NETWORKS OPTIMIZATION OF WATER SUPPLY IN THE IRRIGATION SYSTEMS

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Abstract

The paper presents a mathematical model for irrigation plot's optimization through aspersion, on ground in slope. It is takes consideration the energy total specific consumption generated by the irrigation system substructure. The operational consumption of energy for the service and the guidance of the fittings up's exploitation represents annual a fraction from the energy involved. The annual average specific consumption total of energy has relative values elevated in the case of gravitation irrigation systems and presents a minimum. The system ought to present a period of existence least equal with the period necessary to the recovery the resources anticipated consumed, for to ensure the fitting out's profitableness. The optimum solution corresponds to a variant with the energy total specific consumption minimum on ensemble with many plots.

Key words: *irrigation plot, optimization, pumping station, slope, wetting installation*

1. INTRODUCTION

Operational efficiency for a pumping supply system at deep well is strictly determined by the type of pump used. Best performances are obtained when, so that user's needs to be met, submersible pumps are set to operate at ratings located in the neighbourhood of their maximal efficiency which at its turn must have optimal values for the best machines located in the respective class. As to reach that goal the process of the deep well pump choice has to be based on a thorough acknowledge of all operating parameters of such supply, that is the relations between flow Q and specific hydraulic energy that has to be released towards this flow by the pump H, in all different possible operational configurations

In case of machines that draw water directly from tanks, through the deep well pump's suction pipe, data are relatively easy to gather, determining the network parameters, associated to different static loads, specific for each user's operational rating and approximating some reasonable head losses on each pump's suction and delivery mains.

When pumps are drawing, directly or through a suction collector, from a pressurized supply main that carry water to the station, or from a number of tanks, the delivery being done towards other several tanks, the issue becomes more complex. Hence, to provide the most realistic data in this situation means to determine the head parameter for the pressurized supply, corresponding to different

operating configurations and then assessing the representative operational ratings for the pumps in discussion.

It is necessary the optimization of the big irrigation systems; it is analysed more variants organised through the combination of the infrastructures with network's densities different and with the optimum plots. The optimum solution of ensemble corresponds to the variant that has the total specific consumption of energy minimum.

The technique's optimization of wetting visas the choice of the best technology of wetting's administration; it is respected the restriction imposed by the medium's protection; it is ensured a social level of work acceptable for the personnel of execution, in the conditions of the minimization of the specific consumption total average annual of energy, (associated to the achievement of the respective function of water's distribution at plot's level).

The optimum irrigation plots through pipes under pressure can be defined theoretic for any area and in any climatically conditions. The technique of irrigation limits this theoretical possibility. The technical principal restriction is the maximum diameter's value that can be used on antennas, respective principled pipes. These considerations reduce the area that can be covered by a optimum plot S_{max} = f(q, q_d , T_o). The all specific consumptions of energy generated by the network, while optimum at the plot level have values breeder with S and n. It is preferred the variants of optimum plot with S and n lesser.

2. PROBLEM DEFINITION

It is followed the solution's generalization of increase of the power and economic efficiency of the water's pumping; these will ensure the minimum of the total consumption of energy necessary for the networks under pressure.

The restrictions imposed by the complex climate – ground – plant technique are respected. The model of optimum dimensioning of pumping station through pipes under pressure is elaborated for plan ground and in slope, in any conditions of water need and taking into account by the current technique. The optimization model is applied at the optimum dimensioning of rectangular studs for irrigation through aspersion, respective for the irrigation – in the same conditions of water need – through EUBA installations; it is analysed the influence to the restrictions considered acceptable concerning the technical features and the specific consumption energy.

The following parameters are calculated for the structure's determination of the optimum plot; the functional, energetic and economic specific features of the optimum plot are established as well:

1. It is calculated the geometry in plane of the optimum plot:

- The length wetted of secondary and principal pipe L_{cs}, L_{cp}; the really length of the principal pipes, L_{cpef}; the factor shape of the sector wetted by antenna, l:

$$L_{CP} = n.L \; ; \quad l = \frac{L}{L_{CS}} \; . \tag{1}$$

- The plot's factor shape, f.
- The unitary length of secondary and principal pipes, L_{cs1}, L_{cp1}.
- The section's length of dimensioning, L_H:

$$L_H = L_{CPef} + L_{CS} = \frac{(n-1).l+1}{l} \quad (2)$$

2. The functional and power specific features of the plot with the optimum geometry are established with the following parameters:

a. the debit of dimensioning of the ensemble pumping station under pressure – network is a multiple of the modulus debit Q_l and depend by:

- The size of the area served *S;* the specific debit of dimensioning q_d .

- The section's debit *j* of the antenna, (j = 1, 2, …, n_l); the section's debit *k* of principal pipes, k = 1, 2, ÷, n/2, (k_S – number of served networks by the pumping station under pressure, k_S = {1, 2}, *figure 1*):

$$S_o = \frac{L^2}{5000.l}; \quad S = \frac{k_S.n.L^2}{5000.l} . \quad (3)$$

The ensemble pumping station – network – installations of wetting distributes a water volume W covering a water deficit $M \le M_c$ on the section of area S and the water wastage with output of water's usage η_u :

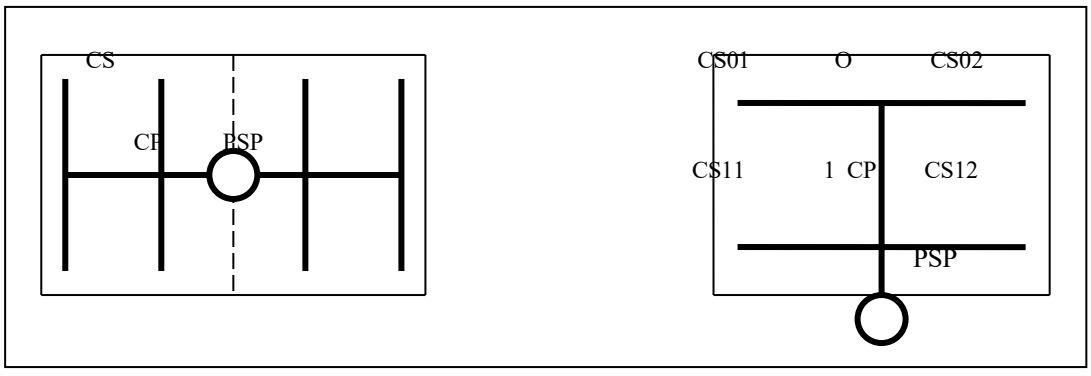
$$W = \frac{10.M.S}{\eta_u} . \quad (4)$$

M_c (mm) represents the deficit of calculation with a frequency commensurate to the fitting out's category of importance; M_c can be established through to take into account the relations water – production and water – energy, determined in the conditions of the system. This service is ensured through the management, on each position of waiting of wetting installations, of a number wetting n_u with an average doze m_o (mm):

$$m_o \le 10.\gamma_v.H_a.(W_c - W_m); \quad M = n_u.m_o . \quad (5)$$

It is wetted a section of area s_{io} and it has to effectuate a number n_m of moves (depending on the distance between the positions of waiting of the wetting installations l_{IU}):

$$s_{io} = L.l_{WI} ; \quad n_m = \frac{n_u.10^4.S}{L.l_{WI}} . \quad (6)$$



a) b)

Figure 1. The scheme of the irrigation system under pressure with networks:

a) k =1; b) k =2.

It is calculated the specific debit of dimensioning of the irrigation system under pressure's elements q_d (l/s.ha), (adequate to the deficit of calculus from rush month of the irrigation season m_v that has to cover through the operating of the irrigation system under pressure in t_z (days), time by t_h (hours/day) with an gross output of the water's usage η_u):

$$q_d = \frac{2,78.\ m_v}{\eta_u.\ t_z.\ t_h}\ . \tag{7}$$

b. Optimum average piezometer slope J_o^* proper of the debit's transport of dimensioning section by optimum diameter. Average piezometer slope J_o of dimensioning of the antennas from the nodes $k \neq 0$. The charge necessary at pumping station for the water's transport in network will be established by the section's length of dimensioning L_H and J_o^*.

c. The pumping station's power for the water's transport in the network is established of the plot's debit of dimensioning and by the load necessary for the water's transport in the network. Also, the reservation of power necessary in the working of the pumping aggregates k_M and the average output of the water's pumping η_p are important. The average power absorbed by the pumping station for the water's transport in the network on the period existence of the irrigation system.

3. The specific consumptions of energy generated by the water's transport through network of the irrigation plots are calculated with the following parameters:

- The unitary energy involved in the fixed network, E_R:

$$E_R = \frac{5000}{n.\ L}.\ \left\{\left[l.\ (n-1) + n - 2\right].\ i_o + \left[(n-1).\ l.\ \varphi(n) + n.\ \psi(n)\right]\right\}.\ \frac{K_J^{\alpha/\beta}.\ (n_t.\ Q_{IU})}{J_o^{\alpha/\beta}}; \tag{8}$$

$$\varphi(n) = \frac{2.\ \sum_{i=0}^{\frac{n}{2}-1} (2.\ i)^{\alpha.\ \gamma/\beta} + n^{\alpha.\ \gamma/\beta}}{n-1};\quad \psi(n) = \frac{2.\sum_{i\ =\ 0}^{\frac{n}{2}\ -\ 1} (1+\ 2.\ i.\ l)^{\alpha/\beta}.\ \sum_{j\ =\ 1}^{n_t} \left(\frac{j}{n_t}\right)^{\alpha.\ \gamma/\beta}}{n.\ n_t}.$$

- The unitary energy involved in the pumping station for the water's transport in network, E_{PSP}:

$$E_{PSP} = \frac{5000.\ l.\ I_{PSo}}{k_S.\ n.\ L^2} + \frac{K_I.\ K_N}{\eta_p}.\ q_d.\ \left(H_g + H_H + H_t\right)\ . \tag{9}$$

- The unitary energy involved in pipes (wetting installations), E_{WI}:

$$E_{WI} = \frac{q_d}{Q_{WI}}.\ \left(I_{WIo} + i_{WI}.\ L\right)\ . \tag{10}$$

- Annual average specific consumption of energy generated by the water's transport in plot's network, C':

$$C' = \frac{K_N.\ q_d.\ T_o}{k.\ \eta_p}.\ \left[\left(\frac{\bar{q}}{q_d}\right)^2 + \frac{\bar{q}}{q_d}\right]\ . \tag{11}$$

- Annual average specific consumption of energy generated by the service and the exploitation of the transport system under pressure of the water, C_I, (k_{re} – coefficient wages):

$$CI = C_{IPS} + C_{NP} + C_{IWI} + k_{re}.C_p;\ \ CI_j = a_j.E_j;\ \ j \in \{PS, NP, WI\}\ . \quad (12)$$

- The annual average specific consumption of energy for the wetting installation's move, C_m:

$$C_m = \frac{M_o.r_m.10^4}{m_o.l_{WI}.L}\ . \quad (13)$$

- The annual average specific consumption total of energy generated by the water's transport in the irrigation plot with the pipes under pressure, [3]:

$$CE = \frac{5000}{n.L}.\left\{\frac{a_{PSP}.E_{PSPo}}{k_s.L} + a_{NP}.i_o.\left[(n-1).l + n - 2\right]\right\} + a_{WI}.\frac{q_d}{Q_{WI}}.\left(E_{WIo} + i_{WI}.L\right) +$$
$$+ \frac{M_o}{m_o}.\frac{r_m}{l_{WI}}.\frac{10^4}{L} + a_{PSP}.K_1.K_N.\frac{Y_1}{\eta_p}.q_d.\left(H_g + H_o + h_{rWI} + \frac{(n-1).l+1}{l}.L.J_o\right) + \quad (14)$$
$$+5\ 000.a.a_{NP}.\frac{(n-1).l.\varphi(n) + n.\psi(n)}{n.L}.K_J.\frac{(n_t.Q_{WI})^{\frac{\alpha\gamma}{\beta}}}{J_o^{\frac{\alpha}{\beta}}}\ .$$

The optimisation problem consists in the minimization of the annual average specific consumption total of energy demanded by the irrigation through pipes under pressure of the relation climate ground – plant. It must be respected the restrictions of functional order and it were adopted the standardized dimensions.

It must be found the size's values J_o , l, L what lead at the minimum of the annual average specific consumption total of energy, equation (14), depending on the equipment's category of wetting used (Q_{WI}, H_o , d_o , K_p):

$$\min CE = \min CE\ (J_o, l, L, Q_{WI}, H_o);\ \ Q_{WI} = \frac{K_{WI}.K_Q.d_o^{\beta Q}.L^{\gamma Q}}{K_p^{\frac{1}{2}}};$$
$$H_o = \frac{d_o}{K_p};\ \ h_{rWI} = \frac{k_{hr}.d_o^{\beta H}.L^{\gamma H}}{K_p}\ . \quad (15)$$

The structure of the wetting installations and the charge necessary at hydrant are established from the condition of the minimum annual average specific consumption total of energy generated by the wetting's realization.

The piezometer slope J_o is expressed depending on the length l and the specific debit of dimensioning, [3]:

$$J_o = \left[\frac{l.\ (n-1).\ \varphi(n) + n.\ \psi(n)}{n.\ \left[(n-1).\ l + 1\right]}\right]^{\frac{\beta}{\alpha+\beta}} \cdot \frac{K_J^{\frac{\alpha}{\alpha+\beta}}}{\left(K_N.\ \frac{K_I}{a}.\ \frac{a_{PSP}}{a_{NP}}.\ \frac{\beta}{\alpha}\right)^{\frac{\beta}{\alpha+\beta}}} \cdot \frac{1}{\left(\frac{Y}{\eta_p}\right)^{\frac{\beta}{\alpha+\beta}}} \cdot \left(\frac{5000.\ l}{L^2.\ q_d}\right)^{\frac{\beta-\alpha\gamma}{\alpha+\beta}} \cdot \quad (16)$$

The reduction of average piezometer slope J_o has like effect a decrease of the operational consumption of energy for pumping and an enlargement of the energy included in the network. The dimensioning of the pumping station – network ensemble is effected for an optimum average piezometer slope J^*_o, established from the minimum's condition of the annual average specific consumption total of energy y established of water's transport in the plot's network analysed:

$$\frac{\partial CE}{\partial J_o} = 0; \quad \Rightarrow J_o^* \ . \quad (17)$$

The debit specific features and output have the following mathematical shapes, [6]:

$$Q_{pk}(n,\ Z_i) = \sqrt{\frac{H_{pf} - H_{pk}}{K_p}};\ \eta(n,\ Z_i) = R_1.\sqrt{\frac{H_{pf} - H_{pk}}{K_p}} - R_2.\ \frac{H_{pf} - H_p}{K_p}. \quad (18)$$

The equation of continuity depending on the load H is written in the following shape:

$$\sqrt{\frac{H_{gf_j} - H}{K_{g_j}}} = \sqrt{\frac{H_{gf_{j-1}} - H}{K_{g_{j-1}} + M_{r_{j-1,j}} + M_{r\zeta_{tj}}}} + \sqrt{\frac{H_{pf} - H}{K_p + M_{ro_j} + M_{r\zeta_{lj}}}}. \quad (19)$$

It is establishing the following mathematical formula what permits the defining of the specific feature of 1, …, j wells:

$$\nu_j = \left(\frac{\nu_{j-1}}{\sqrt{1 + \frac{M_{r_{j-1,j}} + M_{r\zeta_{tj}}}{K_{g_{j-1}}}}}\right) + \left(\frac{1}{\sqrt{1 + \frac{M_{ro_j} + M_{r\zeta_{lj}}}{K_p}}}\right);\ K_{g_j} = \frac{K_{g_{j-1}}}{\nu_{j-1}^2}. \quad (20)$$

It is obtaining the equivalent hydraulic resistance modulus adequate to the different configurations of exploitation of the wells battery K_{g_k}, $k = 1,2,...,n$ and of the front – tank – pumping station ensemble (in the case of front collecting with two branches coupled on same coupling) rolling the personal programme of calculus in MATHCAD.

It results for the overall output of the ensemble pumping station – network pipes the following mathematical expression (p is the number of pumps that work concomitance in pumping station):

$$\eta_o = \frac{\eta_m \cdot \eta_p}{\left(1 - \frac{Q}{Q_{PS-NP}}\right) \cdot \left[1 + \frac{k \cdot \left(Q_{PS-NP}\right)^2}{p^2 \cdot H_{PS-NP}}\right]} \cdot \qquad (21)$$

3. EXPERIMENTAL STUDY

The logical scheme of a calculus programme is achieved proper to the mathematical model.

The optimization model is applied at the optimum dimensioning of rectangular plots for irrigation through aspersion, respective for the irrigation – in the same conditions of water need – through EUBA installations. The influence of the restrictions concerning to the technical features and to the specific consumption energy is analysed through the utilization of a calculus programme.

This pumping station analysed has 21 supply wells from the phreatic water. The wells have the depth between (95 ÷ 150) m and are equipped with submersible pumps. The pumping water from well, through communications, is unloaded in the collector's catching front, (*figure 2*). The pumping aggregates are mounted in a pumping station shaft type with dry room; it is placed convenient to three tanks for the water's storage. These tanks represent aspiration basin of 9 pumps.

Figure 3 presents the load and outturn specific features for pumps and pipes networks from the pumping station Buzau. It is noted with H_{fcr} = f(Q) resultant specific feature of catching front, reduced at pumping station.

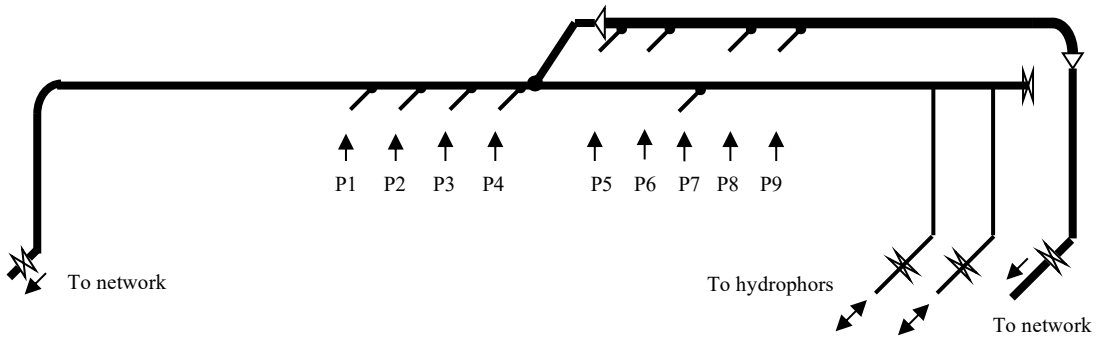


Figure 2. The Scheme of upsetting collector for Buzau pumping station.

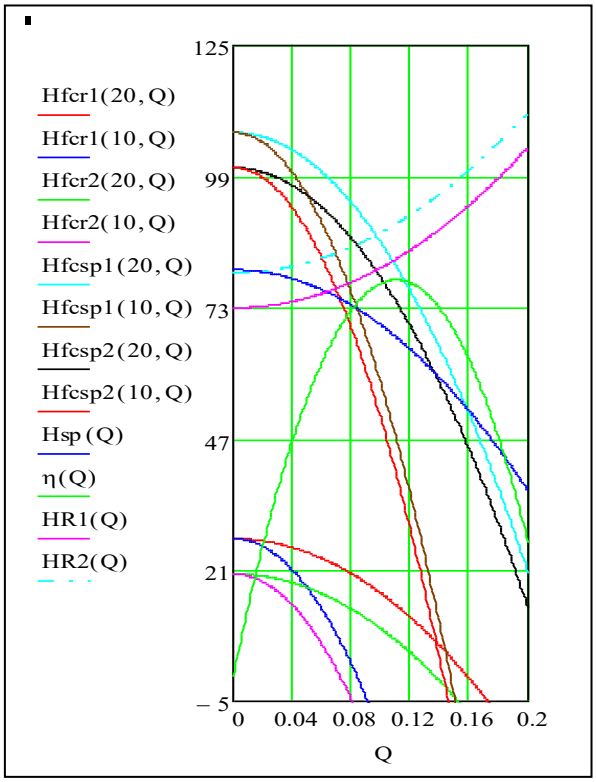


Figure 3. Pumping station Buzau: $H_{fcr} = f(Q)$ resultant specific feature of catching front, reduced at pumping station; $H_R = f(Q)$ pipes networks; $\eta = f(Q)$ pumps outturn.

4. RESULTS AND DISCUSSION

The determination of the regimes working of the wells, in the conditions of exploitation can be achieved resorting at an analytical method based on the mathematical modelling of the system and the utilization analytical specific features of the components.

The constants for the calculation of the annual average specific consumption total of energy are the following values: a_{PSP} = 0,105; a_{NP} =0,075; a_{WI} = 0,175; k_{re} = 0,06; k_m = 1,05; k_S = 1; n = 4; η_{PS} = 0,65 %; a = 1140; α = 1,53; K_I = 1100; K_N = 0,0103; i_o = 70; if Q is express in l/s, result $K_J = 1{,}89.10^{-9}$; if Q is express in m^3/s, result $K_J = 1{,}56.10^{-3}$; β = 5,08; γ = 1,97, m_o = 60 mm; t_z = 30 days; t_h = 20 hours.

Figure 4 presents working regimes and the variation of piezometer quota at ramifications Z_p (m) depending on debit Q (m^3/s) at pumping station Buzau.

The load specific features for the pipes network use the following notations: *Zcx* – 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). It is used in *figure 4.b* Z_{min} = 95 m and Z_{max} = 105 m.

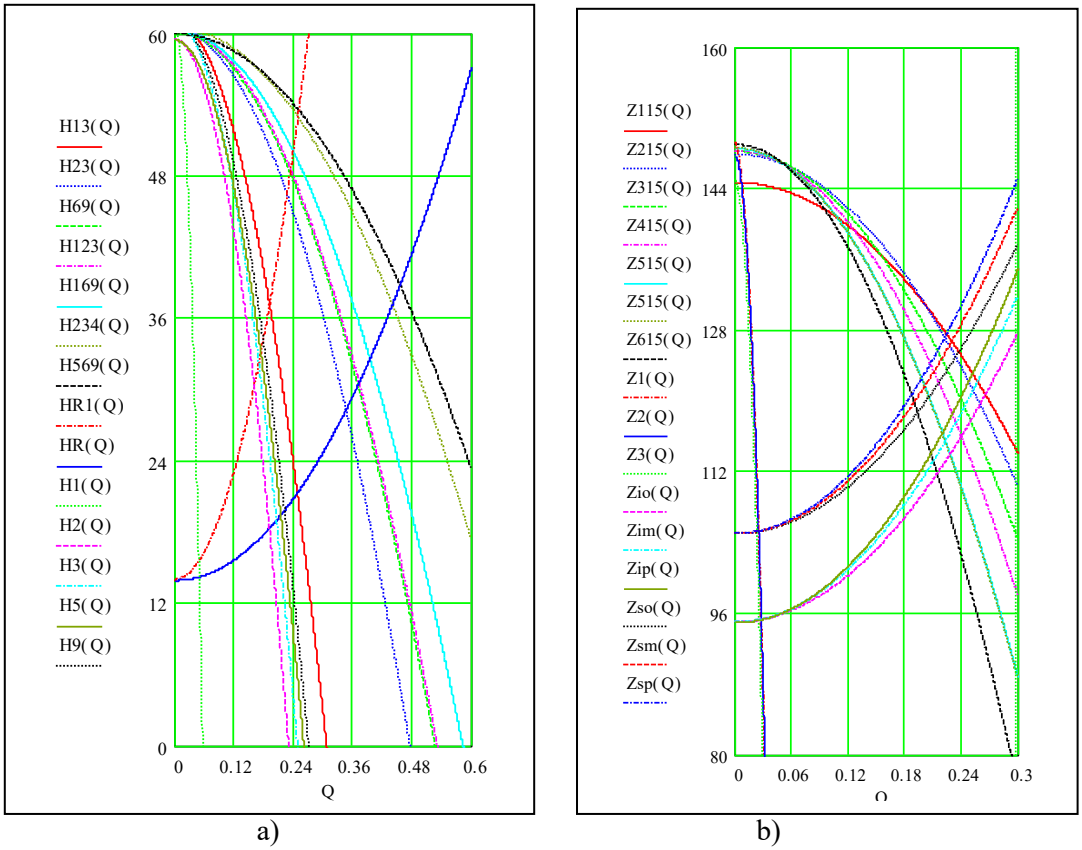


Figure 4. Working regimes of pumping station Buzau: a) Resultant load specific features *H (Q)* of active pumps; b) Load curves for catching front *Z* (*Q*) depending on minimum, average and maximum roughness.

Figure 5 shows the variation of the economic efficiency of investment depending on time for rehabilitation PS Buzau. The symbols utilized are following: *I* - necessary investment for installation rehabilitation; *r* - monthly average rate for updating; u_e (-) actualisation coefficient; *t* (month) recovery time of investment; p_e (€/kWh) - electric energy unit cost; *CE* (MW/year) - the annual average specific consumption total of energy generated by the water's transport in the irrigation plot with the pipes under pressure.

It is used the following values, depending on the type of irrigation:

- in the case of aspersion installations: l_{WI} = 18 m; k_i = 2; r_m = 23 for moves mechanized of wetting installations and r_m =52 for hand moves; i_{WI} = 68,4 for moves mechanized of wetting installations and i_{WI} = 73,1 for hand moves; E_{WIo} = 4200.

- In the case of EUBA installations: l_{WI} = 144 m; k_i = 1; r_m = 275; i_{WI} = 106; E_{WIo} = 1712.

The wetting installations are the constants:

- In the case of aspersion installations: k_Q = 2,43.10^{-4}; β_Q = 2,52; γ_Q = 0,95; k_{hr} =5,06.10^{-11}; β_H = 5,07; γ_H = 2,49.

- In the case of EUBA installations: k_{hr} = 4,22.10^{-5}; β_H = 1,84.

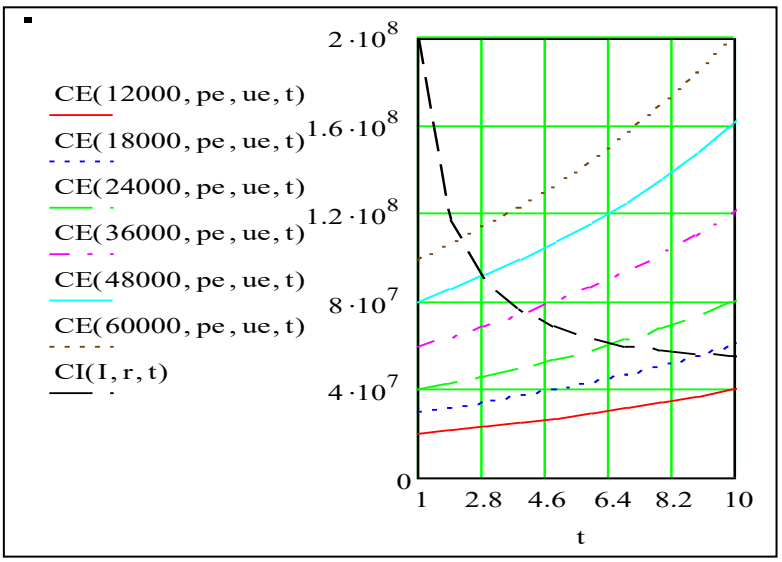


Figure 5. The energy involved in the pumping station.

5. CONCLUSIONS

The strong interactions are between the hydrotechnical systems, surrounding environment and the social – economic conditions. The relative indicators from the structure of the consumption energy depend by the surrounding environment and by the social – economic conditions. The operational consumption of energy for working grows up from minimum values (in the case of the gravitation solutions), unto maximum values (adequate to the installation with pumping). The operational consumption of energy for the service and the guidance of the fittings up's exploitation represents annual a fraction from the energy involved.

The annual average specific consumption total of energy has relative values elevated in the case of the systems of gravitation irrigation (because of the energy's specific features involved) and presents a minimum, (proper to the mixed solution with a special index of pumping). The system ought to present a period of existence least equal with the period necessary to the recovery the resources anticipated consumed, for to ensure the fitting out's profitableness.

The following indicators: the time of system's reply, the stability on operating and the reliability are very important for the economic increase, (established by the irrigation's application). The efficient working of irrigation systems establishes a strong growth economic through the increase of the productivity at hectare of the irrigated crops.

The hydrotechnic fittings out for irrigation ought to present o great adaptability at technological changes; it is facilitated the maintenance of the productivity and of the unitary consumptions in the contiguously to the values ensured by the best technologies.

The results of researches serve at the optimum designing of point of view energetic of the fittings out for irrigations in the zones with plan relief and in slope; the methods proposed allow a reduction with 10 ÷ 15 % of the energy consumption generated by the irrigation through aspersion.

ACKNOWLEDGEMENTS

This work has been supported by the National Centre of Management Programmers, Romania under financial contract No. 21-041/2007.

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