of the network and also the compensation and/or reserve volumes that have to be ensured, within a process which has to also consider the users' behaviour which can be laxer as long as the networks is not saturated.



a) b)

Figure 4. Working regimes SP Tutora, caisson I, currents 1, 2, 3; $H_{gs\ min}$ = 16 m; $H_{gs\ max}$ = 22 m: a) for average roughness; b) for minimum, average and maximum roughness.

Generally the calculus parameters are much influenced by the way the system's operation is forecasted: on request with a certain operating quality; with daily variation of the flows consumed by the great industrial consumers or with agreement upon a certain restriction supply schedule; at least in certain areas. It is obvious that these different types of operating are requesting sensibly different annual expenditure and investments.

The conception used to reinforce a water supply system is the result of a thorough analysis of the operating shortcomings and have as goals the following:

- Modifying the supplying/pumping technologies (pumps number/types; pumping plant operating condition adjustments).
- Modifying compensation capacities needed in the network. The proper reinforcing of the network.

The way to ensure an optimal upgrading of the deficient network, this process is to be completed after an analytical study of the system, study which includes the following phases:

- Analyzing the shortcomings of the current network and the forecasted users' water demands. Quantifying all upgrading technical solutions in the given conditions. Checking proposed solutions by analyzing the new network obtained after the designed modifications.

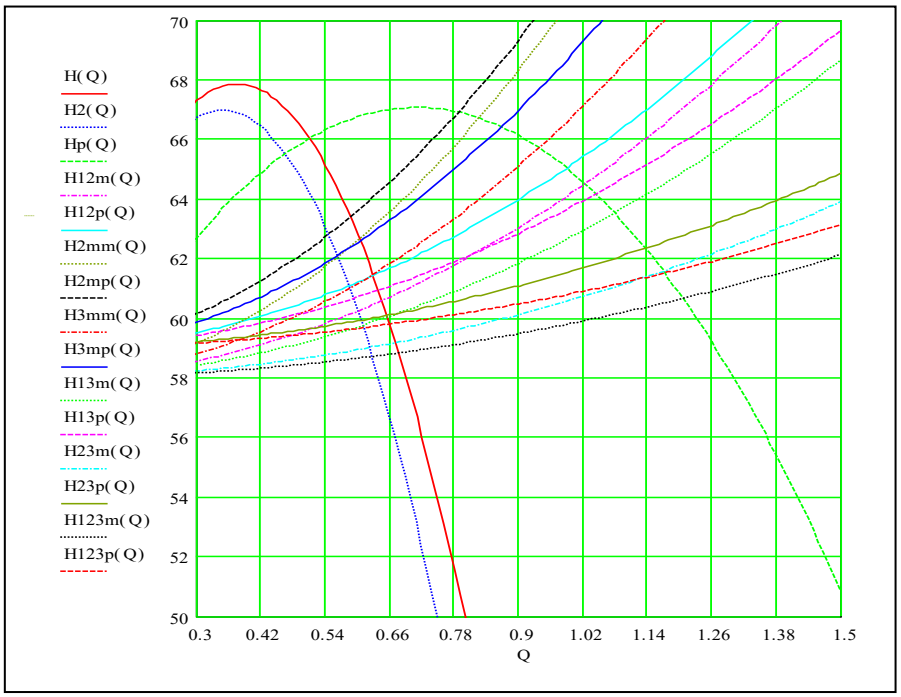
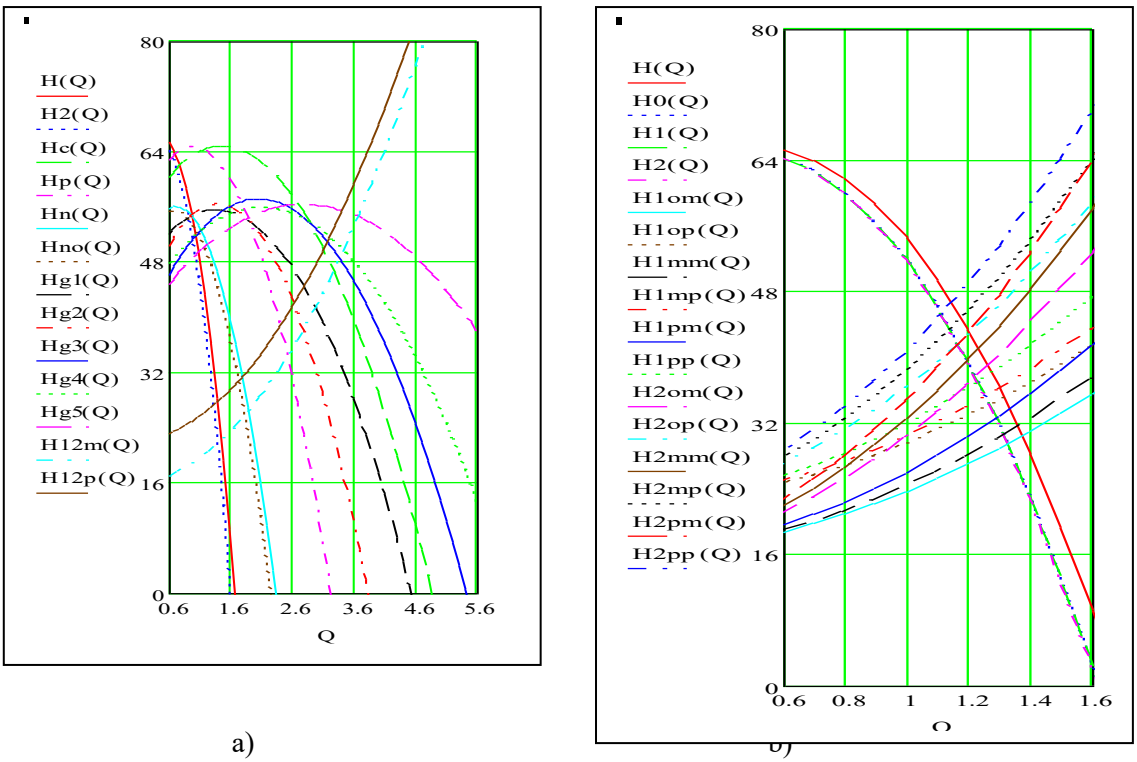


Figure 5. Working regimes pumping station Tutora, caisson II for average roughness; $H_{gs\ min}$ = 58 m; $H_{gs\ max}$ = 60 m.



a) b)

Figure 6. Working regimes PS Tutora caisson II: a) for pump rotational speed, n and n_o; b) for minimum, average and maximum roughness; $H_{gs\ min}$ = 16 m; $H_{gs\ max}$ = 22 m.

- An efficient reinforcement program for water networks cannot be conceived apart the attempt to optimize the reinforcement, a design activity completed in the two phase of the process: quantifying solutions.
- A good methodology for optimizing the reinforcement of water networks based on the analytical study of the links between the parameters that characterize its operation, the geometric and structural parameters and the investment's and operation's costs in the new conditions, are elements that dictate the approach for elaborating the solution, decreases the necessary working time and guarantees the selection of the optimal ways to abate the detected shortcomings.

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REFERENCES

1. Alexandrescu A., Popescu D. (2003) The Optimization of the Pumping Installation's Working with the Hydrophore, 208*ICCES* Proc. *Computer Modelling in Engineering & Sciences*, U.S.A., Cap. 14, Fluid Flow & Heat Transfer, Pub. Tech Science Press, Encino, CA 91316.

2. Alexandrescu A. (2003) Concerning Optimization's Working of the Pumping Station for Water Feedings, Proc. *18th International Conference on Hydraulics and Pneumatics*, Prague, Czech Rep., Pub. Sborník, pp. 263-268.

3. Alexandrescu A., Alexandrescu S. A. (2005) The Analyze of the Working Pumping Station's Ensemble of the Supply with Water - Hydrophore – Consumers, Proc. *Machine – Building and Techno sphere of the XXI Century,* Sevastopol, Ukraine, Pub. Tehnopolis, pp. 285-288.

4. Alexandrescu A., Alexandrescu S. A., Alexandrescu C. A. (2008) Contributions Regards the Optimization of the Hydraulic Systems for the Reduction of Energy Consumption, Proc. *Journal of International Research Publications*, Materials, Methods and Technology, Sunny Beach, Bulgaria, Vol. IV, pp. 24-33.

5. Alexandrescu A., Alexandrescu S. A., Alexandrescu C. A. (2008) Contribution as for the optimization of the pumping stations, Proc. *International Conference on Computational & Experimental Engineering & Sciences*, ICCES0820071216415, Vol. 415, No. 1, Honolulu, Hawaii, U.S.A., pp. 1-11.

6. Alexandrescu A., Alexandrescu S. A., Alexandrescu C. A. (2008) Contributions concerning the power optimization of the pumping stations, *ASME Fluids Engineering Division Summer Conference*, Proc. *11th International Symposium on Advances in Numerical Modelling of Aerodynamics and Hydrodynamics in Turbo machinery*, FEDSM2008-55007, Jacksonville, Florida, U.S.A.

7. Alexandrescu A., Alexandrescu, S. A., Alexandrescu C. A. (2008) Contributions concerning the functional – power optimization of an urban complex system of pumping, Proc. *8th Hydro geological International Congress of Greece*, Athens, Greece, pp. 197-204.

8. Alexandrescu A., Alexandrescu S. A., Alexandrescu C. A., Toma D., 2008, *"Contributions as concerns the complex network's optimization of water supply",* Machine – Building and Technosphere of the XXI Century, Sevastopol, Ukraine, Ed. Tehnopolis, ISBN 966-7907-23-6, pp. 46-50.