ENERGY EFFICIENCY APPROACH OF THE CLEAR WATER SYSTEMS REHABILITATION

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The paper aim to demonstrate the actual challenging facing the municipal companies in the last years, taking into account the consumers behavior and composition, and the costs trends. The work emphases the new ways that should be adopted in the pumping network design rehabilitation consistent to the classical design methods. In the same time, this approach represents a new stage for the effectiveness of pumping networks design. The paper offers two categories of results: (1) general result, consisting in the elaboration of a practical method for the water networks rehabilitation design; (2) particular result, consisting in applying the method for a concrete situation.

Lucrarea doreşte să demonstreze noile probleme cărora trebuie să le facă faţă companiile de utilităţi municipale în ultimii ani, ţinând cont de comportarea şi structura actuală a consumatorilor. Lucrarea evidenţiază noile căi de abordare a reabilitării reţelelor de alimentări cu apă, considerând şi metodele clasice. În acelaşi timp, această nouă abordare reprezină o treaptă superioară a eficientizării proiectării sistemelor de pompare. Lucrarea oferă două categorii de rezultate: (1) rezultatul general constă în prezentarea unei metode practice evidenţiere a efectelor economice şi funcţionale.(2) rezultatul particular constă în alicarea concretă a metodei pentru un oraş real.

Key words: pumping system, consumers behavior, energy efficiency

1. Introduction

In Romania, like in other East European countries, the water municipal networks are facing the necessities of rehabilitation in order to respond to the new structure and the new behavior of consumers. Another problem is the poor efficiency of the pumping stations and other elements of the network, especially caused by the old conception and components. The authors aim to elaborate a method balancing the technical and financial aspects, considering the practical situation in a representative city of Romania. The numerical example supporting the presentation analyzes the technical aspects and offers general information on the financial ones.

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2. Identification of high energy inadequate consumptions

2.1. Water supply network presentation

The application is considered relevant for a Romanian medium sized city. The actual municipal network was designed and realized in different stages, beginning with more than one hundred years ago and modernized twenty years ago. The city has with about 180,000 people supplied by a well developed network system. The average consumption per inhabitant is about 275 l/inh.day. The network characteristics are: *a. Raw water.* Raw water source for drinking water is a river situated near the city, and the intake point is a few meters below the water surface before the weir. The main problem with regard to the water quality is the amount of suspended solids in the water, sometime causing a rise in turbidity up to 2,000 NTU or more. The system has two water treatments plants, nominated as WTPI and WTP2. *b. Water treatment plant I.* In Fig. 1, a scheme of WTPI is shown. WTPI has three pumping stage, of which the characteristics are shown in Table no. 1. WTPI has a total production of 1,300 m^3/h [1]. *c. Water treatment plant II.* In Fig. 2, a scheme of WTPI is shown. WTPI has three pumping stages, of which the characteristics are shown in Table no. 2. WTPII has a total production of 4,320 m^3/h. The filters are backwashed with water taken from filtrated storage space. The raw water pumps are adjusted manually to achieve the same flow as the clear water flow. *d. Distribution system.* From WTPI and WTPII, four different pressure groups feed different parts of the city, nominated as Zone II South (IIS), Zone II North (IIN), Zone Three (III) and Zone Four (IV), supplied by five pressures zones, which characteristics are summarized in Table no. 3. The reservoirs in different zones can only be used partially for distribution and almost 50% for fire fighting. The re-pumping stations characteristics are presented in Table no. 4. *e. Operational and distribution system.* The distribution system is operating manually. To avoid operations on one pump, the pumps of RPS-WTPI and II are running at a constant flow. [2].

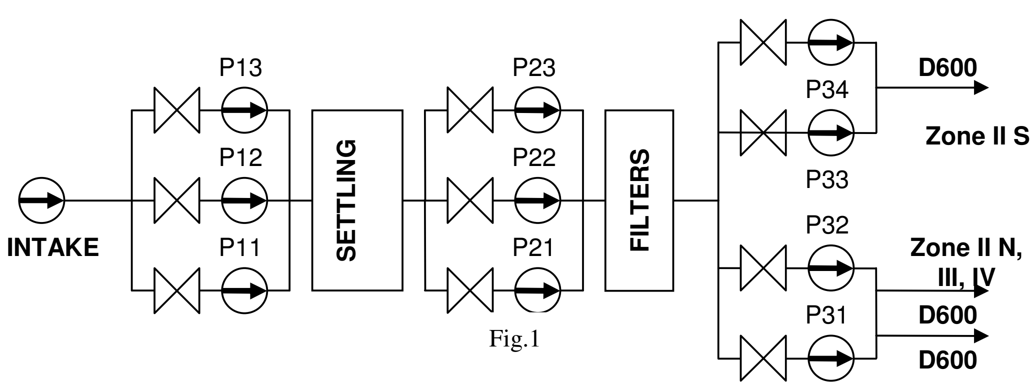

Fig.1

Table no. 1

Storage Pumpcode	Pump characteristics							
	Q (m^3/h)	H (m)	P (kW)	U (kV)	No. of pump		Power (kW)	
					Active	Spare	Installed	Active
I (raw water)								
P11/P12	1,260	20	100	0,4	1	1	200	100
P13	200	20	30	0,4	1	-	30	30
II (settled water)								
P21/P22	1,260	20	100	0,4	1	1	200	100
P23	200	20	30	0,4	1	-	30	30
III (final)								
P13/P32	200	100	100	0,4	1	1	200	100
P33/P34	1,260	62	250	0,4	1	1	500	250
Total WTPI								
	1,460						1,160	610

Table no.2

Storage Pumpcode	Pump characteristics							
	Q (m^3/h)	H (m)	P (kW)	U (kV)	No. of pump		Power (kW)	
					Active	Spare	Installed	Active
I (raw water)								
P1	900	21	75	0,4	3	1	300	225
III (clear water)								
P2	900	62	250	6	3	1	1,000	750
Total WTPI								
	1,460						1,300	975

Table no.3

Pressure zone no.	Consumption (% of total)	Level difference (m)	Reservoir volume (m^3)		
			Total	Fire reserve	Storage
Zone I	71,8 [1]	313-330	12,900	5,400	7,500
Zone IIS	19,9	330-360	5,000	2,500	2,500
Zone IIN	7,6	330-360	2,500	900	1,100
Zone III	0,8	360-390	1,000	450	550
Zone IV	0,0	390-420	200	90	110

[1]) including the amount o water delivered to other consumers outside the city

Table no. 4

Pumping station	Pump characteristics							
	Q (m^3/h)	H (m)	P (kW)	U (kV)	No. of pump		Power (kW)	
					Active	Spare	Installed	Active
RSP-IIS	260	46	37	0,4	4	1	185	148
RSP-IIN	140	60	37	0,4	2	0	74	74
RSP-III	60	78	22	0,4	1	1	44	22
RSP-IV	15	140	13	0,4	1	1	26	13
Total							329	257

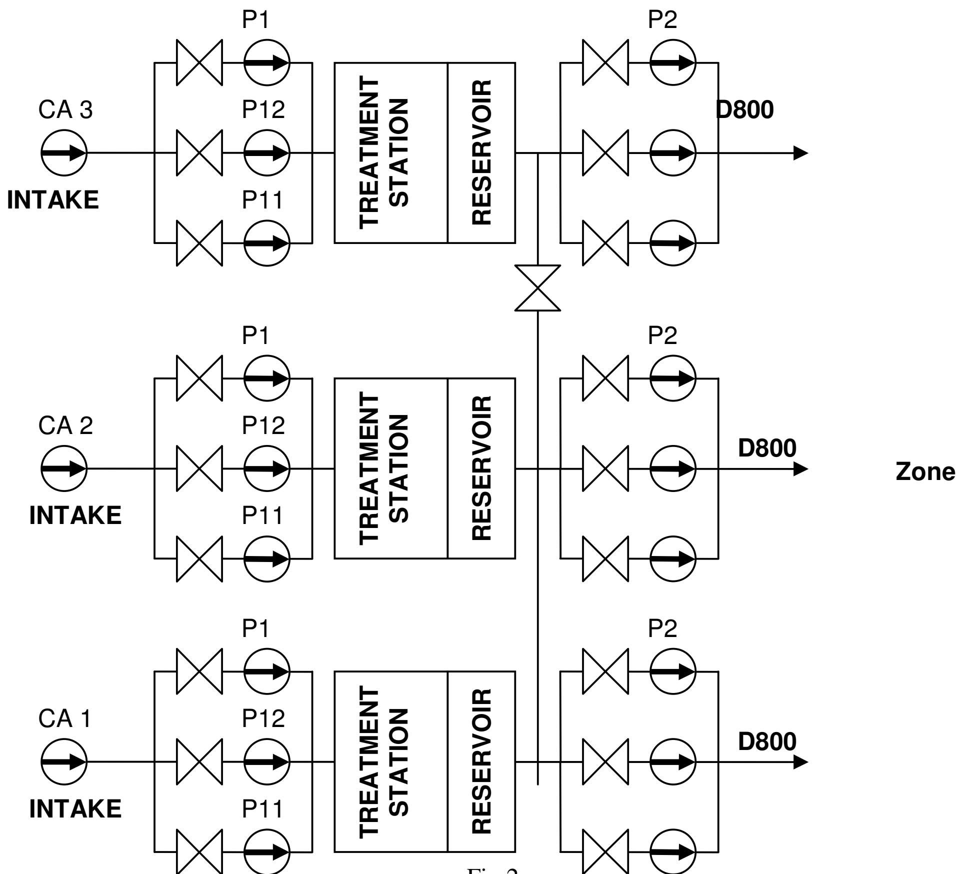

Fig.2

2.2. Summary of the main deficiencies of the network

Main sources of energy losses. The high energy consumption is caused by the following main problems: the high losses of water within the network (water that is pumped and lost again is apart from the lost water also an unnecessary loss of energy); the low efficiency of the used pumps (total efficiency of the pumps and motors is calculated by measurements and represent about 49.5%); the lack of automation that forced the operators to maintain a more or less steady state situation on the pumping station, which is not the most efficient solution; the small amount of storage available in the network.

Problems in the water system network. The water systems are designed based on the consumers' conditions and the topological situation. From the beginning or during the operation, the systems have specific problems of maintenance and operation. There are some concrete problems facing the city network selected for application example: between the zones IIS and IIN there is a district very dens populated and situated on some hills; than the district has the lowest pressure; almost all the apartments in the city are connected to the boiler houses of the city, which are metering and re-pumping the water, but the trend is to use individual boilers for each apartment; almost of the equipment of the boilers houses is old and malfunctioning due to lack of adequate maintenance.

3. Identification of the energy saving solutions

3.1. Water consumption

The drinking water tariff has been subjected to a high increase during the last ten years. The caused are: lack of subsidies from the government and the increase of the energy costs. Do to this increasing tariff, and the fact that about 70% of the consumers is metered, the consumption per capita per day is decreasing every year. The technical losses (backwash water for the filters and others) are estimated to app. 3.5% of the intake. In table no.5 is presented the average monthly production of clear water for the last five years.

Table no. 5

Month	Production (m^3)	Billed (m^3)	Losses (m^3)	Losses (%)
January	2,930,000	2,256,000	674,000	23,0
February	2.580,200	2,247,200	333,000	12,9
March	2,899,200	2,188,800	710,400	24,5
April	2,849,700	2,191,000	658,700	23,1
May	2,892,900	2,279,400	613,500	21,2
June	2,725,300	2,366,100	359,200	13,2
July	2,803,200	2,164,200	639,000	22,8
August	2,906,500	2,079,700	826,800	28,4
Sepember	2,834,500	2,232,700	601,800	21,2
October	2,971,300	2,364,100	607,200	20,4
November	2,923,900	2,049,800	874,100	29,9
December	3,020,100	2,146,100	874,000	28,9
Total	**34,336,800**	**26,565,100**	**7,771,700**	**22,6**

The hour by hour consumption pattern can be derived from the data collected in the logbooks of the production plant. This data is transmitted by radio from several reservoirs and pumping stations in the city. The flow of WTPI is "calculated" from the capacities of the pumps. [3].

3.2. Energy consumption

The energy consumption of the treatment plant makes out 41% of the total costs for water production, as following: water treatment plant - 14,974,600 kWh, booster station -1,754,740 kWh, pumping station -1,229,296 kWh, other small installations -513,740 kWh.

The energy consumption of the treatment plan is approximated on some measures during three days, at March 5th, 6th and 7th, in the year 2007. For each of the three pumps, has been measured the amperage every hour from the ammeters in the electric room. The flow of the pumps working together was measured. The position of the valves was estimated. The outgoing pressure of the pumps and of the discharge pipes of the *Φ=800 mm.* The total consumed power, considering negligible the reactive current [3] is

$$P_{el} = \sqrt{3}U \cdot I \tag{1}$$

where: U: applied voltage; I: measured amperage.
For the flow estimation is considered the absorbed power of the pumps is

$$P_a = \frac{\rho \cdot g \cdot Q \cdot H(Q)}{\eta_P(Q)} \tag{2}$$

where: ρ: densitatea fluidului $\left(\rho = 1{,}000 kg/m^3\right)$; g: accelerația gravitațională $\left(g = 9.81 m/s^2\right)$; Q: debitul curent of the pumps; *H(Q)*: sarcina la dbitul curent; $\eta_P(Q)$: randamentul pompei la debitul curent, then

$$P_{h1} = \frac{\cdot g \cdot Q_1 \cdot H_1 \cdot 2.275}{1.000 \cdot \eta_P(Q)} \tag{3}$$

$$Q_1 = \frac{P_{a1} \cdot \eta_P \cdot 1.000}{H_1 \cdot 2.725} \tag{4}$$

where: P_{h1}: puterea absorbită de o singură pompa; Q_1: debitul curent of a pump. Combined with the total flow

$$Q = Q_1 + Q_2 + Q_3 \tag{5}$$

$$Q = \left(\frac{P_1}{H_1} + \frac{P_2}{H_2} + \frac{P_3}{H_3}\right) \cdot \frac{\eta \cdot 1{,}000}{2{,}725} \tag{6}$$

The pumps efficiency is estimated with the relation

$$\eta = \frac{Q \cdot 2{,}725}{1{,}000\left(\frac{P_1}{H_1} + \frac{P_2}{H_2} + \frac{P_3}{H_3}\right)} \tag{7}$$

Specific energy consumption. The average specific energy consumption at local level is 0.44kWh/m^3. The trend is to increase this indicator in absence of any investment. At Western European countries level, the specific energy consumption is about 0.040 – 0.080 kWh/m^3. The specific energy consumption was measured directly with an ammeter during mentioned three days, at March 5th, 6th and 7th. According to these measurements, the energy consumption of the three pumps at FPS-WTPII during 24 hours is 19,122 kWh, and the specific energy consumption is amounted to 0.30 kWh/m^3. For the FPS-WTPSII, the total energy consumption is 6,979,530 kWh in the same period of time.

Clear water cost. The clear water cost is the total of different expenses, of which the energy cost represent the most important part. These expenses are: energy – 42%; different materials – 5%; chemicals – 11%; raw water – 5%; administration – 7%; taxes – 4%; overhead – 1%; wages – 13%; maintenance – 5%; gas – 1%; transport – 3%; depreciation – 2%; others – 1%.

4. Identification of the effect of energy saving solutions

4.1. The effect of improving the of pumps and motors efficiency

The largest quantity of energy is consumed by the pumping station, depending on three factors: pumps, motors and distribution system. With regard to the distribution situation, there are three main problems causing the high energy consumption: high losses of water in the network, lack of automatization and small amount of storage.

Theoretical, the daily energy consumption can be computed with the relation

$$E = \sum_{Q=Q_{\min}}^{Q=Q_{\max}} P(Q) \cdot T \cdot \rho \cdot g \cdot H(Q) \cdot Q \cdot \frac{1}{\eta_P(Q)} \cdot \frac{1}{\eta_{el}(P_{as})} \tag{8}$$

where: E: energy consumption during T; P: probability of occurency of flow Q; T : time for which energy consumption is calculated; ρ : specific mass coeficient; g: accelerația gravitațională; $H(Q)$: head at the soecific moment; Q: flow; $\eta_P(Q)$: pump efficiency at the momental flow; $\eta_{el}(P_{as})$: efficiency of the electric motor at the current power; P_{as}: consumed power by the electric motor.

From the measurements with the ammeters of the motors, the efficiency of the opereting pumps could be estimated, asuming a reactive current of 0 Amps, and the efficiency of the motors of 90%. An efficiency for the pumps is estimated to 55%, at the working point. In table no. 6 is summarized the effect of replacement of pumps, motors, both pumps and motors.

Tabel no. 6

Replacement options	**Estimated maximum savings of energy**	
	(%)	(kWh/y)
Pump replacement	35	2,444,000
Motor replacement	6	419,000
Motor and pump replacement	39	2,722,000

4.2. The effect of reducing the water losses

Water losses within the network. It is obvious from the table no. 5 that the difference between production and billed water is important, representing about 23%. The water losses reduction can be realized with important structural investments.

Automatization of the process control. Presently, the pumps operation is manually made. Adjusting the pumps function automatically and using variable speed motors, the losses could be reduced with cca. 24%.

5. Final evaluation and conclusions

Table no. 6, are summarized the estimated rehabilitation effects.

Table no. 6

Option	Estimated maximum savings of energy	
	(%)	(kWh/y)
Reduction of water loss with 5%	5	749,000
Pump replacement	35	2,444,000
Motor replacement	6	419,000
Improved process control (FC's)	24	2,722,000

The conclusions that can be drowning are:

Replacement of the four pumps and motors that are operating in the current situation and application of frequency converters (or motors with variable speed) will lead to a maximum reduction of 54% of the current use of electric energy.

All motors could be equipped with variable speed motors or one per station.

An alternative solution is to replace the reservoirs in order to increase the flexibility of the stations operation.

When friction losses are not very high, the difference between indirect and direct distribution with regard to energy reduction is of no significance. The static head loss is independent of the flow, and therefore equal whether the water is first pumped to a reservoir or directly pumped to the consumer. When the reservoir is behind the network, direct distribution is most energy-efficient method because the friction losses are minimized (with a reservoir.

Redesign of the network produce changing in the capacity and head of the pumps, then the power of motors have to be selected after the final results of the pipes computation.

R E F E R E N CE S

[1]. *Mircea Grigoriu*, Using water pumps and their selection, PhD Thesis, University Politehnica Bucharest, 1984.

[2]. *Mircea Grigoriu*, Pumps and pumping stations, Ed.Printech, Bucharest, 2006.

[3]. *Dan Robescu, Mircea Grigoriu*, Pumps, Compressors, Fans, Ed.UPB, 1995.