Energetic Perspective on Irrigation Water Pumping Stations

A. Constantin, C.St. Nitescu, and M. Stanescu

***Abstract*—N**ew sources of clean energy and new technologies for energy generation, more friendly with the environment, are important goals for the scientists, but in the same time they have to focus on the reduction of energy consumption as well as to the efficiency improvement of the greatest existing consumers. The modernization of old pumping stations is a stringent demand in Dobroudja, Romania, where agriculture relays on irrigation. The paper presents two existing pumping stations efficiency increase key-measures, mainly identified on the basis of an energetic analysis of the entire hydraulic system. The energy saving after the modernization of the hydraulic system is calculated in terms of energy consumed for 1000 m^3 pumped water.

***Keywords*—** Water pumping installation, hydraulics, energetic efficiency.

I. ENERGETIC PERSPECTIVE ON WATER PUMPING INSTALLATION

ELECTRIC energy is a support of our entire life therefore our energy needs are growing over time. The discovery of new sources of clean energy and new technologies became an important goal for scientists. An enhanced attention should be paid to the reduction of energy consumption as well as to the efficiency improvement of the consumers. Irrigation water pumping stations are among the most important electrical energy consumers all over the world and especially in Dobroudja, Romania where they have a huge importance in the agricultural land improvement.

An energetic perspective on the pumping stations must take into account both the pumps and the pipelines.

These two components of the hydraulic system should work in good compliance that means the pumps have to meet the energetic needs of the fluid to overcome the static pressure and the resistance to movement opposed by the pipelines.

The increase in efficiency of the existing pumping stations involves an energetic audit of the pumps, a thorough study on the pipelines and identification of the optimal technical measures to improve the energetic transfer to the water.

A. Constantin is with "Ovidius" University from Constanta, Romania; Faculty of Civil Engineering, Department of of Civil Engineering, (e-mail: aconstantina@univ-ovidius.ro).

C. St. Nitescu is with "Ovidius" University from Constanta, Romania; Faculty of Civil Engineering, Department of Civil Engineering (e-mail: claudiu.nitescu@univ-ovidius.ro).

M. Stănescu is with is with "Ovidius" University from Constanta, Romania; Faculty of Civil Engineering, Department of Civil Engineering (e-mail: mada_x_dobre@yahoo.com).

A. Electrically Driven Hydraulic Pump

The most used irrigation water pumps are electrically driven turbopumps which cause a continuous fluid movement by a rotating part: an impeller or a propeller. There are two stages of energy conversion: the first referring to electric energy transformed by the electric motor into mechanical one, and the second referring to the mechanical energy transformed by the impeller into hydraulic energy imparted to the fluid by increasing the flow velocity. As the flow exits the pump and its velocity is reduced, part of the kinetic energy is converted to potential energy (pressure). Each conversion has certain efficiency, so that we may define the overall efficiency of the pumping unit (hydraulic pump and its electric motor) as:

$$\eta = \eta_e \cdot \eta_p \quad (1)$$

where η_e-efficiency of the electric motor, [-];

η_p-pump's efficiency, [-],

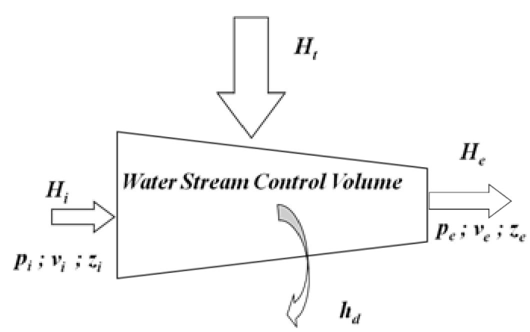

Fig. 1 Specific energy in and out a hydraulic pump, considered a control water volume

If we focus on a hydraulic pump, we may apply the energy conservation law, using the notation in Fig.1, as follows:

$$H_i + H_t = H_e + h_d \quad (2)$$

where

H_i –inflow specific energy (at the suction section of the pump), [m];

H_t –theoretical specific energy received from the impeller by an inviscid fluid, [m];

H_e –outflow specific energy (at the discharge end), [m];

h_d -lost specific energy, [m].

It is well known that the pumping head is the difference between the specific energy in and out the pump:

$$H=H_e - H_i = H_t - h_d \qquad (3)$$

or, if we take into consideration the water flow parameters at the suction and at the discharge section of the pump, we have the relationship:

$$H=\left(\frac{p}{\gamma}+\frac{\alpha v^2}{2g}+z\right)_e - \left(\frac{p}{\gamma}+\frac{\alpha v^2}{2g}+z\right)_i \qquad (4)$$

where

p-pressure, $\left[{}^{N}/_{m^2}\right]$;

γ -water specific weight, $\left[{}^{N}/_{m^3}\right]$;

α -Coriolis coefficient,[-];

g-acceleration due to gravity, $\left[{}^{m}/_{s^2}\right]$;

z-elevation, [m];

i, e-indexes for suction and respectively discharge sections.

Relation (4) allows us to experimentally determine the pumping head of a pump, in-situ and furthermore its efficiency.

The term of energy loss, h_d, consists of three distinct categories:

- mechanical loss, due to friction between parts in relative movement;
- hydraulic loss, due to fluid viscosity and to stream change in direction and cross section;
- volume loss, due to the part of flow that reverses between two vanes of the impeller.

We can attach efficiency to each kind of loss, so that the total efficiency of the pump is given by the relationship:

$$\eta_p = \eta_m \cdot \eta_h \cdot \eta_v \qquad (5)$$

where η_m-mechanical efficiency, [-];

η_h-hydraulic efficiency, [-],

η_v-volume efficiency, [-].

Apart from the volume flow loss, the mechanical and hydraulic energy lost in a pump turn to heat. Therefore a thermodynamic audit of a pump may give a valuable assessment of pump efficiency. The method is more accurate in case of old pumps, with low efficiency

The specific energy imparted by the pump assembly to the water, namely the total head, H, depends both on the discharge and on the rotation speed. For a centrifugal hydraulic pump, this dependence is given by the relationship:

$$H_{(Q,n)} = aQ^2 + bnQ + cn^2 \qquad (6)$$

where:

H –total head, [m];

Q –discharge, [m^3/s];

n –rotation speed, [rot/min];

a,*b*,*c*-constant coefficients.

B. Hydraulic System

The steady operation of a pump on a certain system implies the equality between the specific energy required by the system, Hc, and the specific energy delivered by the pump, H.

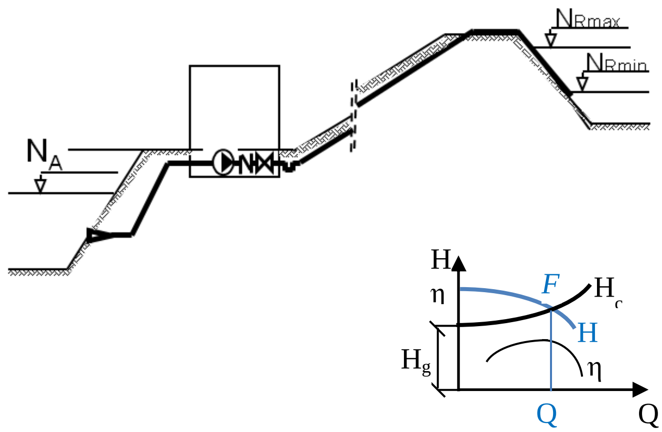

Fig. 2 Layout of a pumping installation with open basins. Duty point F

This equality takes place for the duty point, Fig.2, at a well-defined value of the discharge, Q. We can identify the mathematical expression of the required head, Hc, by the use of Bernoulli's relationship applied on a stream line, between two points placed at the suction basin and respectively the discharge basin free water surface. In the case of open systems, as we meet in agricultural applications, the required head is:

$$H_c = H_g + h_r \qquad (7)$$

where:

Hg – geodetic head, [m];

hr –head loss over the pipelines, [m]:

$$h_r = MQ^2 \qquad (8)$$

M –hydraulic resistance modulus for the entire pumping installation, $[m^{-5}s^2]$.

The duty point, F, is graphically deduced as the intersection between the pump's characteristic curve H(Q) and the pipes one, Hc(Q). The duty point gives the values H and Q delivered by a pump on a certain system. The duty point is optimal if the energetic efficiency of the pump is maximal, η max.

Referring to relationship (6), it is obvious that any change in rotation speed will modify the duty point the pump operates at on a specific installation.

Whatever would be the type of the pumping station, an engineer must conceive the installation in a way the term of energy loss, relationship (8), to be minimal, heading to meet:

- the required discharge, Q;
- at the needed head, H;
- with an efficiency above 80%η_{max}.

The engineering design is oriented not only to low investments but also to low operation costs.

As long as the water stakeholder requires a variable discharge, the pumps in an installation must respond in a cost effective water delivery way. And the consumed electric energy has an important weight in the price of the delivered water. There were conceived three categories of discharge adjusting methods:

a.Acting on the pump;

b.Acting on the installation;

c.Changing the number/ type of pumps operating in parallel.

Before applying one or other of these methods, an analysis in terms of efficiency is needed.

II. Energetic Improvement of Old Pumping Stations

Most of the existing pumping stations in Dobroudja have been in operation for over thirty years, which resulted in an unreliable service and increased costs due to frequent repairs, and low energy efficiency. Therefore the old pumping stations have to be modernized. The improvement of the operation efficiency of a pumping station results in a significant saving of electric energy and consequently into a lower cost of pumped water and furthermore to a cleaner environment.

The engineering design must be customized: every single variant for an old pumping station modernization must be technically and economically analyzed prior to adopt a specific solution. This analysis should be done on both pumps and pipes.

According to the discharge requested from the new pumping installation, the main methods to rehabilitate are as follows:

-pipeline replacement,

-pump adapting;

-pump replacement.

One or a combination of the above mentioned methods may be adopted in accordance with the information given by the inspection and hydraulic analysis of the system.

The main advantages offered by rehabilitation consist of:

- reduction of energy losses;
- lower operation costs due to the new possibility of discharge adjustment;
- improved protection from water hammer;
- elimination of repair needs;
- savings due to automation and monitoring of the pumps operation.

A. Pipeline Replacement

Pipeline replacement, especially the discharge pipeline, may bring a significant gain in efficiency.

Head loss may be diminished by changing the material the ducts are made of, with a smoother one. Attention has to be paid to the type of turbulent flow. By reducing the roughness a developed turbulent flow may turn into a transient or even a smooth one, resulting in a different requested head.

Head loss may also be reduced by increasing the diameter of the conduits or by changing the fittings and valves with new ones that oppose a smaller local hydraulic resistance.

B. Pump Adjustment

Pump adjustment heads a more efficient response of the installation to the changes in discharge requirements. If the new pumping installation will operate at a fixed value of the discharge, a small adjustment of the impeller's diameter may lead to the requested value. If the hydraulic similitude is maintained between the old and the new impeller, affinity laws allow us to predict the new duty point parameters [1], [2]. In Fig.3 it may be noticed how the discharge reduces when the impeller's diameter varies from D2 to D2'.

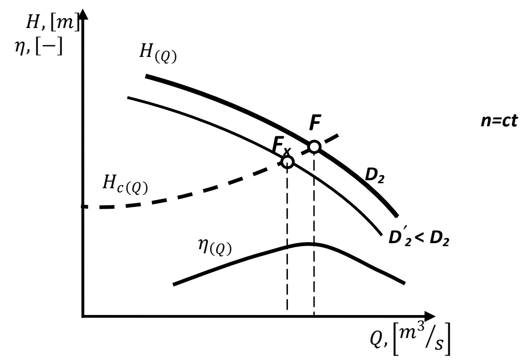

Fig. 3 Duty point displacement according to the impeller's diameter variation between D2 and D2'

The best method, from energetic view point, is to vary the discharge by varying the rotation speed. A hydraulic pump with variable rotation speed is twice as expensive as a constant speed one, but extremely effective. When the impeller's rotation speed is modified, the hydraulic similitude is maintained. Specific affinity laws allow us to predict the change of the duty point with the speed [5]. In closed hydraulic systems, where the geodetic head is zero, the duty point moves on a parabola, maintaining the efficiency. In open systems the efficiency has to be determined for each operation possibility, Fig.4.

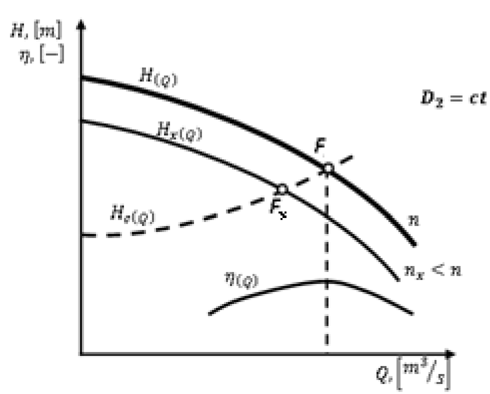

Fig. 4 Duty point displacement according to the rotation speed variation between n and n_x

Frequency converter may be attached to some existing pumps, which is a less expensive method to vary the speed.

C. Pump Replacement

Pumps replacement involves a consistent investment, that's why the decision is made not only on technical criteria, but also on the basis of an economical calculus.

The actual efficiency of an existing pump may be assessed prior to decide to change it. But under installed conditions, this assessment may be done only if the installation is provided with measuring devices, so that data regarding pressure differential across the pump, the flow rate and absorbed power may be experimentally collected, Fig.5. The efficiency is expressed as follows:

$$\eta = \frac{\gamma Q H}{P_a} \qquad (9)$$

where P_a - absorbed power, [w].

The head H may be calculated with relationship (4), neglecting the difference in water velocity across the pump.

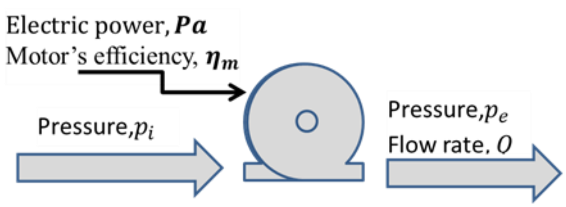

Fig.5 Quantities needed to experimentally determine pump's efficiency, by regular method

On-site constraints often make it difficult to accurately measure pump's efficiency, especially in case of large diameter of the discharge duct, as it usually happens in irrigation water pumping installation. Pumping stations designated to agricultural purposes aren't provided with flow meters. These measuring devices are expensive and introduce additional head losses.

More suitable is the thermodynamic method which is based on the assumption that all head losses transform into heat, absorbed by the pumped water. It relies primarily on the measurement of two parameters: the differential temperature across the pump and the differential pressure across the pump, as it is suggested in Fig.6.

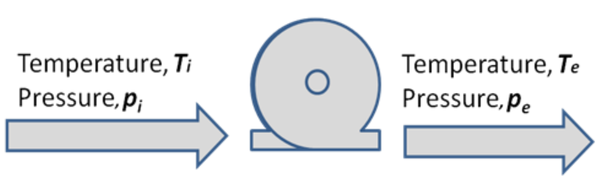

Fig.6 Quantities needed to experimentally determine pump's efficiency, by thermodynamic method

By this method, flow is not necessary to determine efficiency.

The accurate measurement of temperature is very difficult, because the values are extremely small. In Fig.7 there is represented the increase in water temperature for a centrifugal pump, as a function of pumping head. The temperature difference ranges between 10 and 20 mK.

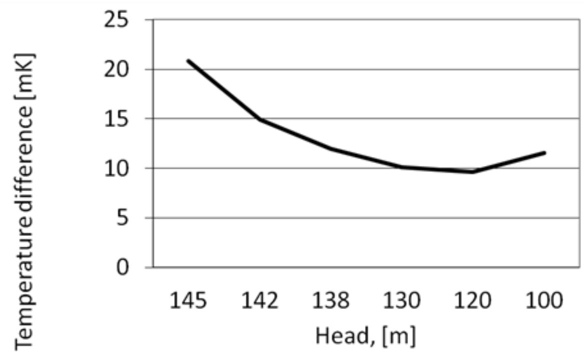

Fig.7.Water temperature differential across a pump

The pump energetic audit shows if it is necessary to change the pumps in an installation to more efficient ones.

It might be changed not only the type of pump (with a type with a better inner hydraulics) but also the number of pumps might be changed considering that a greater number of smaller discharge pumps allow a finer discharge adjustment and consequently a greater efficiency.

III. Lift Pumping Stations Modernization. Case Studies

A. Daeni Irrigation Water Supply Pumping Station

The irrigation water supply pumping station SRP 10 Daeni was designed at the technological level of the 60's. It is equipped with 4 vertical column centrifugal pumps mounted in parallel. The discharge duct is concrete made and its diameter is 800mm.

The discharge is $Q = 1.8\ {m^3}/{h}$ at a total head $H = 59m$. The geodetic head is only $H_g = 37m$ that means the head loss is $h_r = 22m$.

Apart from this huge loss of energy, the pumping installation operates properly only with 4 pumps, as it may be seen in Fig. 8. When three pumps operate in parallel, cavitation is very likely to occur. Therefore the possibilities to vary the discharge are limited.

According to the efficiency of the pumps given in the catalog (and neglecting the wear over time) the specific energy consumption of the pumping installation, *e*, calculated at $1000\ m^3$ is:

$$e = 214.4\ kwh/1000\ m^3$$

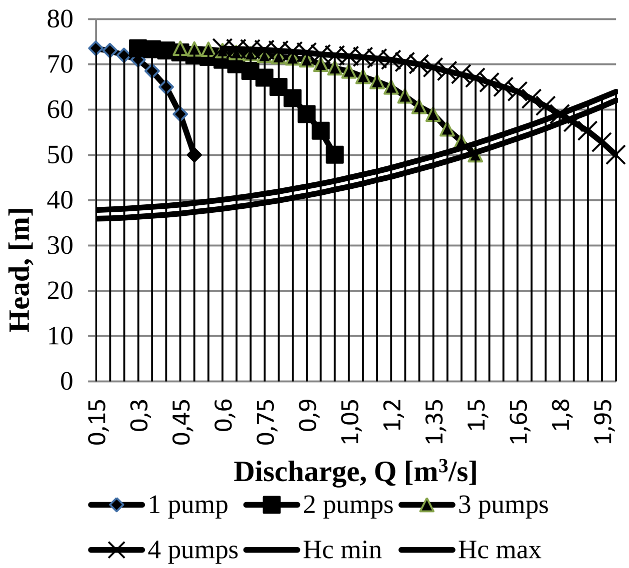

Fig. 8 Duty points for the old pumping station

The study of the transients in this pumping installation shows that pressure may increase up to 245 mwc (meters water column) and cavitation occurs along the duct during water hammer if the duct has no protection equipment. Pressure variation in this case is shown in Fig.9 in four calculus cross sections of the discharge duct: n1, n4, n8, n12.

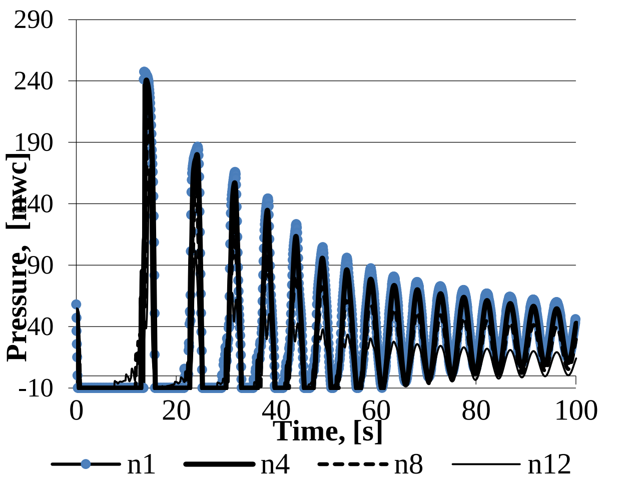

Fig. 9 Pressure variation during water hammer for unprotected discharge duct. Daeni old pumping station

The graphical representation of the pressure was obtained by solving the water hammer equations by using the method of characteristics and finite differences technique [10]. The high total head of the old pumping station is not only a waste of energy, but also involves dangerous extreme values of pressure during the hydraulic shock. On the other hand, head losses lead to a quick dump of pressure oscillation during water hammer [13], as it may be seen in Fig.9.

The proposed solution for improving the energy consumption was to replace the discharge duct with one made of glass reinforced polyester. The hydraulic resistance modulus of the discharge duct decreases from $M = 6.5\, m^{-5}s^2$ to $M' = 3\, m^{-5}s^2$. The inner roughness of the new duct is much smaller than the one of the concrete made duct, so the Moody criterion decreases from $Mo = 643$ to $Mo' = 2.78$, therefore the developed turbulent movement turns into a smooth turbulent one.

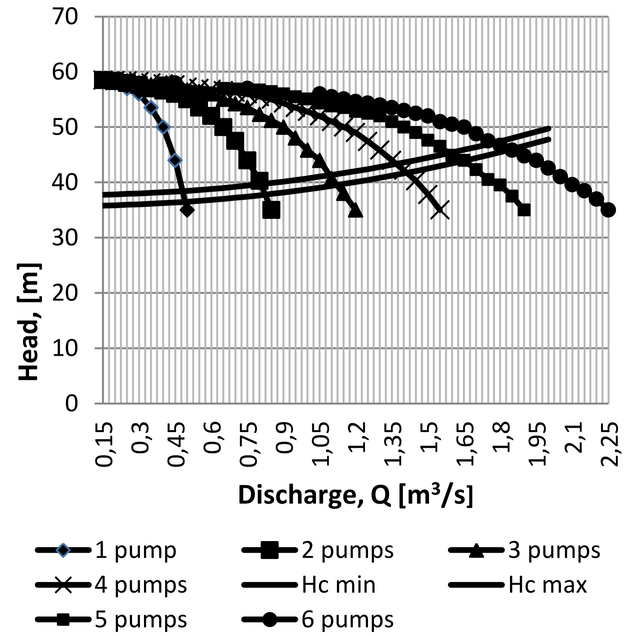

Fig. 10 Duty points for the proposed pumping station

Total head decreases so that the pumps have to be changed also. We proposed the replacement of the old pumps with 6 new ones with smaller head. The duty points of the proposed installation are shown in Fig.10. It may be noticed that any combination of the pumps in the group may properly operate in parallel.

The new discharge is $Q = 1.83\ {m^3}/{h}$ at a total head H=47m

The specific energy consumption decreases to:

$$e' = 171\ kwh/1000\ m^3$$

Table 1 Daeni PS specific energy consumption coefficient, e_{1000}(kwh/1000m^3) for two main duty points

	Duty point	**e_{1000} [kwh/1000m^3]**
Old system	H_{max}=59m; Q=1.8 m³/s	214
New system	H_{min}=47m, Q_p=1.83 m³/s	171
	Saving	**43**

The data referring to energy saving, given in Table 1, were calculated by neglecting the pumps depreciation in time, which means the actual saving is greater than 43 kwh/1000m^3.

The elasticity of the new conduit leads to smaller celerity and, as a consequence, to smaller maximal pressure values during hydraulic shock. The discharge duct still needs protection from water hammer, but this protection may be simply provided by a specific closing law of the check valve on the discharge duct.

Pressure oscillation during water hammer in the old discharge duct (concrete made) protected by a check valve with a two-phases closing law, shown in Fig.11 may be compared with pressure oscillation in the new proposed duct (glass reinforced polyester made) protected by a similar check valve with the same closing law, Fig.12.

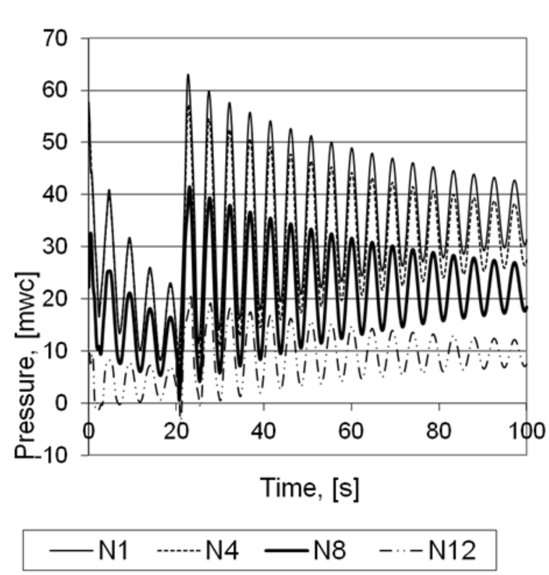

Fig.11 Pressure variation during water hammer for discharge duct protected by check valve with two stages closing law. Old pumping station

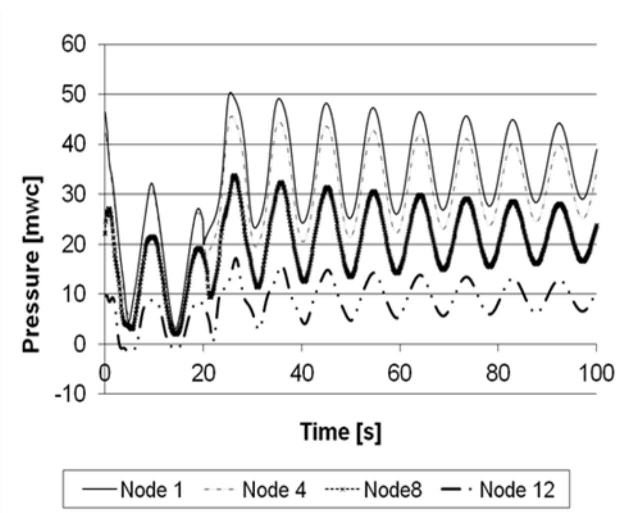

Fig. 12 Pressure variation during water hammer for discharge duct protected by check valve with two stages closing law. Proposed pumping station

Maximal pressure value and the pressure oscillation frequency decrease for the new system.

The proposed modernization measures result not only in energy saving but also in a better response of the system to a hydraulic shock.

B. Galesu Irrigation Water Supply Pumping Station

Galesu is a lift pumping station that takes water from canal CA1 and delivers it through two main discharge ducts of 1000mm in diameter and 900m in length, as it is represented in Fig.9.

SRP Galesu supplies water to a farming region of about 4000 ha.

The geodetic head (static pressure) varies between Hgmin=26m and Hgmax=26,35m

The old pumping installation was equipped with five horizontal centrifugal double flux pumps, type 18 NDS and had the following parameters:

- ✓ discharge flow rate: Q = 3,1m^3/s,
- ✓ head: H = 34 m ,
- ✓ installed power: P = 2215 kW,
- ✓ voltage: 6kV.

The existing station has been operating since 1970. As the pumps deteriorated, the operation and maintenance costs became unacceptable. Thus the pumping station ought to be re-equipped with new pumps and hydraulic equipment. The discharge ducts were in good condition, so it wasn't necessary to replace them.

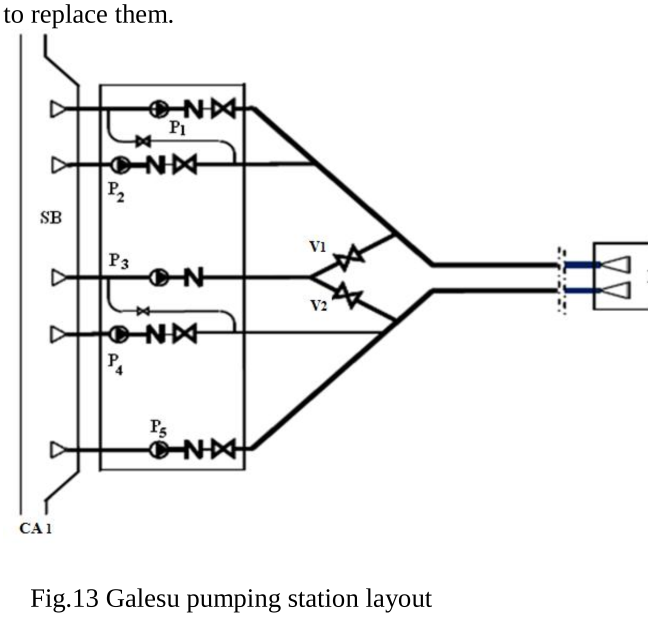

Fig.13 Galesu pumping station layout

Thus, the proposed modernization consists of:

- ➢ Internally worn pumps replacement with five new horizontal centrifugal double flux pumps, with constant rotation speed. The new pumping station has the following parameters:
  - ✓ discharge flow rate: Q = 3,1m^3/s;
  - ✓ head H=34 m;
  - ✓ installed power: P =1575 kW;
  - ✓ rotational speed n=980 rpm;
  - ✓ voltage: U = 6 kv.

- Two more valves mounted on the branches of the middle pump discharge duct, as is is shown in Fig.13.

In the old pumping system, these valves (V_1 and V_2) didn't exist, so the middle pump could deliver water only on both main discharge ducts. The addition of these valves introduces the possibility the middle pump to deliver water on one single main discharge duct. Therefore, a new duty point, for three pumps (including the middle pump) in parallel operation, occurred:

- ✓ $Q=5830m^3/h$;
- ✓ H=37m;
- ✓ η =88%.

It isn't a recommended duty point, but we were aware that it may occur by accident, by an operation mistake. So, a new hydraulic study of the transients should be performed.

Data referring to the efficiency improvement and energy consumption decrease, for the new pumping station in comparison with the old one, are presented in Table 2.

Table 2 Technical parameters for the main duty points. Old and new Galesu PS

Duty point	Parameter	Old system	New system
H_{max}=34m Q=5400 m³/h	η_p (%)	82	89
	P_a (kW)	2215	1575
H_{min}=29m, Q_p=2760m³/h	η_p (%)	73	87
	P_a (kW)	400	315

The results regarding energy saving are gathered in Table 3, where data for the old pumps neglect their depreciation over time.

Table 3 Galesu PS Specific Energy Consumption Coefficient, $e_{1000}(kwh/1000m^3)$ for two duty points

Duty point	Old system	New system	Saving
H_{max}=34m Q=5400 m³/h	113	104	9
H_{min}=29m, Q_p=2760m³/h	108	91	17

Due to the new duty point, numerical simulation was developed using a special elaborated programme which solves the transients' problem by the use of characteristic method and finite differences technique.

In the beginning, there were calculated the extreme values of pressure in the case the ducts have no protection equipment, Fig.14.

Minimal pressure values reach the cavitation limit almost along the entire duct. Maximal pressure, even greater than the regime value, is not dangerous, because the duct's nominal pressure is 10 bars. Therefore, it is necessary to protect the duct from cavitation.

There were searched optimal devices for protection at a low cost. We considered different protection devices in various combinations and the most suitable was the combination of air/vacuum valve protection set and butterfly check valve with two-phase closing law.

The first investigated device was a butterfly check valve with two-phase closing law: 0; 6; 21 s. We noticed a considerable improvement of the extreme values of pressure along the discharge duct. The minimal pressure is reached in a section close to the pump; therefore we introduced an air/vacuum valve in the second calculus node, which is placed 90m downstream the pump. The minimal pressure rises along the duct. In this case, the minimal value of pressure is recorded in the 7th calculus node, about 630 m downstream the pump. A second air/vacuum valve was introduced in the 7th node. The result is that the minimal pressures grow even if they are still negative.

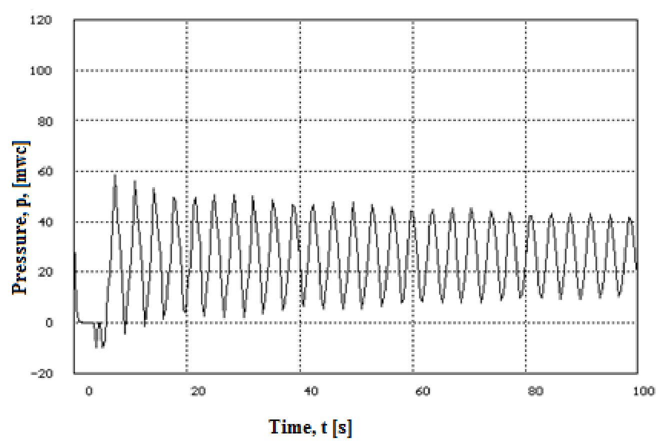

Fig. 14 Pressure variation during water hammer for unprotected discharge ducts. Galesu old pumping station

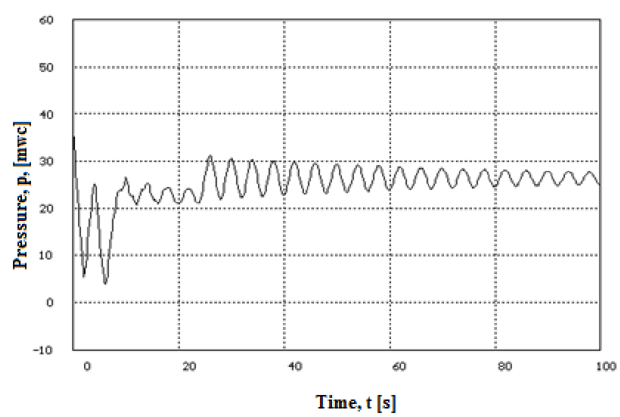

Fig. 15 Pressure variation during water hammer for discharge duct protected by check valve with two stages closing law and air/vacuum valves placed in two different sections. New pumping station

In Fig. 15 there was plotted the pressure variation in the most vulnerable section, close to the pump, in the case the duct is fully protected by the above mentioned combination of devices.

The maximal pressure is only 32mwc. The minimal pressure becomes positive, so the cavitation is no longer a threat.

IV. Conclusion

Existing pumping stations have significant electric energy consumption, not only because of their depreciation but also because they were oversized from the very beginning.

A thorough hydraulic analysis of the pumping system may point out the most appropriate methods to decrease its energy consumption and to increase its efficiency. All or part of the system may be replaced or only adjusted in order to improving both operation and efficiency. The most suitable technical variant of rehabilitation must be chosen on both technical and economic basis.

Pipelines replacement may significantly improve the energy consumption, especially if the new ducts have larger diameter or are made of smother materials. But such a replacement determines a change in the hydraulics of the system; therefore the type of turbulent water movement should be prior determined. A study of the transients is also needed.

The decrease in total head required by the pipeline imposes a pump performance adjustment, which can be achieved by reducing the impeller's diameter or by using, if suitable, a frequency converter to adjust the rotation speed.

Pumps replacement is an expensive investment but it results in significant energy saving during operation, especially in the case of oversized systems. An analysis of the life cycle of an existing pump shows if it's better to change to more efficient pump, which means a comparison between the pump price and its electrical energy expenses, considering a lifetime of 10 years.

Pumps replacement, if properly chosen, may lead to a better operation of the system and to an increased efficiency.

In the presented case studies, the pumps have constant rotation speed. By replacing the existing pumps with a greater number of new pumps with smaller discharge, a better discharge adjustment is possible according to the stakeholder requirement.

The study of transients in this installation showed a decrease of maximal pressure values as the total head decreased and the celerity decreased also due to the properties of the new material the ducts are made of. The decrease of head losses along the pipeline result not only in energy saving but also in a better response of the system to the hydraulic shock.

In both studied cases the specific energy consumption coefficient theoretically indicates a substantial gain, ranging between 9 and 25%. But if we take into account the pumps efficiency depreciation over time due to wear and corrosion, the real gain is much greater.

References

[1] C.E. Brennen- *Hydraulics of Pumps*, Cambridge University Press, 1985
[2] Burchiu,V, Pumping Installations, E.D.P. Bucharest, 1987.
[3] E. Cabrera, A. F. Vela, *Improving Efficiency and reliability in Water Distribution Systems*, Kluwer Academic Publishers, Dordrecht, Nederlands, 1995.
[4] Chaudhry H., Applied hydraulic transients, Van Nostrand Reinhold Company, New York, 1987.
[5] Constantin, A, Niţescu C S, Stănescu M, Hydraulic machinery and pumping stations, Ovidius University Press, Constanţa, 2011.
[6] Hancu, S., Marin, G., Hydraulics. Theory and Application, Vol.1, Ed. Cartea Universitara, Bucharest, 2007.
[7] B.E. Launder and D.B. Spalding, "The numerical computation of turbulent flows", Comput. Meth. Appl. Mech. vol.3,1974, pp. 269-289.
[8] M.N. Maziyah, S.N. Muhammad, S.A. Nurhanim "Simulator of Water Tank Level Control System Using PID-Controll" Proceedings of the 3rd IASME / WSEAS International, Cambridge, UK, Feb 2008
[9] P. Nevriva, St. Ozana, L. Vilimec- "The Finite Difference Method Applied for the Simulation of the Heat Exchangers Dynamics", Proceedings of the 13th WSEAS International Conference on Systems, Wisconsin, USA, 2009, pp.109-114
[10] Popescu, M., Arsenie, D.I., Vlase, P., Applied hydraulic transients for hydropower plants and pumping stations, Aa. Balkema, 2003.
[11] Popescu, M., Hydropower plants and pumping stations –Transient hydraulic operation, Ed. Universitară, 2008.
[12] A. Predin, I.Biluš- "Cavitation Swirl in the Inlet Pipe of the Radial Pump", Proceedings of the 2nd IASME / WSEAS International Conference on Water Resources, Hydraulics & Hydrology, Portoroz, Slovenia, May 15-17, 2007, pp.31-34.
[13] Sanks R L, Pumping Station Design, Butterworth-Heinemann, Boston, 1998.
[14] Stoicuta, O, Nan, MS, Dimitrache, G, Buda, N, Dandea, D.L., Research regarding the use of new systems to control fluid flow in pipelines, WSEAS Transactions on Fluid Mechanics, Issue 3, Vol. 5, 2010.
[15] Streeter, V.L., Wylie, B. E., Hydaulic transients, McGraw – Hill Book Company, New York, 1987.
[16] . P. K. Swamee, A. K. Sharma *Design of Water Supply Pipe Networks*, John Wiley & Sons, Inc., Hoboken New Jersey, 2008.
[17] * * * Manual of Water Supply Practices. PE-Design and Installation, American Water Works Association, Denver, 2005

Anca Constantin was born in Constanta, Romania, in 1959. She graduated in mechanical engineering at The Polytechnic University of Bucharest, Romania, in 1983 and took her PhD degree in hydraulics and fluid mechanics at The Faculty of Civil Engineering, "Ovidius" University, Constanta, in 1998.

She worked as a researcher, and since 1999 she has been teaching at "Ovidius" University, Constanta, The Faculty of Civil Engineering. She published five books and over 60 scientific articles. Her research field is fluid mechanics and applied hydraulics.

Assoc. Prof. Eng. Constantin is a member of The General Association of the Engineers in Romania since 2004, and a member of Romanian Committee for History and Philosophy of Science, since 2010.