ГОДИШНИК НА УНИВЕРСИТЕТА ПО АРХИТЕКТУРА, СТРОИТЕЛСТВО И ГЕОДЕЗИЯ
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NUMERICAL SIMULATION OF A SMALL WATER DISTRIBUTION NETWORK OPERATION

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Keywords: *water distribution network, variable speed pump, numerical simulation*

ABSTRACT

The water demand in rural communities has a considerable variation during the daytime. Consequently the water distribution network operation has to comply with this variation in order to assure comfort to the inhabitants, at an affordable price of the pumped water.

EPANET software makes possible the numerical simulation of small water distribution networks operation under different settings and configurations, easily performing a complete hydraulic analysis of the system.

Numerical simulation performed on the water distribution system of a small village of 2500 inhabitants, placed in Constanta County, returned the field of pressure and velocity at different moments of the day, making possible the optimization of the technical parameters of the water network.

Considering the same standard pattern for the demand flow rate, stipulated by the technical design regulations, the use of variable speed pumps instead of constant speed ones leads to an average energy saving of more than 0,10 kWh/m^3.

1. Introduction

Nowadays, more and more regions in the world face water scarcity threatening, with a negative social and economic impact. The scientists have drawn attention to the need of a more

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rational management of water resources in the context of the rapid climate change and population growth. Furthermore, the problem of drinking water supply cannot be regarded otherwise but connected to the energy efficiency. Water and energy efficiency is one of the most important aspects of a sustainable development in either urban or rural regions. An affordable price of a high quality drinking water may be achieved by performing a cost-efficient operation of the water supply system and by adopting leakage surveillance technologies in order to decrease the non-revenue water in the distribution network.

The design of drinking water supply systems benefits from new tools for sizing and operation analysis: various specialized software, such as EANET. An EPANET conventional model was developed for Tariverde village in Constanta County, which has a small water distribution system. The study aims to analyse the hydraulic parameters in different operation scenarios and to determine the most energy efficient pumping method by numerical simulation in EPANET. It continues an analysis made for the constant pressure pumping case [1].

2. Description of the Water Distribution System Model in EPANET

Tariverde, a village in the central part of Dobroudja region, has a water supply network built for 2500 inhabitants, as the population has been estimated for the year 2020. The network pipes, PEHD made, follow the direction of the main streets, as it may be seen in Fig. 1.

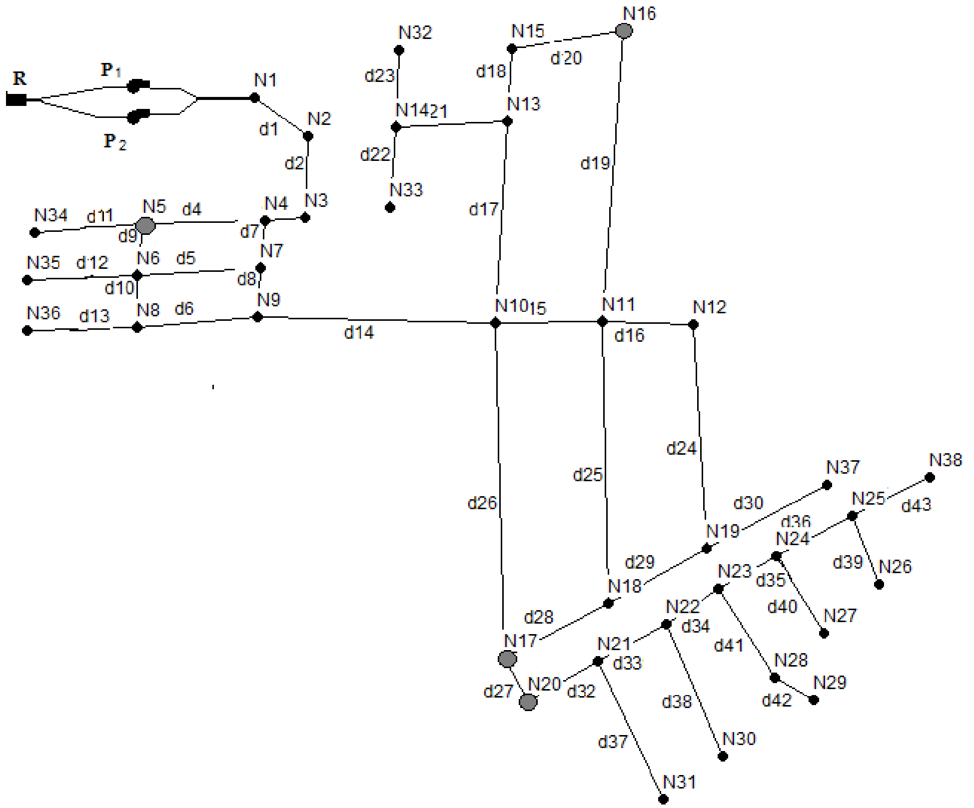


Figure 1. Tariverde water distribution system. Grey circular marker for the nodes with extreme elevation values

The water supply system was modelled in EPANET-2, software released by the United States Environmental Protection Agency, which provides a very good accuracy in modelling small networks [2]. The network is composed of links (a pipe or a pump) which connect junctions (nodes). The water demand is concentrated in nodes. All the features of a system (network topography, pipe geometry and roughness, pump performance and efficiency, etc.) can be easily introduced or modified. The water demand pattern is introduced according to the chosen time step. The pumps operation over time can be simulated by the help of scripts introduced as programme controls.

The network is a low-pressure one, being supplied by a group of two pumps P mounted in parallel, which take water from a reservoir. The extreme terrain elevation values are 41,13 m in node N17 and 66,72 m in node N5. Other two nodes with elevation values of interest in this simulation are the node N16 at 65,96 m and node N20 at 41,84 m, see Fig. 1.

The system has underground water sources that supply the suction reservoir R, (Fig. 1). The pumps deliver water directly in the network. Each pump has a butterfly valve on its discharge duct that can be used for throttling.

The design discharge is 15,04 l/s, which represents 12% of the maximal water demand during a day [1]. It was considered the standard hourly water demand variation for a rural settlement, as stipulated by the Romanian regulations [3], and characterized by a high variation of the water demand during a day. The pumping station has to provide thirteen distinct discharge values within 24 hours.

3. Operation Simulation in Different Scenarios

3.1. Constant Speed Pumps

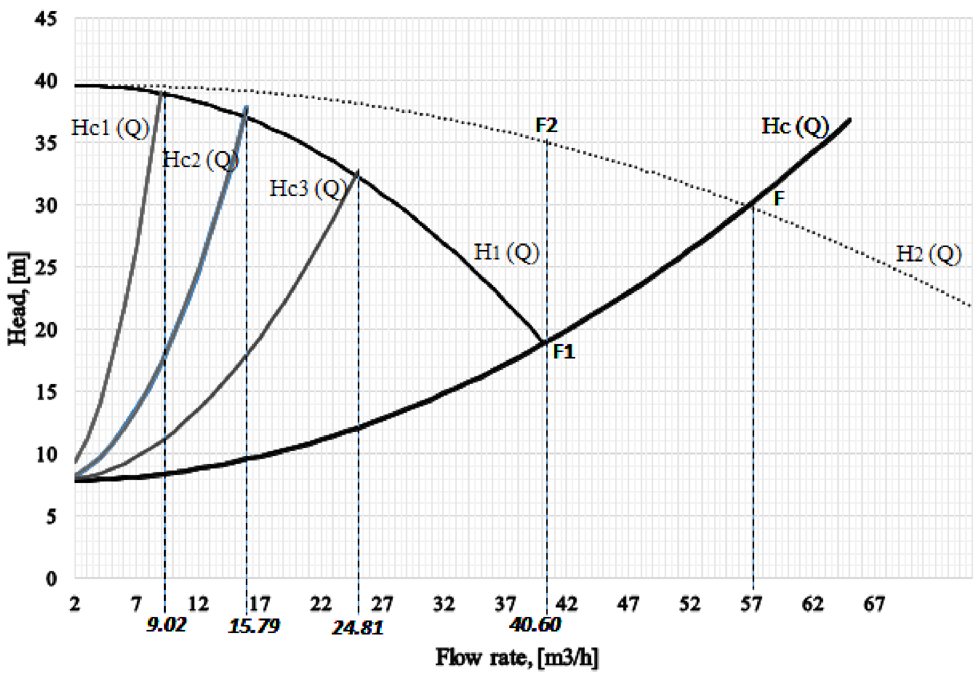


Figure 2. Constant speed pumps. Main operation points

The analytical study of the operation of two constant speed pumps is referred to in the graph in Fig. 2. The system's curve $Hc_{(Q)}$ is drawn for completely open valve on the discharge duct of each pump. There are shown only a few duty points, pointing out that the small or medium discharge values, such as 9,02 m^3/h, 15,79 m^3/h and 24,81 m^3/h are obtained by partly closing the butterfly valve on the discharge duct of one constant speed pump.

The discharge of 40,60 m^3/h can be provided by one single pump, in the duty point F1, with the butterfly valve completely open. The disadvantage is that this duty point is close to the cavitation limit of the pump. The same discharge value can be provided by both pumps operating in parallel, in the duty point F2, but again the butterfly valves have to be partly closed. It can be noticed that the maximal discharge is 57 m^3/h, which exceeds the maximal demanded one of 54,14 m^3/h (duty point F in Fig. 2).

The choice of constant speed pumps alternative is the most economic solution with respect to investments, but the operation with the butterfly valve partly open leads to significant additional energy consumption, as the pressure increases when the flow rate is small.

3.2. Variable Speed Pumps

Variable speed pumps, in spite of their high price that involves a high investment cost, usually provide lower operation costs due to their energy-efficiency and possibility to comply with the water demand. The pump type has been selected in such a way that the characteristic curve at the maximal rotation speed is identical to that of the constant speed pump. These pumps have to run at specific rotation speeds, determined in advance as function of the desired discharge and head, by the help of affinity laws [4], [5].

The operation graph in Fig. 3 shows some of the duty points where the variable speed pumps deliver the discharge values specific for the standard demand pattern in rural area. It is considered the pumping method that assures the proportionality between discharge and head. The pump's characteristic curves are plotted for different speed values. These values had been determined by imposing the equality between the system head and the pump one (as a function of the rotation speed) for each value of the demanded discharge.

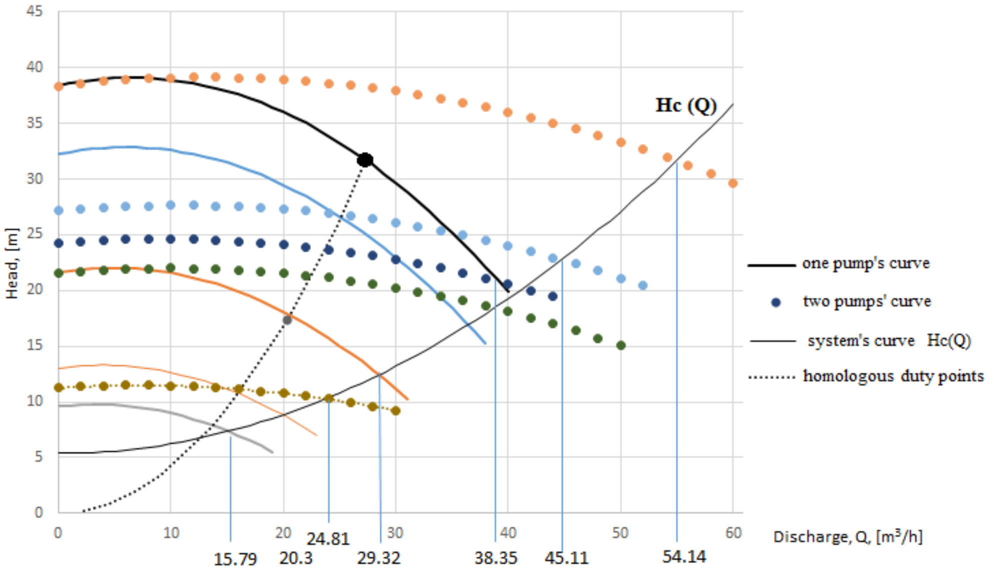


Figure 3. Variable speed pumps. Operation points

In Fig. 3, for a single pump operation, the curve is plotted as a solid continuous line, and for two pumps working in parallel the curve has circular markers. The system curve is Hc and it is plotted with continuous solid line. The dashed parabolic curve that originates in (0, 0) is the geometrical place for all the duty points homologous with the point where the pump has been selected (27,07 m^3/h, 31 m).

It may be noticed that the minimal discharge value which can be delivered on this specific network with a completely open butterfly valve, by decreasing the speed of a pump, is 15,79 m^3/h.

4. Simulation Results. Discussion

The simulation was performed for duration of 24 hours, with a step of 1 hour for the hydraulic analysis.

The water velocity field in the ducts of the network, within 24 hours, meets the requirements for low pressure distribution networks, which means the velocity is higher than 0,3 m/s [3]. There is one exception, the velocity in the duct d20, which is 0,05 m/s, less than 0,06 m/s – the lower limit recommended in [6] for one dimensional flow. A periodical flushing is needed on this duct [7].

In the network represented in Fig. 4 there are marked with grey line the external ducts where velocity is less than 0,1 m/s as recommended in [3]. The observation is made for the velocity field at time 4 a.m. We refer to the ducts d11-d13, d22, d23, d30, d39, d40 and d43 that have oversized diameters, being designed for a future expansion of the network.

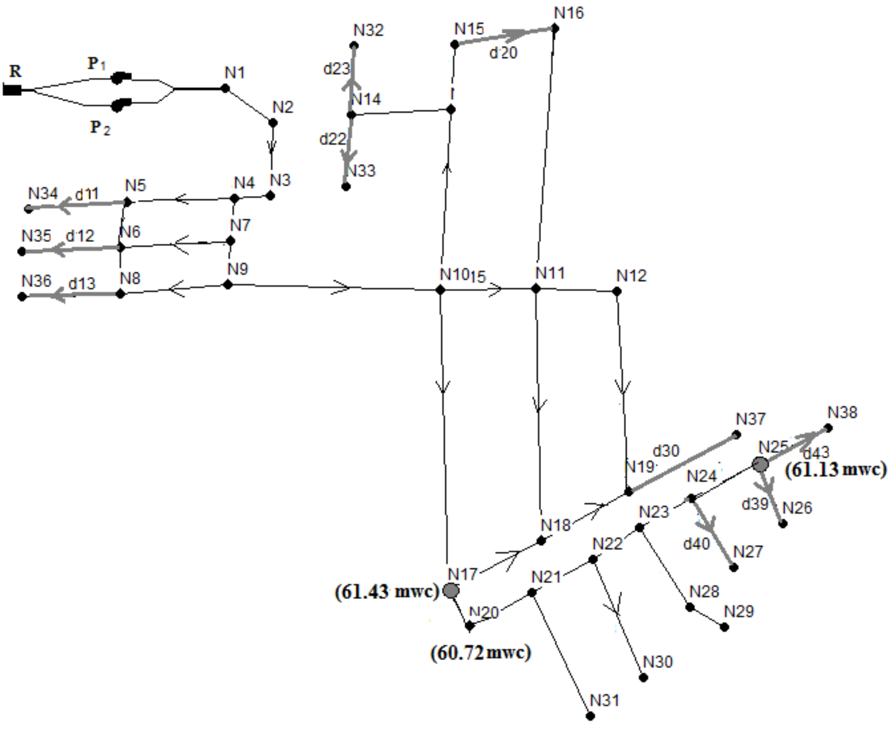


Figure 4. Constant speed pumps. Maximal pressure values at 4 a.m., expressed in mwc (meter water column)

Referring to the technical parameters of the constant speed pumps operation, the duty points are gathered in Table 1, [1].

Table 1. Operation points for constant speed pumps [1]

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

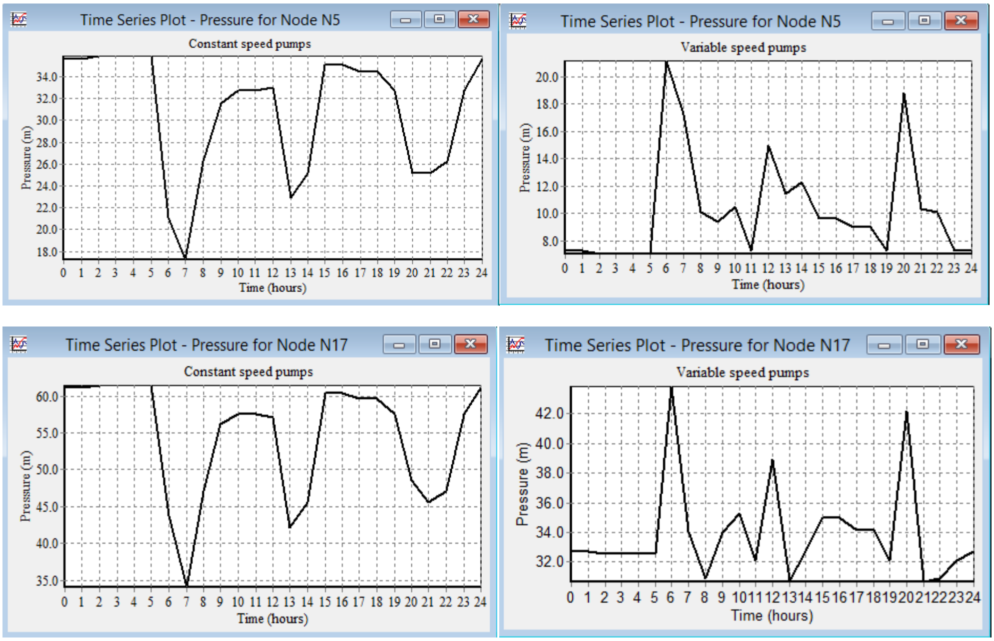
As it was mentioned in [5], the most relevant energy indicator is the specific energy consumption *e*, which means the energy amount consumed for pumping 1 m^3 of water. In the case of constant speed pumps, taking into account the results from [1] and considering the average utilization time of each pump, the value is $e_c = 0{,}213$ kWh/m^3.

Average consumed power is 4,47 kW.

With respect to pressure, one can notice in Fig. 4 that during the night time, pressure in the nodes N17, N20 and N25 exceeds the maximal allowed value for low pressure water distribution networks, which is 60 mwc (588,4 kPa). It is well known that constant speed pumps deliver small discharge at high head.

The simulation of the network operation supplied by variable speed pumps was carried on aiming to study the same main parameters: velocity field, extreme pressure, energy consumption. The selected variable speed pump has the same characteristic curve at the maximal speed as the constant speed pump type.

The controls in EPANET were set for a variation of the pump's speed such as the head to be proportional to the discharge. It was not possible for the smallest values of the discharge, therefore the minimal speed was 55% of the maximal one, in order to avoid pressure values less than 7 mwc in the node N16, as it is requested for a hydrant.



a. Constant speed pumps *b. Variable speed pumps*

Figure 5. Time series for pressure variation in nodes N5 and N16. Constant vs. variable speed pumps

The maximal pressure, recorded in node N17, decreases from 61,43 mwc, in the case of constant speed pumps operation, to 44 mwc when variable speed pumps operate, as shown in Fig. 5.

In the same figure, it may be noticed that minimal pressure in the highest node, N5, does not decrease under 7 mwc during 24 hours, when variable speed pumps operate the network.

Pressure time series for the furthest nodes N37 and N38 show a minimal pressure of 20 mwc, thus a future expansion of the network is possible in that direction.

The head values corresponding to the demanded discharge, for the case when variable speed pumps are used, are given in Table 2. It may be noticed a considerable decrease of the head values. In Table 2 there are given the head, H, the discharge, Q, and the rotation speed ratio, n/n_{max}.

In this case, the specific energy consumption is e_v = 0,106 kWh/m^3, considering the same average utilization time of each pump. The average consumed power is 2,69 kW.

Table 2. Operation points for variable speed pumps

Q [m^3/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]	12,7	12,4	15,2	14,7	16,5	15,6	21,8	26,24	29,3	20	21,8	27,7	31
n/n_{max} [-]	0,56	0,56	0,62	0,62	0,62	0,68	0,75	0,92	1	0,78	0,75	0,85	1

In a previous study on the same network and pump type, it was pointed out that the energy consumption is 0,12 kWh/m^3 for one variable speed pump when the pump operates at constant head [1]. That means an average consumption of 0,16 kWh/m^3 for both pumps, according to the utilization time of each one during 24 hours, and if the same water demand pattern is taken into account. Thus, an improvement of the energy consumption was obtained by the pumps operating at the variable head.

5. Conclusion

Numerical simulation has become a reliable, flexible and encompassing method to get a whole image of the operation possibilities and technical parameters of a hydraulic system. The engineers in charge of the design, execution or operation of water distribution systems can easily check on the operation of a hydraulic system in different scenarios and detect possibilities to optimize it.

Numerical simulation of the Tariverde water distribution network operation revealed:

- the ducts where velocity is slower than the recommended values, which may affect water quality; a periodical cleaning of these ducts has to be done;
- possibilities of network extension, according to the diameter size of the external ducts and pressure variation in end nodes;
- extreme values of the pressure field;
- the best operation variant in order to meet the required technical parameters and save energy.

In the case of the studied network, a consistent operation improvement has been pointed out when using variable speed pumps instead of constant speed ones. Maximal pressure is less than the admitted upper value of 60 mwc. Energy consumption decreases with about 0,1 kWh/m^3. Furthermore, when the variable speed pumps provide the head proportional to the delivered discharge, the energy saving is about 0,053 kWh/m^3 than in the case of constant head analysed in a previous study, considering the same pattern of water demand specific for the rural area.

REFERENCES

1. *Constantin A., Niţescu, C. St.* Water Distribution Network Design Based on Numerical Simulation in EPANET. International Scientific Conference People, Buildings and Environment, 2016, Luhacovice, Czech Republic, 2016.

2. *Henshaw, T., Nwaogazie, I. L.* Improving Water Distribution Network Performance: A Comparative Analysis, Pencil Publication of Physical Sciences and Engineering, 1(2), pp. 21-33, 2015.

3. *** Norm Regarding the Design, Execution and Exploitation of Water Distribution Systems, NP 133-2013, Bucharest, 2013.

4. *Burchiu V.* Pumping Installations, E.D.P. Bucharest, 1987.

5. *Constantin, A., Niţescu, C. St., Stănescu, M.* Hydraulic Machinery and Pumping Stations. Ovidius University Press, Constanţa, 2011.

6. *Pothof, I. W. M., Blokke,r E. J. M.* Dynamic Hydraulic Models to Study Sedimentation in Drinking Water Networks in Detail. Drinking Water Engineering and Science 5, pp. 87–92, doi: 10.5194/dwes-5-87-2012, www.drink-water-eng-sci.net/5/87/2012/, 2012.

7. *Hancu, S., Marin, G.* Hydraulics. Theory and Application, Vol. 1, Ed. Cartea Universitara, Bucharest, 2007.

ЧИСЛЕНО МОДЕЛИРАНЕ НА РАБОТАТА НА МАЛКА СЕЛИЩНА ВОДОПРОВОДНА МРЕЖА

А. Константин[1], Кл. Ницеску[2]

Ключови думи: *селищна водопроводна мрежа, помпи с променливи обороти, числено моделиране*

РЕЗЮМЕ

Разходът на вода в населените места варира значително през денонощието. Работата на водопроводната мрежа трябва да бъде съобразена с това, за да се осигури нормално водоподаване на приемлива цена в случаите на помпено захранване на мрежата.

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Компютърната програма EPANET позволява симулиране на работата на малки водопроводни мрежи, при различни настройки и конфигурации, като лесно се постига цялостен хидравличен анализ на системата.

В резултат от численото моделиране на водопроводната мрежа на малко село с 2500 жители в окръг Констанца бяха получени наляганията и скоростите в различни моменти от денонощието в характерните точки от мрежата, което позволи оптимизирането на техническите параметри на системата.

При зададена схема на изменението на потреблението в денонощието, предвидена в нормите за проектиране, бе установено, че използването на помпи с променливи обороти води до средна икономия на енергия от над 0,10 kWh/m^3 спрямо варианта с обикновени помпи.