Progresses in the operation and functioning of pumping stations for water and wastewater networks

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Abstract

Simultaneously with the social and economical transformations within urban areas, the operating and functioning conditions for all the components of water and wastewater systems have modified in a specific manner in each area. One important aspect of these changes is the adjustment of pumping stations operating parameters to the new water network demands so that the operating costs of these pumping stations achieve a sustainable level for the water companies. In this context, the paper presents the results recorded by upgrading and rehabilitating the pumping stations for an urban water network with a primary goal of diminishing the operation and maintenance costs and a secondary goal of reducing the water losses in the water distribution network.

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1. Introduction

In Romania, the construction of distribution and wastewater systems began as early as the end of the 19th century. Although currently at a national level there are water and wastewater systems in most of the urban areas and partially in the rural areas, not all the population benefits from these features. This fact makes the modernization and expansion

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works of these public utility systems to be in a continuously state of transformation both physically (by extending the service area) and technically (by introducing more performing equipment and materials). At the same time, the adaptation of the water and wastewater systems operating parameters to the needs of the consumers and the sustainability of operation for these systems imposed the technological rehabilitation of all the component elements for a water and wastewater system, so that the operating costs and the energy consumption reach a minimum. Consequently, the technical and technological progress in the industry of equipments an tools used in the water distribution and wastewater collection determined the rethinking of the design, execution, operation and surveillance solutions for all the technological elements comprised in the water and wastewater systems.

2. Pumping stations characteristics in water and wastewater systems operation

The process of pumping water within the operation of water and wastewater systems represents the activity with the highest energy consumption and therefore optimizing energy costs is a continuous and priority task for the operators. Within the existing centralized water and wastewater systems in Romania, the pumping stations share some similar characteristics, such as:

- The pumping groups within the pumping stations are in most part composed of pumps coupled in parallel
- The pumped water volume is variable in the course of the day and differs from one day to the other, depending on random factors or restricted by objective factors (exaggerated consumption, restrictions for pumps operation)
- The daily flow variation is done within a limit of maximum and minimum pressure in the discharge pipes, the pressure being imposed by starting/hauling of pumps
- Pumps were chosen based on nominal flow and head, these values being determined based on approximate data that take into account a specific consumption for every type of consumer

The construction of the pumping stations was done in several steps within the distribution systems because the extension works of the water infrastructure developed based on the urbanization of the localities and based on the water demands which at the end of the 20th century registered very high values (specific consumption of 500 l/day/pers.). At the same time, in the time period in which these pumping stations were designed and built, the quota of energy costs from the total operating costs was relatively low by today tariffs, when the energy price tends to align with the price in other EU countries. A fundamental requirement that pumping station within distribution systems have to accomplish is to ensure a flow variation in correlation with the consumer needs at a constant pressure, and this is done by adjusting the operating parameters of the pumps.

3. Methods of adjusting the pumping stations operating parameter within water and wastewater systems

Depending on the role of the pumping station within the water and wastewater system, on the type of pumps, on the characteristic parameters of the pumps and on the variable consumer demands, the possibilities for pump adjustment can be one of the following:

- External adjustment – changing the network characteristic, but keeping the pump characteristic unchanged
- Internal adjustment – changing the pump characteristic, but keeping the network characteristic unchanged
- Mixed adjustment – simultaneously changing both characteristics (pumps characteristic and network characteristic)
Initially the pumping stations intended to serve the water and wastewater systems in Romania were designed based upon the available technology at the time, where the pumps were actuated by constant speed motors and the adjustment of the operating parameters was sequential. The sequential adjustment involves starting and stopping the pumps based on the pressure variation in the pump station discharge pipe; the pressure variation which is caused by the increase and decrease of demands in the distribution network (see Fig. 1).

Fig. 1. Sequential adjustment for a pumping station when the water consumption is increasing

For such type of operating regime, in order to ensure the necessary pressure within the imposed limits (H_{\text{min}} and H_{\text{max}}), it is noted that as the demand is increasing the pumps are started one by one until the pump station reaches the maximum load (F8). The projection of resulted the duty points in order to reach the desired pressures on the flow axis leads to discrete or sequential variation intervals of the total pumped flow. This particular operating regime generates time periods where the pumped flow is higher than the demanded flow for the consumers, immediately after a pump starts. This phenomenon is similar in operating situations where the demand is decreasing (according to night periods) but in this case the operating sequence stops the pumps and generates periods where the pumped flow is insufficient for the consumer’s demands.[1]

The second widely used type of sequential adjustment for correlating the pumping station operating parameters with the demands of the consumers from the distribution network is by throttling the discharge valve. This adjustment method for the operating parameters of the pumping station is applied in cases where the operating personnel typically have to address certain operating restrictions, such as: avoiding electric motor currents past a certain maximum value and avoiding opening the discharge valves past the limit where cavitation may appear. Figure 2 illustrates an operating sequence for a pumping station composed of two identical pumps with both discharge valves throttled. For the resulted duty point obtained by coupling the two pump characteristics in parallel (Q_{\text{ans}}, H_{\text{ans}}) one can determine the power consumption of the entire pumping station as:

\[
P_u = \rho \cdot g \cdot Q_{\text{ans}} \cdot H_{\text{ans}}
\]  \hspace{1cm} (1)

By rationing the effective power to the sum of the power consumption of the two pumps, the total efficiency of the pumping stations is obtained. This particular result represents the quality factor of the pumping process.

\[
\eta_{\text{ans}} = \frac{P_u}{P_1 + P_2} = \frac{\rho \cdot g \cdot Q_{\text{ans}} \cdot H_{\text{ans}}}{2 \cdot \rho \cdot g \cdot Q_1 \cdot H_1 \cdot \eta_1} = \frac{Q_{\text{ans}} \cdot H_{\text{ans}}}{2 \cdot Q_1 \cdot H_1} = \frac{1}{2 \cdot \eta_1} \cdot \frac{H_{\text{ans}}}{H_{\text{ans}}} = \frac{1}{2 \cdot \eta_1} \cdot \frac{H_1}{H_{\text{ans}}} = \frac{1}{\eta_1} \cdot \frac{H_1}{H_{\text{ans}}}
\]  \hspace{1cm} (2)
The conclusion is that the pumping station efficiency depends on the $H_1/H_{ans}$ ratio. If this value is high, then the pumping station efficiency is low and consequently the energy consumptions are higher and depend on the throttling of the discharge valves. The difference between $H_1$ and $H_{ans}$ represents the dissipated (lost) energy by closing the valves. [2]

This adjustment method of the operating parameters is the simplest to be put in practice because of the low investments, but on the other hand presents a huge disadvantage because of the significant energy losses.

The progresses made in time, as well as the new EU regulations regarding the manufacturing of electrical motors (specifying that starting with 2017 all electrical motors up to 375 kW should be fitted with frequency converters), made it that the concept of variable speed pumps be applied also in the water and wastewater systems. This approach represented an important step in operating the pumping stations, because by modifying the speed the pump is capable of continuously adjusting the pressure in order to optimally adapt itself to the consumer’s demands, at the same time ensuring important economy savings without compromising the operating life time of the pump.

The analysis of such pumping station with four pumps coupled in parallel connection, in which one pump presents variable speed drive and the other three have fixed speed drives, is illustrated in Fig. 3. The goal of this operating sequence is to maintain a constant pressure in the discharge pipe of the pumping station. [3]

One can observe that by varying the speed, the pumping station operates at a constant head and the resulting duty points migrates on the horizontal corresponding with $H = \text{constant}$. The variation of the pumps parameters is done according to the affinity laws. [1], [2] When the variable speed pump reaches the nominal operating parameters, a
second fixed speed pump is started within the pumping station simultaneously with a decreasing of the variable speed. It can be noted that by this particular method, when projecting the duty points on the flow axis, the pumping station is capable to ensure any flow rate within the given interval, without discontinuities in the pumped flow.

4. Progresses in measuring the pumps operating parameters

Being able to measure “in situ” the parameters that characterize the operation of a pumping station is an important leverage, with tremendous implications in knowing the availability level and the operational and maintenance manner of the technological elements within the pumping station. The execution of measurements allows establishing the operational efficiencies of the pumps and the balance sheets for material and energy consumption necessary for the pumping process.

The classical and often used method of measurement for the pumps parameters is based on pressure gauges for pressure measurement and flowmeters for the flow measurement. This method presents a certain degree of incertitude because in order to determine the pump characteristics, for each data acquisition of the duty point a number of parameters must be red and registered simultaneously (flow rate, suction pressure, discharge pressure, power consumption). This fact makes the accuracy of the measurements to presents some errors due to equipment calibration, delayed readings, data transcription and handling etc.

The progress made in this field is the implementation of an integrated system in which all the measured data are red instantaneously and after they can be processed and interpreted against the characteristics presented by the pump manufacturer. Such measuring equipment is the YatesMeter, a system that can directly measure the pump efficiency using the thermodynamic method (see Fig. 4).

![Fig. 4. Thermodynamic method for measuring pump parameters](Image)

The measuring principle is that the pump efficiency is considered to be ratio between the produced energy and the consumed energy $\eta = \frac{E_p}{E_a}$. The difference between the two energies is actually the dissipated energy $E = E_a - E_p$. By measuring the difference in temperature at the suction and discharge sides of the pump we can obtain $\Delta T$. Considering $m$ the mass of pumped water, the heat exchanged by the pump is $mc\Delta T$, therefore the consumed energy is
\[ E_a = E_p + mc\Delta T \]  
\[ (3) \]

and the energy given to the fluid is

\[ E_p = gmH \]  
\[ (4) \]

Taken into consideration relations (3) and (4), the pump efficiency can be stated as following

\[ \eta = \frac{gmH}{gmH + mc\Delta T} \text{ or } \eta = \frac{1}{1 + \frac{c\Delta T}{gH}} \]  
\[ (5) \]

The temperature difference is measured by two temperature sensors and the pump head by the two pressure sensors, installed on the suction and discharge sides of the pump. If this system is supplemented with an additional module for measuring the power consumption \( P_{\text{aux}} \) and the motor efficiency is known (or rather estimated) three important parameters can be obtained \( P, \eta, H \). Taking into consideration the expression for power consumption as \( P = \rho g QH/\eta \) an additional fourth parameter can be then calculated – the flow rate \( Q \). \[ (4) \]

The precision for measuring the pump efficiency by the termodynamic method is significantly better than the classical method using pressure gauges and flowmeters.

5. Case study. Transformations in pumping optimization for high-pressures networks in Tei-Colentina area

The district Tei-Colentina is situated in north-eastern part of Bucharest and it is supplied by a water distribution system that was built in several construction phases based on the occupancy in the area. Simultaneously with construction of apartments blocks, in this particular area begun the construction of water networks capable of ensuring the operating parameters for water supply of 8 and 10 story buildings. Consequently, between 70s and 80s, in separate construction phases, three new pumping stations were built (Teiul Doamnei, Petricani and Lacul Tei) in this district as seen in Fig. 5. Initially, the booster stations Teiul Doamnei and Petricani were designed and built to operate like a classical pumping station, that is taking the water from a battery of reservoirs and pump it in the high pressure distribution system. The pumping station Lacul Tei receives the water directly from the low pressure water network and then discharges the water in the appropriate high pressure area. All of these three pumping stations were equipped with locally manufactured pumps type NDS, DN/TN with fixed speed drive. \[ (5) \]

The operating regime adjustment for these pumping stations was sequential by manually starting/stopping of pumps. This task was accomplished by the local personnel that took into considerations two important factors: the discharge pressure and the water level in the reservoirs. In time, the operating regime of the pumping stations suffered major transformations and their effect was a modification in the operational parameters, in a sense that the actual parameters of the pumping groups were significantly different from the nominal pump parameters and as a consequence the power consumptions were extremely high. \[ (6) \]

The first phase began in early 90s when, due to the new social and economical transformations, the water consumptions decreased. As a consequence the pressure in the low-pressure network begins to increase so the pumping stations Petricani and Teiul Doamnei by-passed the reservoirs and took the water directly from the low-pressure network. In this new operational manner, the pressure from the distribution network (which varied between 15 – 25 mCW) was used by the pumping stations. At first glance this solution appeared to bring some added value, but in reality, because the original pumps parameters were in the vicinity of 360 m³/h nominal flowrate and 60 m head, led to a throttled valve operation so that the discharge pressure will not surpass the maximum admissible pressure in the network (6 bar). The result was that the pumps were working at very low efficiencies and with high energy costs. \[ (6) \]
The second major phase in modifying the operational regime of the pumping stations began as a result of a vast measurement campaign for the pumps operational parameters and it was decided that the existing pumps will be replaced with new variable speed pumps. At the same time, a hydraulic study was conducted in order to understand how the high-pressure distribution networks are behaving and one of the conclusions was the pumping station Petricani should be closed and all the corresponding consumers should be supplied from Teiul Doamnei. So, at the beginning of 2005, all the connections in the initial high-pressure zone were supplied exclusively from the newly refurbished and modernized Teiul Doamnei and Lacul Tei pumping stations.

![Fig. 5. District Tei-Colentina. Localization of the initial three pumping stations and their supply areas](image)

The third and final phase (to date) in optimizing the pumping process for the high-pressure distribution networks in Tei-Colentina district begun as a result of large leaks detection and repairing program. Using an updated version the hydraulic models from the previous phase, the simulations done in January 2013 revealed that the new upgrades for the distribution network can lead to also permanently closing the Lacul Tei pumping station, and this task was accomplished in march 2013. The progresses made by optimizing the three pumping stations from the initial area led to substantial energy savings, as seen in fig. 6. At the same time, the pumped water volume showed a continuously decreasing trend until it reached relatively constant values which proved that the network leakages were significantly diminished (see fig. 7).

6. Conclusions

The pumping stations have an essential role in transportation and distribution of drinking water and also in collection and transportation of wastewater. The progresses made in the technology of pump and electrical motors manufacturing and also the advanced technical solutions from the field of operational parameters measurements, of data acquisition and processing made possible a more efficient pumping process and created new operational possibilities in order to ensure a continuous water supply without producing bursts in the distribution network.

Fitting the pumping stations with variable speed pumps, designing the pumping stations in such a way that no energy losses exits within their perimeter, switching to an automated operation, introducing means of surveillance an
control of the pumps parameters by measurements taken “in situ” are essential elements in order to optimize the operational costs and in particular the energy costs.

![Evolution of energy consumption](image1)

**Fig. 6. Evolution of energy consumption for pumping stations in Tei-Colentina district**

![Evolution of pumped water volume](image2)

**Fig. 7. Evolution of pumped water volume for pumping stations in Tei-Colentina district**

### References

4. ***, Yates Mater – User Manual**
5. A. Anton, S. Perju et al., Măsurători parametri hidroenergetici și analize de rețea la 24 stații de repompare, Hydraulic study, Bucharest, 2003