Considerations on the efficient functioning of the urban water pumping stations

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Abstract. Current urban water systems aim to ensure hydraulic and water quality parameters for all consumers connected to the water distribution network, with the highest possible efficiency. This corresponds to reduce primary energy consumption and a responsible control of drinking water sources in order to supply water to urban areas. Most of the time, a low efficiency of water supply systems is due to the following factors: inefficient operation, poor maintenance, incorrect sizing and unmetered water consumption. This article analyzes the efficiency of the solutions applied in the pumping station as a component part of the water supply systems. The case study focuses on the operation of pumps in water supply systems and presents the analysis of the relationship between water consumption and electricity of a pumping group in an urban water supply system. This paper is a first step in order to obtain global parameters for energy optimization of the urban water system.

1. Introduction
The term of drinking water include water intended for human consumption, which can be: water in its natural or treated form, used for drinking, food preparation or other household purposes or water used as a source in the food industry.

Council Directive 98/83/EC regulates water quality parameters for all the member states of European Union and, at national level Law 458/2002 in actualize form is applied. The water quality indicators that are monitored are: physical indicators, chemical indicators, biological indicators, bacteriological indicators.

The term Urban Water System (UWS) defines all the systems that serve a city in terms of water. UWS consists of a number of subsystems (figure 1):
- Urban Water Supply System, which have the role of capturing and transporting water from the source to the treatment area;
- Urban Water Purification System, which have the role of treating water for drinking;
- Urban Distribution System, having the role of supplying consumers with water, it is often the largest and most complex component of UWS;
- Urban Water Draining System, which has the role of collecting waste water and treating it;
- Urban River System, which is composed of all the drainage basins that flow through an urban area [1].
- Our research has focused on the Urban Water Supply System and Urban Distribution System, where the main energy consumers are pumps.
2. Research methodology on pump efficiency

This research was made by consulting various online data-bases (Science Direct, IEEE, Springer Link, Google Scholar and other on-line sources) using a predefine search algorithm. For an increased accuracy the scientific literature was filter based on research title, keywords, year of publication and subject areas to determine the relevancy of the sampled research.

Water Energy Nexus (WEN) concept is the best way to understand the relationship between water and energy. This concept is an important factor in the present urban development and for the future developments. In the last three years WEN has been studied in order to understand and to increase the UWS global efficiency.

According to Lam et al. [2] the most important consumers of the UWS are the pumping stations and therefore it is an important task to increase their energy efficiency. The study was conducted on a population of around 170 million persons which live in 30 major cities.

Blinco et al. [3] propose an optimization strategy based on dynamic-level-feedback-control approach to increase the efficiency of a studied tow stage pumping system. A large amount of energy is being used for water pumping in UWS. The energy cost for water suppliers in a municipal area is 65% of their total operating costs. A 7% energy reduction can be obtained by optimizing the driven energy and driven cost for a tow stage pumping system with uncertain water demand for a better reliability, durability and economy.

Another approach on pump efficiency can be made by controlling the pumps speed to be closer as possible to the best efficiency point (BEP). The ideal case is when the pressure demand and water flow are delivered with the minimum energy consumption. The manufacturers are providing the efficiency characteristic and the performance of each pump type [4].

Supervisory Control and Data Acquisition (SCADA) are complex systems that help control an UWS. These systems are complex and need constant maintenance and investments. Salomons et al. [5] present a simple and practical methodology for real time pumping scheduling without computation hardware. This methodology can be deployed on the pumping stations standard hardwear for reducing the operation cost and the energy consumption.

Considering the rewired studies, this was the motivation to monitor the electric energy consumption of pump systems and to establish the ways for improving the efficiency of this system.

The case study was conducted using gathered data from a part of Brasov’s UWS that cover an area of 0.4 km² in which the drinking water is being pumped to the consumers. We propose to manage the measurement of the hourly electrical energy consumption of the pumping station for a period of 30 days, for 1 January to 31 January 2020, and to analyze the pumps consumption, pump efficiency and system reliability.
2.1. Centrifugal pumps efficiency

Hydraulic machines are technical systems that transform mechanical energy and hydraulic energy in both directions depending on the application. Hydrodynamic pumps, such as centrifugal pumps, are machines in which the mechanical energy is converted in hydraulic energy, using an impeller which interacts with the working fluid. The energy received by the fluid from the impeller is in the form of kinetic energy and potential pressure energy [6].

Centrifugal pumps are widespread in areas such as: water industry, sewage, agriculture industry and petroleum industry. The main advantages of this constructive type are: reliability, simple engineering, ability to transport high flows and low maintenance.

The mathematical relation mechanical power which converted in hydraulic power. ns (1) and (2) define the hydraulic energy $E_h$ and power $P_h$ for a centrifugal pump:

$$E_h = \rho \cdot g \cdot V \cdot H \quad (1)$$
$$P_h = \rho \cdot g \cdot Q \cdot H \quad (2)$$

where: $\rho$ - fluid density, $g$ - gravitational acceleration, $V$ - water volume, $H$ - pumped head in m, and $Q$ - water flow in m$^3$/s.

If the power needed for supply the electric motor of the pump is $P_e$ and the efficiency of the motor in $\eta_e$, a relationship for the efficiency of the pump results:

$$\eta_p = \frac{P_h}{P_e} = \frac{P_m \cdot \eta_m}{P_e} = \eta_h \cdot \eta_e \quad (3)$$

where $\eta_p$ is the pump efficiency and $P_m$ is the mechanical power, which is converted in hydraulic power.

There are empirical relations which describe the average pump efficiency in relation with fluid flow $Q$, as those proposed by Araceli Martin-Candilejo et al. in [7]:

$$\eta_p = 0.1286 \cdot \ln(2.047 \cdot \ln Q - 1.7951) + 0.5471 \quad (4)$$

where: $Q$ is fluid flow in l/s.

2.2. Ways for pump efficiency optimization

One important step is to increase the efficiency of the motor. Nowadays, electric motors used for drive the pumps are of efficiency series E3 even E4, of high efficiency.

Another important step is to optimize the operational schedule. The most frequently method that is been used to operate the pumping station is by using the feedback control strategies such as pressure or water level monitoring. Using a water level monitoring system, the pumps are being turn on/off according to a predefined water level in the storage area.

Another method that is commonly used in pumping stations operation is by scheduling the functioning program. Due to the constantly changing water behavior of the consumers and the complexity of the system, the scheduling control approaches is more challenging [8].

3. Case study

The case study was conducted using gathered data from a part of Brasov’UWS that cover an area of 0.4 km$^2$ in which the drinking water is being pumped to the consumers.

This part of the city was manly an industrial area, but in the last five years the area is being constantly changing and evolving, a lot of new buildings are being constructed.

The pumping station is equipped with multistage centrifugal pumps with a nominal flow of 64 m$^3$/h and a maximum flow of 85 m$^3$/h. The maximum operating pressure is 16 bar.

The current system was designed for a required flow $Q_r = 193$ m$^3$/h, at a pressure of $P=4$ bar. As urban areas are constantly evolving, the system was design with the possibility to add two more pumps to ensure water flow in the future.
### 3.1. Pump system

The studied pumps are vertical multistage centrifugal type with the suction side and the pressure side in line. These pumps have a cast iron base with three impellers and two reduced diameter impellers made of stainless steel. The net weight of a pump is 179 kg.

For a safe operation is recommended to not exceed the Ambiental temperature of 60°C. Every pump is driven by a three-phase 2 poles motor rated at 28 A, 380V. The starting current can vary between 660% and 780%. In table 1, the electrical characteristics according to the producer are shown.

According to the producer $\eta_p$ is between 60 - 80% and is directly influenced by $Q$ and $H$. BEP is obtain at $Q_{BEP} = 65.6$ and $H_{BEP} = 55.5$. The pump performance curves are represented in figure 2.

### Table 1. Pumps - electrical motor data [9].

| Parameter                  | Value       |
|----------------------------|-------------|
| Rated power:               | 15 kW       |
| Main frequency:            | 50 Hz       |
| Power factor:              | 0.89-0.87   |
| Number of poles:           | 2           |
| Rated speed:               | 2930 - 2950 rpm |
| Rated full-load torque:    | 49 Nm       |
| Efficiency according to IE3| 91.9%       |

### Figure 2. Pump performance curves [10].

#### 3.2. Measuring data

We manage to measure the hourly electrical energy consumption of the pumping station for a period of 30 days, for 1 January to 31 January 2020. A total of 744 values were measured according to a predefined interval of 60 minutes starting with 0 hours of each day.

Figure 3 represents the hourly electrical energy consumption of the studied pumps that is directly related to the water consumption.
Figure 3. Hourly electrical consumption.

Figure 4 represents the daily electrical energy consumption of the studied pumps that is also directly related to the water consumption.

![Pumps hourly electrical consumption](image)

**Figure 3.** Hourly electrical consumption.

3.3. Data proceeding

The analysis of hourly measurement data (figure 1) has shown a maximum hourly consumption was $E_{\text{max}} = 21 \text{ kWh/h}$. This value was reached on 08.01, 09.01, 15.01 and 20.01. On 20.01.2020, the maximum hourly consumption for both days 21 and 22 was also reached. These measured values of consumption peaks are obtained in the second part of the day.

The minimum electric energy consumption value of $E_{\text{min}} = 14 \text{ kWh/h}$ was recorded on 28.01 and 31.01. Unlike the peak consumption which is obtained in the evening, the minimum consumption is realized in the morning.

The average hourly consumption for January 2020 was $E_{\text{av}} = 17.6 \text{ kWh/h}$.

Analyzing the daily electrical consumption (figure 4), we manage to identify the minimum and maximum consumption. The daily peak consumption of $E_{\text{max}} = 455 \text{ kWh/day}$ was measured on 09.01, the same day with the maximum hourly consumption.

The minimum consumption was recorded in 01.01, and was $E_{\text{min}} = 385 \text{ kWh/day}$.

For establish the correlation between the electric energy consumption and water flow, the relation (4) is applied. Figure 5 represents the pumps efficiency for the maximum and minimum daily consumption.

![Pumps daily electrical consumption](image)

**Figure 4.** Daily electrical consumption
The obtained overall efficiency of the pumps was between $\eta_{\text{min}} = 64.8\%$ and $\eta_{\text{max}} = 67.73\%$. The average efficiency for the maximum consumption day (09.01.2020) was $\eta_{\text{av}} = 66.7\%$.

According to performance curves at nominal point the global efficiency is around 80% [10] but we obtain an average efficiency of 66.7% which means the pumps are working far from BEP.

4. Conclusions
During the analyzed period, water consumption was $V = 20743$ m$^3$ and the electrical energy consumption was $E = 13116$ kWh, which correspond to a specific energy consumption: $E_s = 0.63$ kWh/m$^3$. This is an important indicator of the efficiency and will be monitored in the future research to find tools and methods of its reduction.

Following the analysis of hourly consumption, it was observed that the consumption peaks are in the second part of the day, between 21.00-22.00, and the minimum hourly consumptions in the morning, in period 3.00-5.00. This type of water consumption behavior is characterizing for domestic consumers, which means the studied area served is mainly a residential area.

Measures proposed for increasing the pumps efficiency should be: operate the pumps according to a well-established schedule, so that the motors have the maximum efficiency; decrease the hydraulic losses from the intake and discharge pipes; regular maintenance, and worn parts replacement.

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