IMPROVEMENT SOLUTIONS OF PUMPING STATION'S PERFORMANCES

Aurora ALEXANDRESCU[1]

Lucrarea prezintă soluțiile tehnice adoptate pentru modernizarea stației de pompare CUG din oraşul Iaşi. S-au urmărit optimizarea parametrilor functionali ai stației de pompare si îmbunătățirea calitații apei potabile furnizate consumatorilor. Reabilitarea statiei de pompare s-a realizat prin proiectarea şi montarea unor sisteme performante de monitorizare şi potabilizare a apei, necesare pentru adaptarea funcționării stației de pompare la regimurile variabile de functionare din sistemul hidraulic. S-a calculat economia de energie electrică obținută prin aplicarea mă de reabilitare şi s-a estimat timpul de recuperare a investiției în stația de pompare şi în rețeaua de distribuție a apei potabile.

This paper presents the technical solutions for upgrading the pumping station in Iasi CUG. The aim of the study is to optimize the functional parameters of pumping station and improve the quality of drinking water supplied to consumers. The exoneration of pumping station was done by the projection and installation of performance monitoring systems and drinking water, necessary to adjust the pumping station operation at variable operating regimes of hydraulic system. It is calculated the electric power saving achieved by the application of rehabilitation measures and was estimated the recovery time of the investment in pumping and water distribution network.

Keywords: adduction, conductivity, chlorine, pipe network, tank

1. Introduction

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, [4].

The paper shows a determination method about the pumping installation's average global output in the adjustment situation through hydro – pneumatic loads. It is presented an analyze method about power and economical efficiency of the pumping installations equipped with only one type of pumps.

[1] Eng., Technical University "Gh. Asachi" of Iasi, Romania

Many systems for which a centrifugal pump is otherwise suitable may, however, have a variable demand in which case, a certain loss of efficiency may have to be accepted from part of the head or part of the capacity used for control purposes, using either discharge throttling or bypass control. Both methods will inevitably result in power loss, so if economic regulation is of primary importance, discharge regulation by speed control should be investigated first since this is less wasteful of power and there is usually a considerably smaller loss of pump efficiency. Speed control is now a particularly attractive proposition with the increasing availability of variable frequency power units. The adaptation to variable regimes is done by the hydrophore's usage, [2].

The best power and economical performances will correspond to the pumping solution that ensures the covering of the request area (Q, H) with the best output. The theoretical considerations are accompanied by the examples concerning an under pressure station from a collective system about supplying with urban water. 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.

Instead of friction head, and thus total system head, being determined for a single pipeline size or a specific combination of sizes as indicated by optimum flow conditions, it can be instructive to calculate the friction head at the flow rate required for a variety of alternative pipe sizes – spot calculations only being necessary, [3].

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, [1, 5].

Pumping costs should be estimated as direct cost based on a nominal gallon age selected so as to arrive at cost figures of the same order as total installation costs or based on a specific period of working. Pump wear will inevitably result in a loss of performance, increase in the direct cost of pumping. In some systems the loss of performance may not be noticed at all as the pump is still apparently working satisfactorily. In other cases it may affect the whole process involved. Loss of performance is likely to be noticed in the case of centrifugal pumps since the working point can be shifted considerably with a substantial reduction in capacity and efficiency.

Loss of pump efficiency represents a higher cost of pumping and hence an increase in gradient of the total cost curve for the pump compared with its original performance on a gross discharge basis. This can be compared with the total cost curve for a new pump (inevitably with a higher initial cost) to establish a break-even point when the new pump becomes more economic. This is an over-simplification of the problem since it assumes that the efficiencies of the old and the new pump remain constant up to breakeven point. In practice the old pump is likely to suffer a greater loss of efficiency than the new pump, so the breakeven point will occur at a lower future gross discharge figure although this could be offset by a further rise in the initial cost of the new pump in that period, [4].

2. Nomenclature

Latin symbols

a	Relative spore of debit pumped in gap hours
$a_{PS, (R)}$	Average overall quota in pumping station, (pipe)
D	Pipe's rated diameter
D_o	Optimum pipe diameter
e	Electric power specific consumption planted
e_a	Electric power specific consumption present
ΔE	Electric power economy
Δe	Energy consumption reduction
F	Constant of energy
H_o	Nominal head
$I_{min, (max)}$	Total investment minimum, (maximum)
$i_{o, (p)}$	Investment parameter for pipe, (pumping station)
$I_{p, (R)}$	Investment in constructions and installations, (network pipes)
$K_{f, (N, t)}$	Parameter that allows using certain measure units
$k_{\eta, (Q)}$	Outturn, (flow) coefficients
L_R	Pipe length
m	Coefficient
n	Pump rotational speed
n_o	Optimum number of discharge pipes
n_q	Specific rotational speed
p_e	Electric energy unit cost
$Q_{o, M}$	Flow rate nominal, (maximum)
$T_{RI\ min, (max)}$	The recuperation time of minimum, (maximum) investment
z	Number of pump stages
$Z_{i, (e)}$	Economic function for the investment in pumping station and pipes, (water transport)
Z	Economic function
W_o	Water volume absorbed from sources

Greek symbols

α	Load coefficient

β Parameter of hydraulic slope
γ Constant of hydraulic slope
η Overall outturn
$\eta_{o,\,SP}$ Nominal, (pumping station) outturn

3. Problem definition

The objective function of the optimization problem is the economic function *Z*; it depend on economic function for the investment in pumping station Z_i and the investment in water transport pipes Z_e: $Z = Z_i + Z_e, [RON]$. The economic function for the investment in pumping station Z_i and the investment in the water transport pipes Z_e can be calculated used the following mathematical terms:

$$Z_i = \frac{a_{SP} \,.\, i_p \,.\, K_N \,.\, m \,.\, Q_M^{1+\gamma} \,.\, L_R \,.\, 1{,}1}{\eta_{SP} \,.\, n^{\gamma} \,.\, D^{\beta}} + a_{SP} \,.\, I_p + a_R \,.\, L_R \,.\, i_o \,.\, n + a_R \,.\, a \,.\, n \,.\, L_R \,.\, D^{\alpha}. \quad (1)$$

$$Z_e = \frac{K_N \,.\, m \,.\, L_R \,.\, Q_M^{\gamma} \,.\, F \,.\, W_o \,.\, p_e \,.\, 1{,}1}{3600 \,.\, \eta_{SP} \,.\, n^{\gamma} \,.\, D^{\beta}}. \quad (2)$$

The annual average total expenses *Z* will have the form:

$$Z = a_{SP} \,.\, I_p + a_R \,.\, i_o \,.\, n \,.\, L_R + a_R \,.\, a \,.\, n \,.\, L_R \,.\, D_n^{\alpha} + a_{SP} \,.\, i_p \,.\, K_N \,.\, K_f \,.\, 1{,}1 \,.\, \frac{m \,.\, L_R \,.\, Q_M^{1+\gamma}}{\eta_{SP} \,.\, D_n^{\beta} \,.\, n^{\gamma}} \,. \quad (3)$$

The solution for the pair of variables (*D, n*) is given by the values that minimize the economic target function *Z*(*D, n*); mathematically this means: $\frac{\partial Z}{\partial n} = 0; \ \frac{\partial Z}{\partial D} = 0$. The optimum number of discharge pipes n_o and the optimum pipe diameter D_o are established by the mathematical formulas:

$$n_o = \left(K_t . K_f\right)^{\frac{1}{1+\gamma}} . \left[\frac{a}{i_o} . \left(\frac{\alpha . \gamma}{\beta} - 1\right)\right]^{\frac{\alpha+\beta}{\alpha.(1+\gamma)}} . Q_M \,;\; D_o = \left(K_t . K_f\right)^{\frac{1}{\alpha+\beta}} . \left(\frac{Q_M}{n}\right)^{\frac{1+\gamma}{\alpha+\beta}}, [\mathrm{m}] \,.$$

$$K_t = \frac{\beta . \, a_{SP} . \, i_p . \, K_N . \, m}{\alpha . \, a_R . \, a . \, \eta_{SP}} \;;\; K_f = 1 + \frac{F . \, p_e . \, W_o}{a_{SP} . \, i_p . \, Q_M . \, 3600} \,. \quad (4)$$

The maximum pump efficiency, for a certain technological level, depends on its size. This factor is determined by the nominal flow Q_o, and by the rotor geometry. Another parameter is specific speed, which depends on the nominal head H_o, rotational frequency n and number of stages z. It follows that for the maximum theoretical output η of the best pumps:

$$\eta = (\eta_o - k_Q . Q_o{}^{\alpha}) - k_\eta . \left[\log(\frac{45}{n_q}) \right]^2 , \ [\%]. \quad n_q = n \ . \ Q_o^{1/2} . \ H_o^{-3/4} . \ z^{3/4} . \tag{5}$$

The reduction of the electric power Δe is calculated depending on electric power specific consumption planted e and electric power specific consumption present e_a . The energy economy it is expressed depending on the unitary specific through the mathematical form:

$$\Delta E = \frac{W_o \ . \ e_a}{100} \ . \ \Delta e = W_o \cdot (e_a - e) \ , \ [\text{MWh/year}]. \tag{6}$$

The recuperation time of minimum investment $T_{RI\ min}$ and maximum investment $T_{RI\ max}$ can be calculated depending on total investment I, the reduction of the electric power Δe and electric energy unit cost p_e likeness:

$$T_{RI\ min} = \frac{I_{min}}{\Delta E_{max} \cdot p_{e\ max}} \ ; \ T_{RI\ max} = \frac{I_{max}}{\Delta E_{min} \cdot p_{e\ min}} \ , \ [\text{years}]. \tag{7}$$

4. Case study

The optimization method is applied in the CUG Iasi pumping station for drinkable water. The pumping station is equipped with two 8NDS pumps and rotational speed of n = 1450 rpm. Using several original mathematical algorithms, author developed a computer program for analysis and graphics that calculates the functional parameters of the pumping station as well as the available consumer parameters. It is selected also the best pump for the water supply of consumers. The computer program has analysed eight pumps variants for the replacement of 8NDS pumps. It is obtained the following diagrams: head depending on flow rate H = f(Q), *fig. 1*; pumping outturn depending on flow rate η = f(Q), Fig. 2.

The annual average total expenses Z is calculated for the following coefficients: m = 1,6 . 10^{-3}; β = 5,09; γ = 1,97; i_o = 1,9 . 10^6; a = 4,5 . 10^6; K_N = 9,81; η_{SP} = 0,75%; α =2,75; a_R = 0,0355; i_p = 2,2 . 10^6; a_{SP} = 0,058. Daily average time of water pumping "of basis" head turn t_p is estimated at (10 ÷ 15) hours.

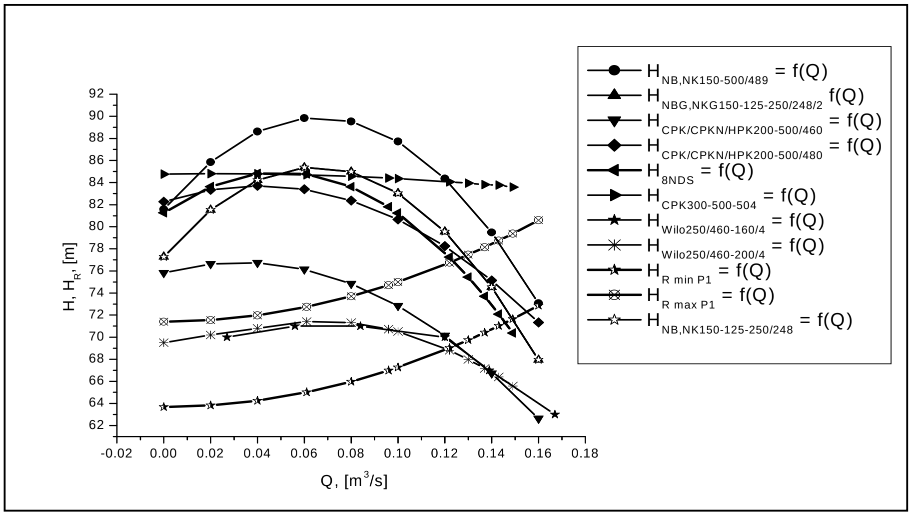

Fig. 1. Head variation depending on flow rate Q for pumps H = f(Q) and pipes network H_R = f(Q).

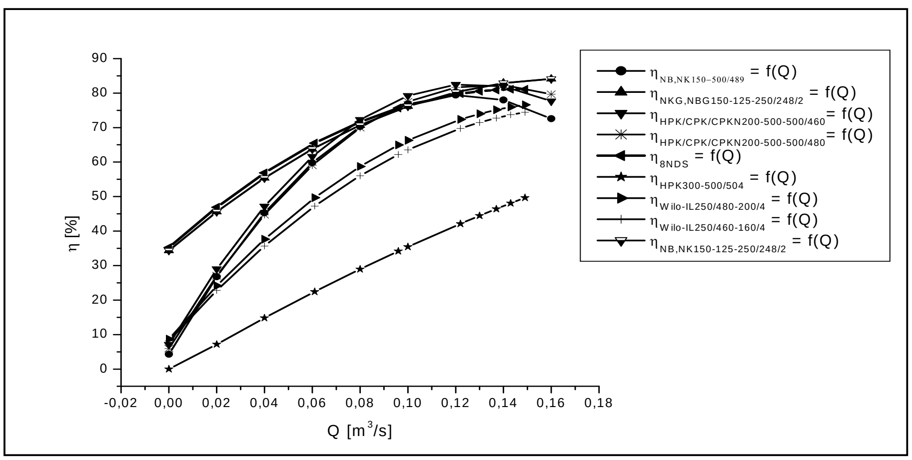

Fig. 2. Outturn variation depending on flow rate Q, η = f(Q).

Daily average time of water pumping "of top" head turn t_{vp} is estimated at (2 ÷ 6) hours. The hydraulic system has the parameters with values: Q_M = 0,2 m^3/s; W_o = 2,04.10^6 m^3/year; F = 0,82; L_R = 700 m. The optimum number of discharge pipes n_o = 1 and the standard values for the optimum pipe diameter D_o = 0,25 ÷ 0,4 m, using the mathematical *term* (*4*) are established. The annual average total expenses Z is analysed for pipes with diameter D = 0,1; 0,2; 0,3; ...; 1,8 m, (Fig. 3).

It is calculated the electric power economy ΔE depending on electric power specific consumption planed e; it is allowed water volume values pumping minimum, average and maximum, (Fig. 4).

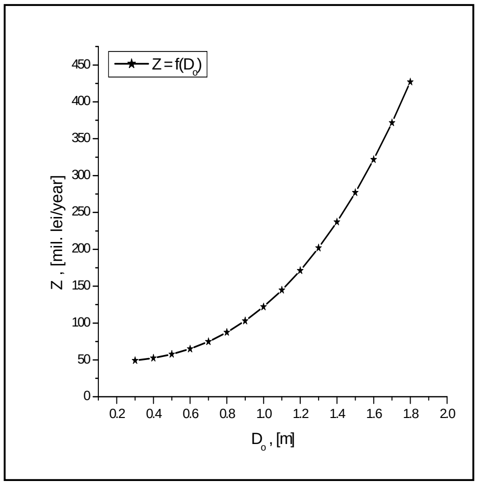

Fig. 3. Annual average total expenses Z variation depending on diameter D_o.

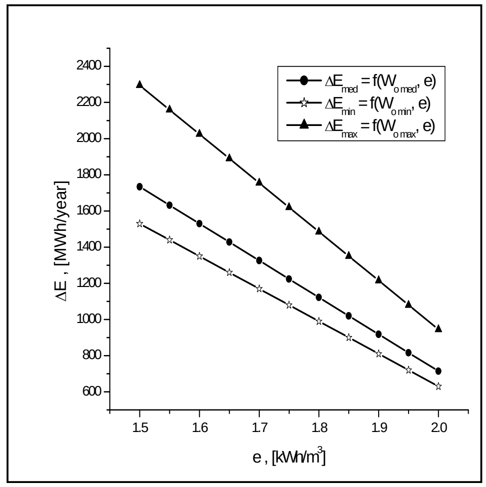

Fig. 4. Electric power economy ΔE depending on electric power specific consumption planed e.

The investment's recuperation time T_{RI} is calculated for the minimum W_{omin} = 1,8 . 10^6 m^3/year and maximum volume W_{omax} = 2,7 . 10^6 m^3/year values of water transported. *Figure 5* represents the variation of the investment's recuperation time T_{RI} for the minimum I_{min} and maximum investment values I_{max} depending on total investment I, electric power economy ΔE_{med} and electric energy unit cost p_e.

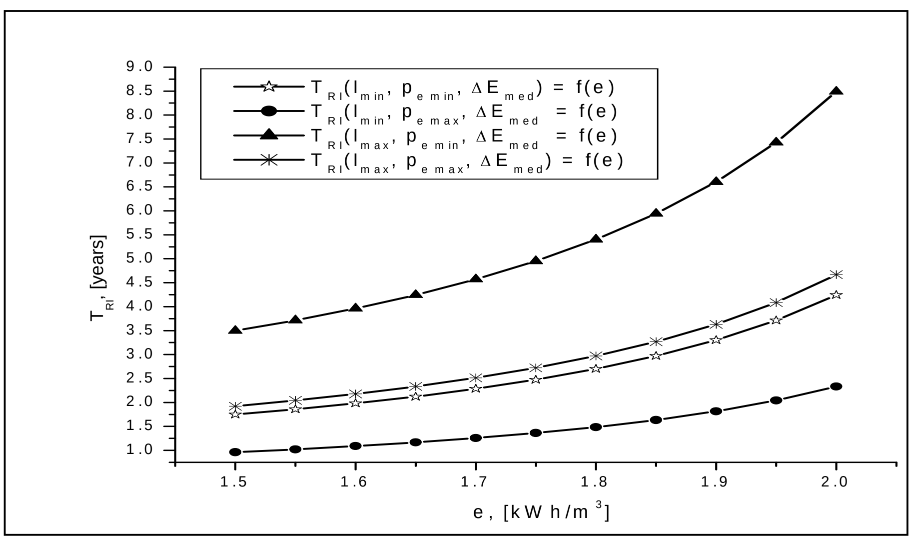

Fig. 5. Investment's recuperation time T_{RI} depending on total investment I, electric power economy ΔE_{med} and electric energy unit cost p_e.

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 computer programs created by authors permit the selection of the best pumps for the water supply of hydraulic system. The beneficiary of project S. C. APAVITAL S. A. Iasi will choose a variant depending on the price acquisition, the speed, the outturn of the pumps; the cost price of the investment in avatars that will be made in the pumping station CUG Iasi are very important.

The investment's recuperation time is advised to be (1 ÷ 8,5) years.

The research results are used for design optimization of the water supply installation for areas with various relief forms. The proposed method for the optimization allows a reduction with 10 ÷ 15 % of the energy consumption required to operate the pumping station – network – consumers ensemble.

R E F E R A N C E S

[1] *S. Ashby, D. Richards, & R. Wallace*, Simple to complex tools for sustainable water resource management, Proceeeding of Fifth International Conference on Sustainable Water Resources Management, Brebbia, C.A. & V. Popov (Ed), pp. 47-54, ISBN: 978-1-84564-199-3, Series Volume 125, Malta, September 2009, Publisher WIT Press, Southampton, Boston, USA, 2009.

[2] *G. Festa, D. Verde, & R. Magini*, Rehabilitation of a water distribution system with diffused water losses, Proceeeding of Fifth International Conference on Sustainable Water Resources Management, Brebbia, C.A. & V. Popov (Ed), pp. 259-280, ISBN: 978-1-84564-199-3, Series Volume 125, Malta, September 2009, Publisher WIT Press, Southampton, Boston, USA, 2009.

[3] *T. R. P. E. Hardee*, Piping System Fundamentals, The Complete Guide to Gaining a Clear Picture of Your Piping System, Engineered Software, Inc., ISBN 978-0-918601-10-0, USA, ESI Press, Engineered Learning, 2008.

[4] *H. Ren, W. Zhou, K. Nakagami, W. Gao, & Q. Wu,* Multi-objective optimization for the operation of distributed energy systems considering economic and environmental aspects, Proceeeding of International Conference on Applied Energy, ICAE 2010, pp. 3642-3651, ISSN 0306-2619, Singapore, April, 2010, Volume 87, Issue 12, December 2010, Elsevier, SUA, 2010.

[5] *V. Mihok, & I. Kvasnica,* Drinking water quality in the Slovak republic and its supply, Journal of International Scientific Publication, Ecology & Safety, Volume 1, Part 1, Available from: http://www.science-journals.eu ISSN 1313-2563, pp. 271-279, Publishing by Info Invest, Bulgaria, 2009.