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MATHEMATIC MODELING OF A WATER SUPPLY SYSTEM FOR A RURAL AREA WITH 4000 INHABITANTS

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Abstract: In this paper, the mathematical modeling of a water supply system in rural areas is carried out. The modeling of the drinking water supply system was done using the EPANET programming software, which performs hydraulic and water quality simulations in the pipeline networks. The calculation of technological consumption and water losses is made by each operator providing the public water supply and sewerage service taking into account the water quality at source, the water treatment and purification technologies, the materials from which the public supply networks the duration of public water supply networks, the length of public water transport networks, the length of public water distribution networks, the level of water consumption metering, hydrogeological conditions, etc.

As a result of the analysis and interpretation of the results, it has been shown that with a calibrated and very well monitored water supply system (pressures and flows) the areas where the hidden damages or even theft of the water in the network can be easily determined. In this situation, they can take very rapid intervention.

Keywords: mathematical modeling, water distribution system, pressure, velocity, roughness

1. INTRODUCTION

The drinking water distribution system has the objective of supplying water to the required quantity and quality without risk to human health. The rise in living standards, technological developments and constraints imposed by the need to align with European and international standards of water quality and safety have led to the need to implement performance management systems for water distribution networks. Such solutions must, among other things, allow efficient and accurate modeling of the behaviour of these networks, provide powerful tools for analysing demand and water quality, and ensure the possibility of identifying weaknesses in the system and predicting its behaviour in the case the occurrence of extreme events. The primary objective of any organization dealing with the distribution of drinking water is to ensure a continuous and efficient supply and to maintain a high level of water quality. The water must have a constant pressure and leakage losses should be minimal. Achieving this goal depends on a number of factors such as weather conditions, industry regulations, security, etc. The economic recession that began in the 1990s as a result of the change in the social system, moving from the centralized economy to the free market economy, has generated important mutations in all spheres of activity, including public services, namely production and distribution of drinking water in most of our localities. Substantial reduction of drinking water consumption due to diminishing / stopping industrial activities in populated centers, changing the production profile of most economic agents, measuring the actual consumption of each consumer and even temporarily reducing consumers by departing or migrating to other areas, but also the rise in the price of water, together with other factors of influence, led to radical changes both in the parameters of water production and especially in those related to the distribution of drinking water on the heights of many localities.

The distribution networks within these communities have been dimensioned under the conditions of ensuring water demand and service pressure at all points of consumption. The hydraulic calculation of the distribution networks was made on the basis of the water demand and the economic speed for transport in each of the characteristic areas of the locality. Switching to a new operation chart of the water distribution / pumping system in the grid by drastically reducing the demand for water and the volumes of pumped water as well as the water pressure when leaving the pumping stations using the existing distribution network, the emergence of new situations related to the provision of a proper maintenance and exploitation service on the quality of the water distributed to each consumer and especially with regard to operational safety by avoiding the risk of water self-polluting water in the water networks, reflected by the substantial reduction of residual chlorine and flow rates well below the permissible limits [1], [2], [3], [4].

2. EDITING INSTRUCTIONS

Flow of water in a distribution network is a non-permanent flow due to the daily and hourly variation of flows and the degree of simultaneity of concentrated and distributed consumption; they can

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lead, in short time intervals, to changes in the value of the pressure, the velocity of the flow rate and some even the flow direction. To simplify calculations, the assumption of permanent movement in distribution networks, taking into account the maximal simultaneity of consumption by the coefficients of daily variation (K_{zi}) and hourly (K_o). The Colebrook - White formula is used to determine the friction factor of task,

$$\frac{1}{\sqrt{\lambda}} = -2\log\left(\frac{2.51}{Re\sqrt{\lambda}} + \frac{k}{3.71 D}\right)$$

and the unit headloss is determined by the Darcy – Weisbach formula:

$$h_r = \lambda \frac{L}{D}\frac{v^2}{2g} = \lambda \frac{L}{D}\frac{Q^2}{2gA^2} = MQ^2, \ (m)$$

Where:

L – length of pipe, m;

D - diameter of the pipe, m;

Q - flow rate, m^3 / s;

v - water velocity, m / s;

l - hydraulic resistance coefficient;

Re - number Reynolds;

k - absolute roughness of the pipe wall, m;

M - hydraulic resistance module, s^2 / m^5.

3. MODELING THE DRINKING WATER DISTRIBUTION SYSTEM FOR AN URBAN LOCALITY

Description of the water supply system

The village, consisting of approx. 4000 inhabitants, which is the subject of the case study, is a settlement with a non-significant geodetic difference in the north-south direction. The water supply system of this locality is more than 50 years old. The village had a water supply system, initially comprising 5 wells located on the territory of the locality and distribution network of about 26 km. The water supply system serving the inhabitants did not meet the water quality parameters and required interventions both to ensure the flow requirements and to expand the distribution network.

Under these conditions a detailed analysis of the water supply system was carried out, resulting in the need to provide investments with beneficial and immediate effects in the operation of this system.

In order to ensure the flow required for the water supply of the locality, the connection of the water system of the locality to the water supply system in Timisoara was made through a conduit. The adduction pipeline between locality and Timişoara is made of PEHD 315mm, PN 10, PE100 and has a length of 5992 m, it is equipped with a flowmeter furnace, shaft lifts, ventilation shafts and drainage. In the village are used various types of material such as: OL: 14,611 km, PVC: 1,177 km, PEHD: 10, 726 km, Connections: 1326 pcs.

In order to ensure the chlorination of water, the provision of compensation and fire volumes and the water pressure on the network, there is a water house in the locality.

It consists of a water chlorination station, a water storage tank and a pumping station.

Figure.1. Distribution of diameters in distribution system

The pumping station is equipped with a pumping group (2A + 1R) with frequency converter on each engine and expansion vessel. The pumps are equipped with a frequency converter, which produces the variation of the speed at each pump so that a constant pressure and a variable flow are achieved in the distribution network, which will be adapted to the consumption curves. In this way the energy consumed is minimal. The water processed by the water house ensures the consumption of domestic drinking water, for the satisfaction of public needs, fire reserved and industrial water. Each pump has the following features: Q = 56mc / h, H = 30mCA, Pmax = 7,5kW.

The operating mode is continuous.

The water supply system has the technological flow based on the following scheme:

- PEHD adduction at 315 mm, from Timişoara to the Water Household

- Primary disinfection prior to storage with chlorine gas

- Storage of water in 2000mc tank; cylindrical tank placed vertically, overhead and thermally insulated

- Disinfection of water with chlorine gas and correction of residual chlorine before distribution

- Pumping water and maintaining constant pressure (3bar) in the distribution network

The characteristic debits according to the calculation pivot are as follows:

Qzi med = 1122mc / day, Qzi max = 1304 mc / day, Qorar max = 126.68 mc / h, QII C = 166.94 mc / h

Operating flows in the year 2017 are:

Q pumped: 326804 mc / year = 895.35 mc / day, Invoice: 189924 mc / year = 520.339 mc / day, Loss: 136880 mc (42%) = 375.01 mc / day

The water management system is designed to ensure continuous operation in optimum conditions for both minimum and maximum flow rates. The water management is fully automated and monitored, all phases of the process being integrated into a SCADA system.

4. FLOW MODELING RESULTS

The exact modeling results depend on the precision of the model calibration, which involves making adjustments to the parameters to ensure consistency between the model values and observed field values (eg junction pressure and pipe flows). Thus, calibration is of vital importance and is included in Epanet. An integrated approach is included to allow modellers to select any combination of three model types, pipe roughness parameters, junction request and pipeline status (pipes and / or valves). The calibration function gives users the flexibility to make tolerances and calibration accuracy. Modeling and data processing was performed in two simulation scenarios, as follows: Scenario 1 in no-damages; Scenario 2 with one damage, in junction 30 with 5 l/s. The initial flow rate was 10.36 l / s. Figures 2 and 3 show the flow rates in the distribution network pipes, and respectively Figures 4 and 5 pressures in both scenarios. Epanet can estimate the location and leakage level hidden in underground pipes. It can automatically identify leak points by simulating leaks in the model and comparing with existing field data. The Epanet can identify the locations with the greatest losses by colour codes.

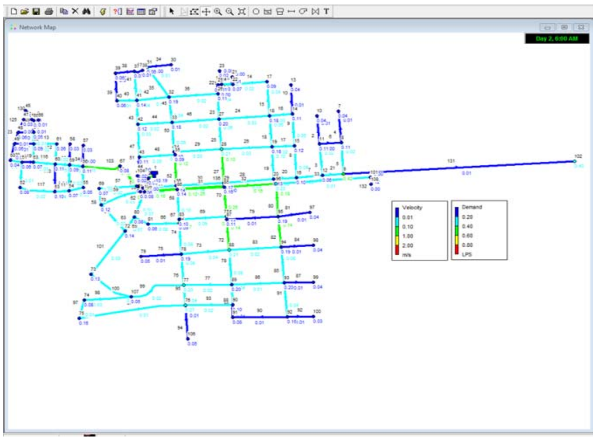

Fig.ure 2. Velocity in distribution networks without damages

In the figure below simulating a failure at a point near the water house, it can be seen that the flow to the damaged point changes.

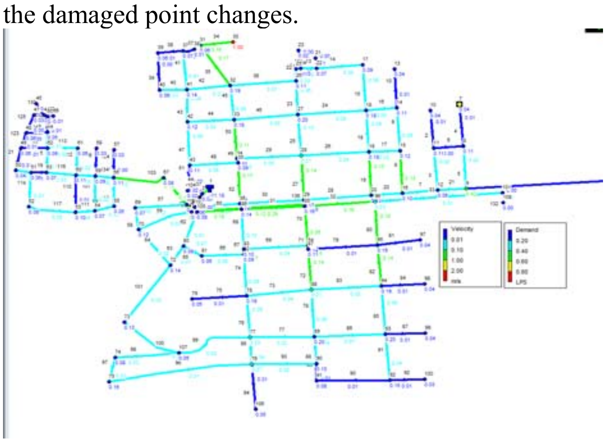

Figure.3. Velocity in distribution networks with damage in junction 30 with 5l/s

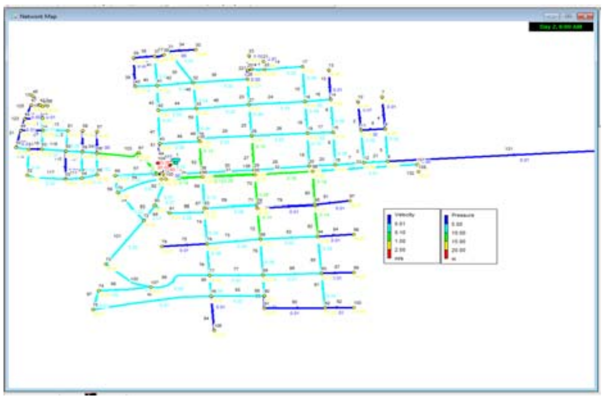

Figure 4. Pressure in distribution networks without damages

Figure.5. Pressure in distribution networks with damage

In Figures 6, 7, a comparison of the respective pressures in the two scenarios is made.

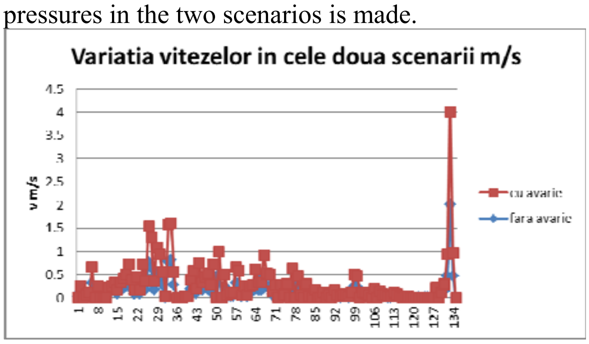

Figure. 6. Velocity comparison in both scenarios

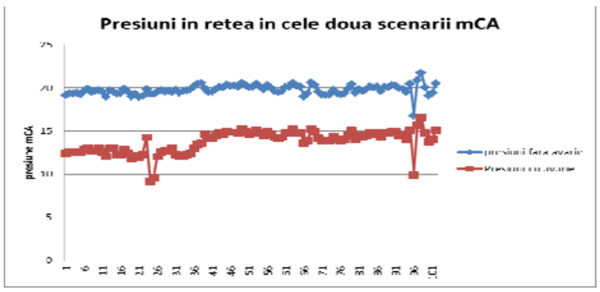

Figure 7. Comparison of pressures in both scenarios

5.CONCLUSIONS AND RECOMMENDATIONS

In order to maintain in good condition the functioning of all the constructions and equipment of the distribution networks with the assurance of the consumption flows, the service pressures, the minimum flow rates of the water through the pipes and the residual chlorine doses are necessary in the operations of the operation and technical maintenance operations : washing, cleaning, periodically disinfecting pipes where self-cleaning rates and minimum residual chlorine doses are not ensured; the weekly opening of fire hydrants in which the water stagnates or flows at very low speeds or the commissioning of the permanent flowing cistern, the supervision of the operation and condition of the pipelines, the joints, the fittings, the measuring instruments and the control of the buildings and the state of the buildings ; control of indications on water meters and manometers; detection and combat of water losses and pressure drops; replacement of old and degraded pipeline sections, control and refilling of residual chlorine on pipe sections with values below the limits allowed by technical regulations; executing new connections and reviewing existing ones. Given that distribution networks and their accessories will be made of high quality materials and placed in clean, pollutant-free environments, operating and maintenance issues will be greatly simplified. Water consumption is the driving force behind the hydraulic dynamics that occurs in water distribution systems. During the simulation of these dynamics in the water distribution model, an exact representation of the system demands is as important as the exact modeling of the physical components of the model.

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