WATER DISTRIBUTION NETWORK DESIGN BASED ON NUMERICAL SIMULATION IN EPANET

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Abstract

Water supply in rural area supposes a rigorous design of water distribution network, in good compliance with the goals of sustainable development. EPANET programme is a reliable tool for the hydraulic analysis of a water distribution network, therefore we used it in order to optimize the technical parameters of water network from Tariverde, Constanta County and to identify the possibilities of adjusting this network in accordance to the future increased water need. Tariverde is a small village of 2500 inhabitants, with a large variation of the water demand during a day time.

Numerical simulation of this hydraulic system, for different operation scenarios, allowed us to identify the ducts where the velocity is out of technical design regulations, and to recommend specific pumping method using constant or variable speed pumps, aiming to save electric energy and consequently to decrease the water price. Considering the same pattern for the demand flow rate, the use of variable speed pumps leads to consistent energy saving.

Key words

efficiency; numerical simulation; variable speed pump; water supply network

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1 INTRODUCTION

Water and energy efficiency as well as a rational resource management should be deeply embedded in our society [1]. As one of the most important goals of the society is the sustainable development, water and energy efficiency has been paid more and more attention in all aspects of the human life. Water utilities in either urban or rural area have to implement a wide range of cost–efficient operation methods and leakage monitoring technologies in order to reduce water price and to mitigate the non-revenue water.

Zdor and Sinistyn show in [2] that eliminating over pressure in the water distributing network, energy consumption may decrease by 15–20 % depending on the over pressure fixed level.

The strategy for drinking water supply has to ensure a high water quality at an affordable price, reliable networks which can be adapted to an increased demand and new technologies.

In order to comply with these goals, drinking water quality and cost can be improved by a rigorous design and accurate execution of the hydraulic system composed of pumps and distribution network. Specialized software, such as InfoWorks HS or EPANET have been released as powerful and rapid tools for design and operation analysis of water supply hydraulic systems. Our comprehensive study focused on a small rural water distribution system aiming to assess the hydraulic parameters in different operation alternatives and to determine by numerical simulation in EPANET the most appropriate and energy efficient pumping method. Therefore, an EPANET conventional model was developed for Tariverde village. In the future, the knowledge offered by such a conventional model, may be used to produce near optimal data for on-line control settings [3].

2 DRINKING WATER DISTRIBUTION NETWORK IN TARIVERDE VILLAGE

Tariverde is a small village in the northern part of Constanta County. The water supply network was built for 2500 inhabitants, figure estimated for the year 2020. The network pipes follow the main streets of the settlement, as it is shown in Fig.1.

The scheme is drown in EPANET-2, a specialized software released by United States Environmental Protection Agency. Its high accuracy in modeling simple networks with relatively flat terrains is mentioned in [4]. This computer programme regards a network as an assembly of links and junctions. The water demand is concentrated in nodes. A link, that means a pipe or a pump, connects two nodes (junctions).

Elevations of the nodes are in the range 41.13m in node N 17 and 66.72m in node N 5. The node N16 has also a high elevation, of 65.96m. The pipelines are HDPE made. The network is a low pressure one, supplied by a group of two pumps ***P*** mounted in parallel, which take water from the reservoir ***R***, Fig. 1. Underground water sources supply the reservoir R and the pumps deliver water directly in the network. The lower nodes are N 17 and N 20, with an elevation of 41.13 m and, respectively 41.84m.

The design discharge is 15.04 l/s which represents 12% of the maximal water demand during a day. A high variation of the water demand during a day is specific for a rural settlement. According to Romanian regulations [5], the standard hourly water demand variation comprises thirteen discharge values which should be provided by the pumping station.

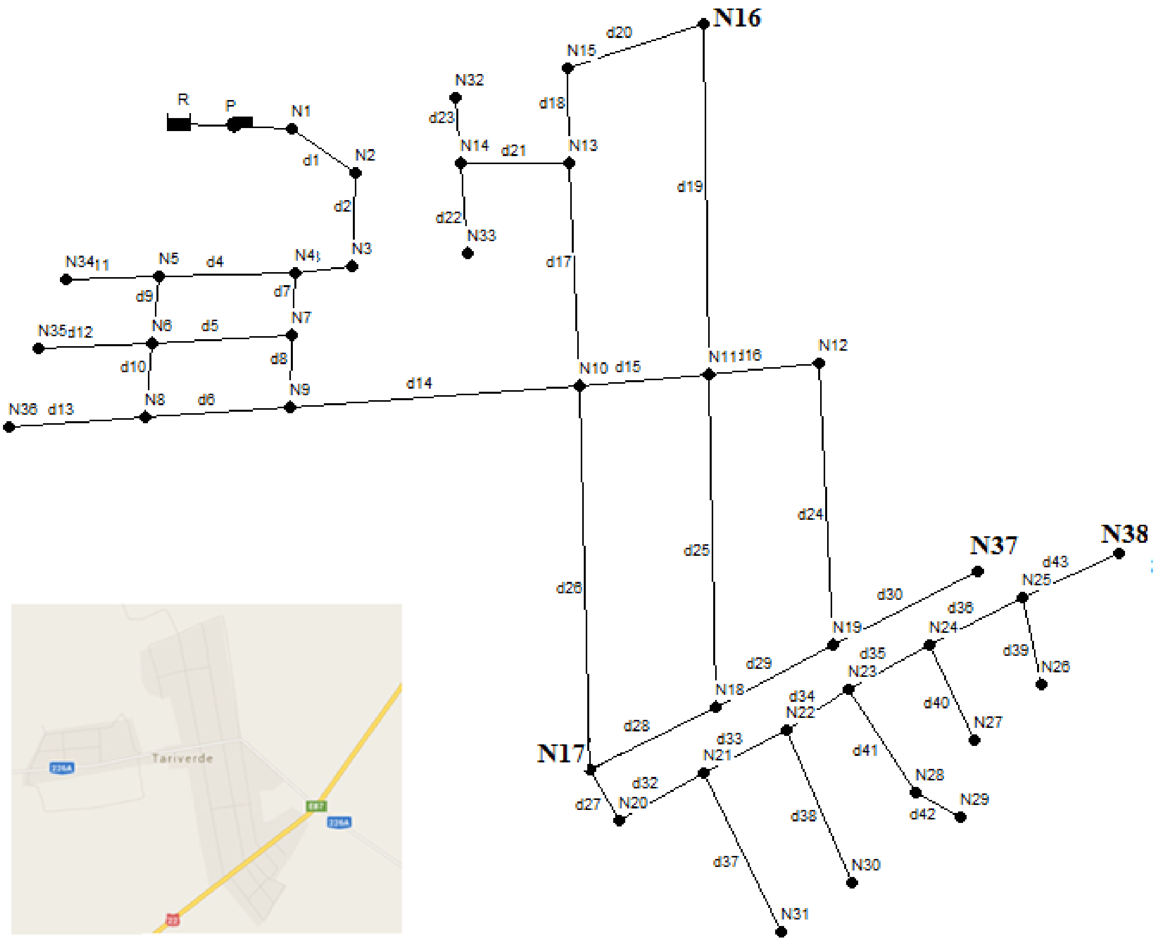

Fig. 1: Layout of Tariverde water supply network

3 SIMULATION OF WATER DISTRIBUTION NETWORK OPERATION

The flexibility of EPANET software allowed us to simulate different variants for the network operation, changing the number or the type of pumps, but maintaining the same standard pattern for the water demand over a day time. This variation of the pumped flow rate that equals the total water demand is represented in Fig.2.

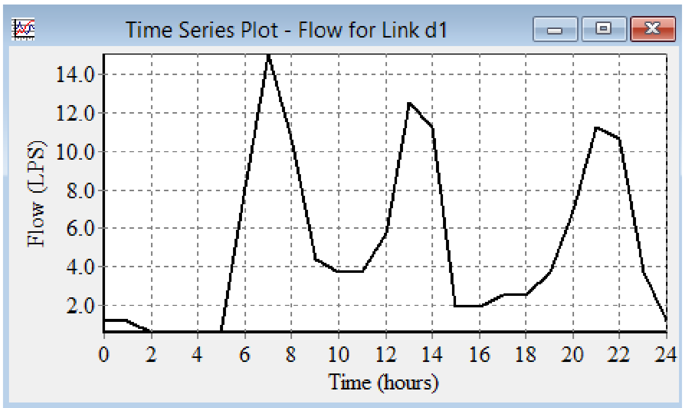

Fig. 2: Pumped flow rate

We'll present the operation simulation of the existing network for being supplied by:

- ✓ two centrifugal pumps with constant speed;
- ✓ two centrifugal pumps with variable speed;

3.1 Network supplied by constant speed hydraulic pumps

The existing water distribution network is supplied by two pumps with constant speed, which is the most economic variant with respect of investment expenses. The only possibility of these pumps to deliver the most values of the standard demanded discharge is to operate with the check valve on the discharge duct partly open. This kind of operation incurs additional energy consumption, especially for the small discharge values, because as it is well known, the pressure increases when the flow rate is low.

The graph in Fig. 3 presents the two duty points provided by the group of constant speed pumps operating with the check valves completely open. The maximal discharge is 57 m^3/h which exceeds the maximal demanded one. The other values have to be delivered by partly closing the valves. Moreover, the duty point for one pump is close to the cavitation limit. For instance, in order to deliver the smallest discharge, the system's curve should be changed from $H_{c(Q)}$ to the steeper curve $H_{cp(Q)}$, as shown in Fig. 3, by partly closing the check valve of one operating pump.

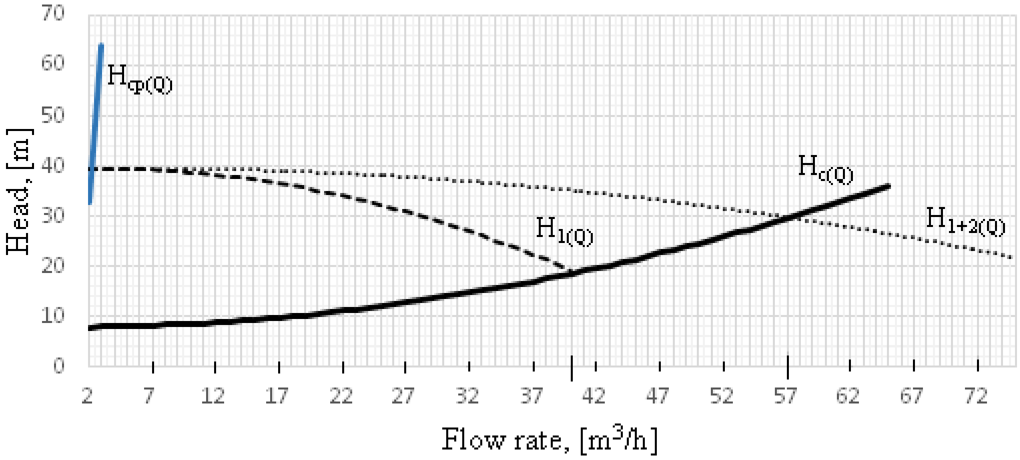

Fig. 3: Duty points for constant speed pumps. $H_{c(Q)}$-system's characteristic curve for completely open valves; $H_{cp(Q)}$-system's characteristic curve for partly open valves

3.2 Network supplied by variable speed hydraulic pumps

Utilization of variable speed pumps to supply hydraulic systems should be adopted after a technical and economic assessment. Taking into account their high prices, the investment cost is high, but variable speed pumps may provide lower operation costs due to their energy-efficiency. These pumps have to run at specific rotation speeds, previously determined as function of the desired discharge and head. Be $H_{x(Q)}$ the pump curve determined by the help of affinity laws [6], corresponding to unknown speed n_x. The desired discharge Q_x should satisfy the equality (1), between pump's head $H_{x(Q)}$ and system's head, $H_{c(Q)}$.

$$H_{x(Q)} = H_{c(Q)} \tag{1}$$

In the relationship (2), there were expressed both terms of the equality (1) as functions of flow rate:

$$aQ_x^2 + bn_xQ_x + cn_x^2 = H_g + MQ_x^2 \tag{2}$$

where a, b, c- constant coefficients determined by fitting pump's curve for maximal speed to a second order polynomial;
H_g-static head of the network, [m];
M-hydraulic resistance modulus for the entire network, $\left[{s^2}/{m^5}\right]$.

We determined the speed by imposing each value of the demanded discharge. Taking into account these speed values, the operation graph is given in Fig.3. We adopted the constant head pumping method. According to the buildings height in Tariverde, the constant pumping head is H=27.5 m.

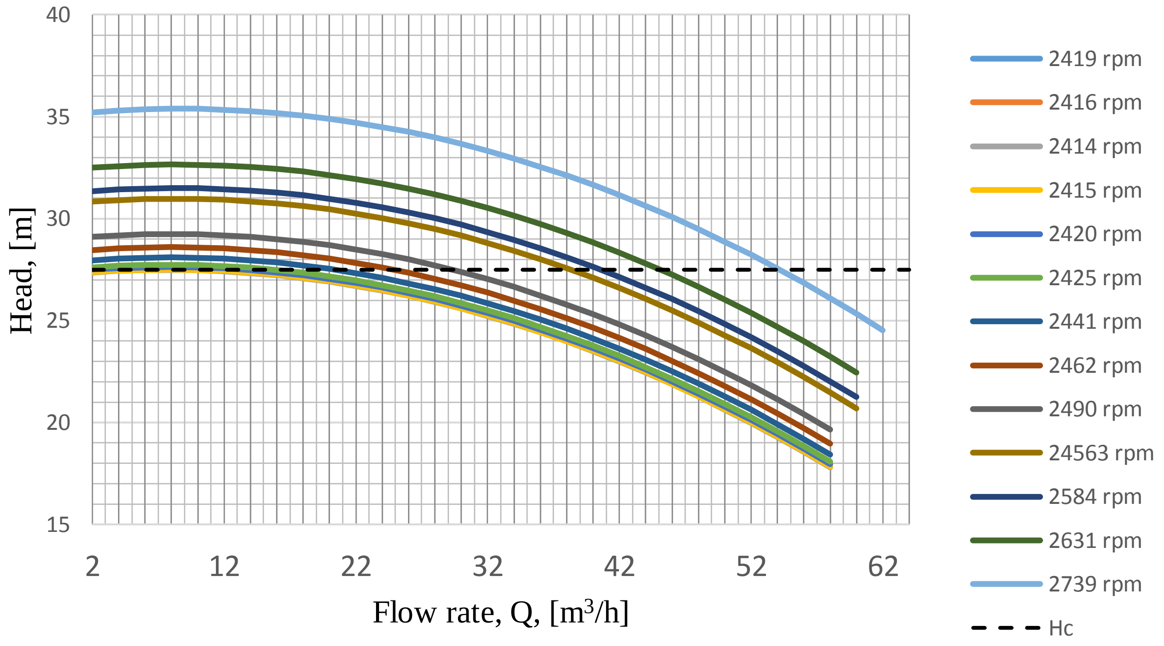

Fig. 4: Duty points for variable speed pumps. Pumps' head is represented for different values of the rotation speed, n [rpm]

4 RESULTS OF THE NUMERICAL SIMULATION

4.1 Simulation results regarding water velocity

The water velocity in the ducts of the network meets the requirements for low pressure distribution networks that means velocity is higher than 0.3 m/s [5], in all the sides of the network loops, excepting for the duct d20 whose diameter was oversized. Velocity on this duct is 0.05m/s, less than the minimal value of 0.06m/s stipulated by Pothof and Blokker in [7] for one –dimensional flow. It means a periodical flushing is needed.

In the external ducts velocity is higher than 0.1 m/s as recommended in [5] excepting for the short ducts as d11, d22 and d39. Moreover the velocity is low in the external ducts d37 and d38 that also have oversized diameters, being designed for a future expansion of the network. Due to the fact that the ducts d7 and d8 convey a great flow rate, needed to supply the most part of the network, the loops that include these two ducts do not obey the recommended diameter ratio: ${}^{d\,max}/_{d\,min} \leq 2$, as stated by Ianculescu and Ionescu in [8]. Another feature of the network configuration is the length of ducts d25 and d26 that exceeds the recommendations given in [8].

4.2 Simulation results regarding energy efficiency of the constant speed hydraulic pumps

The duty points obtained in the case of constant speed pumps operation are gathered in Tab. 1. For each discharge there are given the head, H, consumed power, P, and efficiency, η. It may be noticed the head has to be increased by partly closing the valve, in order to get the imposed discharge. This manoeuvre results in additional consumed power.

Tab. 1: Duty points for constant speed pumps

Q [m3/h]	2.26	4.51	6.77	9.02	13.53	15.79	20.30	24.81	29.32	38.35	40.60	45.11	54.14
H [m]	39.5	39.9	39.5	39.3	37.7	37.0	34.8	32.3	29.6	20.5	34.9	33.8	31.0
P [kw]	2.1	2.0	2.3	2.5	2.8	2.9	3.2	3.5	3.7	4.0	6.3	6.6	7.2
η [-]	0.12	0.22	0.31	0.40	0.52	0.55	0.60	0.63	0.63	0.51	0.60	0.62	0.63

The specific energy consumption *e*, as mentioned in [9] that means the energy amount consumed for pumping 1 m3 of water is:

$$e_c = 0.34\, {}^{kWh}/_{m^3} \tag{3}$$

4.3 Simulation results regarding energy efficiency of the variable speed hydraulic pumps

The duty points obtained for variable speed pumps operation are given in Tab. 2. For each discharge there are given the head, H, rotation speed, n, ratio of speed to the maximal speed of the pump, n/n_{max}, consumed power, P, and efficiency, η.

Tab. 2: Duty points for variable speed pumps. Constant head

Q [m3/h]	2.26	4.51	6.77	9.02	13.53	15.79	20.30	24.81	29.32	38.35	40.60	45.11	54.14
H [m]	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5
n [rpm]	2420	2416	2415	2415	2420	2425	2441	2462	2490	2563	2584	2631	2739
n/n $_{max}$ [-]	0.8	0.8	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	1.0
P [kw]	1.5	1.4	1.5	1.6	2.0	2.2	2.3	3.0	3.4	4.7	4.7	5.5	6.4
η [-]	0.12	0.25	0.34	0.41	0.52	0.55	0.65	0.63	0.64	0.61	0.65	0.62	0.63

The efficiency increases for many of the duty points, but especially for the discharges 38.35 ${}^{m^3}/_{h}$ and 40.60 ${}^{m^3}/_{h}$. Maximal pressure of 48.5 mwc is reached in node N 17 during night hours, and the minimal one, of 7.33 mwc in node N 16, at 7 a ’clock am. Pressure variations in these two junctions are given in Fig. 5 and Fig. 6 respectively.

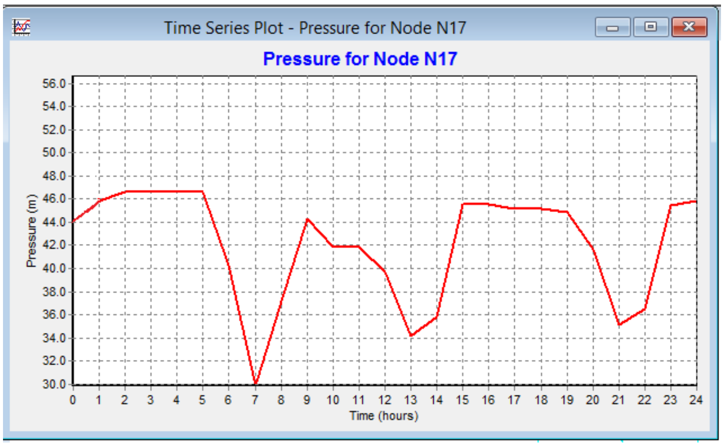

Fig. 5: Maximal pressure in the network, Node 17. Variable speed pumps

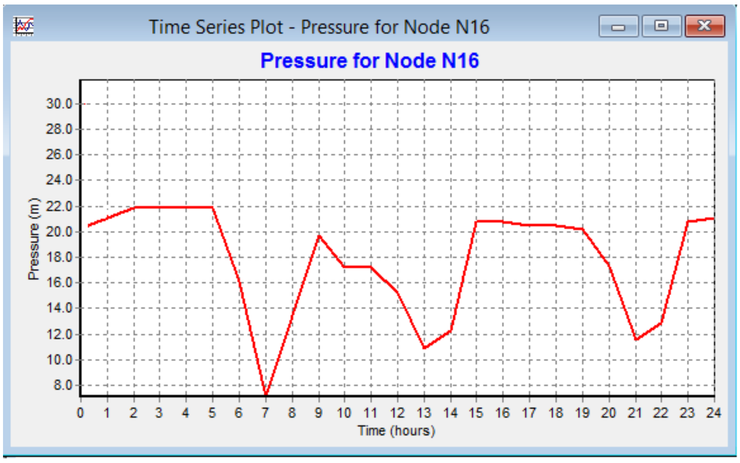

Fig. 6: Minimal pressure in the network, Node 16. Variable speed pumps

Numerical simulation of the variable speed pumps operation in accordance with the rotation speed values given in Tab.2 and the standard variation of the water demand over a day time resulted in a much smaller energy consumption:

$$e_v = 0.12\,{}^{kWh}\!/_{m^3} \qquad (4)$$

5 COMPARISON BETWEEN THE TWO VARIANTS

In the case of constant speed pumps, discharge adjustment can only be made by partly closing the check valves on the discharge ducts, therefore the maximal pressure values in the nodes of the network are higher than in the case of variable speed pumps, as it may be noticed in Tab. 3. Besides, maximal pressure in nodes N17 and N20 exceeds the recommended value of 60mwc for low pressure water distribution network [5]. One also can notice a strong difference among the pressure values in the extreme nodes: take for example pressure of 35.5mwc in node N34 and 61mwc in node N17.

Tab. 3: Pressure values in the extreme nodes of the network

Node		***N16***	***N 17***	***N20***	***N31***	***N32***	***N34***	***N36***	***N37***	***N38***
Constant speed pumps	**p** $_{\mathbf{min}}$ [m wc]	10	32.74	31.92	28.22	15.64	16.16	18.67	22.4	21.9
	p $_{\mathbf{max}}$ [m wc]	36	61	60.1	57	42	35.5	39	50.2	51
Variable speed pumps	**p** $_{\mathbf{min}}$ [m wc]	7.9	30	29	31.25	32.27	13	16	19	19
	p $_{\mathbf{max}}$ [m wc]	23.4	48.5	47.7	44.5	32.3	23	26.5	37.8	38.3

In the case of variable speed pumps, medium pressure values are appropriate for this kind of water distribution network. Due to the constant head pumping method, pressure in extreme nodes shows no such great difference as in the previous case. Extending the discussion to all the network nodes, we may notice smaller differences among pressure values, which results in a better operation regime.

In both cases, minimal pressure in the extreme nodes is higher than the imposed value of minimum 7 m wc for hydrants [5].

6 CONCLUSIONS

The importance of the quality and the hydraulic parameters of drinking water for the life of either urban or rural area inhabitants give a large responsibility to the engineers in charge with the design and execution of water infrastructure. EPANET software offers a flexible and easily handling tool to simulate operation of a hydraulic system in different scenarios and detect possibilities to optimize it.

In the case of Tariverde village, the operation of water distribution network supplied by two constant speed pumps results in an important energy consumption. Besides, maximal recommended pressure of 60mwc is exceeded in two of the network nodes, as it was determined by numerical simulation. When simulation refers to variable speed pumps, maximal pressures are less than the admitted values and a consistent energy saving can be made. For an average flow rate of $318\ {}^{m^3}/_{day}$ the energy saving the estimated energy saving would have been up to $220\ {}^{kWh}/_{1000m^3}$, considering the same pattern of water demand.

Numerical simulation of the network operation showed the ducts where velocity is slower than the recommended values, which may affect water quality. A systematic cleaning of these ducts has to be carried out periodically. External ducts' diameters are designed for a future increase of the water demand, thus for a larger flow rate in accordance with the increase of the inhabitants number in a second stage of the network development. Therefore, velocity in these ducts will increase and fit the recommended range.

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