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Original Research Article

MODELLING PARAMETERS CHARACTERIZING SELECTED WATER SUPPLY SYSTEMS IN LOWER SILESIA PROVINCE

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A b s t r a c t

The work presents issues of modelling water supply systems in the context of basic parameters characterizing their operation. In addition to typical parameters, such as water pressure and flow rate, assessing the age of the water is important, as a parameter of assessing the quality of the distributed medium. The analysis was based on two facilities, including one with a diverse spectrum of consumers, including residential housing and industry. The carried out simulations indicate the possibility of the occurrence of water quality degradation as a result of excessively long periods of storage in the water supply network. Also important is the influence of the irregularity of water use, especially in the case of supplying various kinds of consumers (in the analysed case - mining companies).

Keywords: water supply system, water pressure, flow rate, water age, EPANET program

1. INTRODUCTION

The main task of water supply systems is providing recipients with water of adequate quality and with sufficient pressure. The systems vary greatly in terms of size, layout, way of supply, or the characteristics of consumers. Various percentage shares of water usage during a day are characteristic of the individual elements of spatial development [2, 6, 8]. All of these factors lead to the

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assessment of operational parameters characterizing a given system being so important, both at their design stage as well as over the course of their operation. Also important are calculations regarding the flow rate of water within the network, in which the assumed variant of mixing water flowing into the tank with stored water is important [5]. The obtained results ought to be analysed in terms of the risk of secondary water contamination in the network [10]. The possibility of modelling the parameters of water supply systems is provided by software programs, one of these being the EPANET program made available by the USA Environmental Protection Agency.

Two water supply systems which provide water to consumers, who are diversified when it comes to the volume and irregularity of use as well as requirements regarding water quality and pressure, were subjected to analyses. Mining companies are the main consumers of water in the Lubin system, which also supplies industrial and service operations. Residential buildings in four villages with a total population of 2,900 inhabitants are also connected to the system. The Głogów system supplies water to approx. 66,500 residents of the city, as well as a series of industrial and service operations, and public utilities.

2. METHODOLOGY

Using the EPANET program, models of the analysed systems were developed. The program allows for both calculating hydraulic parameters, as well as those characterizing the quality of the water. It is applied to analyse networks at the design stage, but also existing ones and those undergoing modernization.

The solution for heads and flows at a particular point in time involves solving simultaneously the conservation of flow equation for each junction and the headloss relationship across each link in the network. This process requires an interactive technique to solve the nonlinear equations involved [9].

Calculations of linear water pressure loss can be carried out using the EPANET program applying the following formulas: Darcy-Weisbach, Chezy-Manning and Hazen Williams.

The most commonly applied method in Polish conditions is the Darcy-Weisbach method [3]:

$$\Delta h_l = \lambda \frac{v^2}{2g} \cdot \frac{l}{d} \tag{2.1}$$

where:

Δhl - losses of pressure on the length of pipe, m;

λ - linear friction coefficient;

v - average water flow rate, $m \cdot s^{-1}$;

g - gravitational acceleration, m·s^{-1};
l - length of pipe, m;
d - inside diameter of pipeline, m.

The linear friction coefficient is calculated depending on the values of Reynold's number using the following formulas [9].

$$\lambda = \frac{64}{\text{Re}} \tag{2.2}$$

- Coolebrook - White's (for Re>4000):

$$\lambda = \frac{0{,}25}{\left[\ln\left(\frac{\varepsilon}{3{,}7d} + \frac{5{,}74}{\text{Re}^{0{,}9}}\right)\right]^2} \tag{2.3}$$

where: ε - pipe roughness, mm
- cubic interpolation from Moody Diagram (for 2000 < Re < 4000) (Fig. 1)

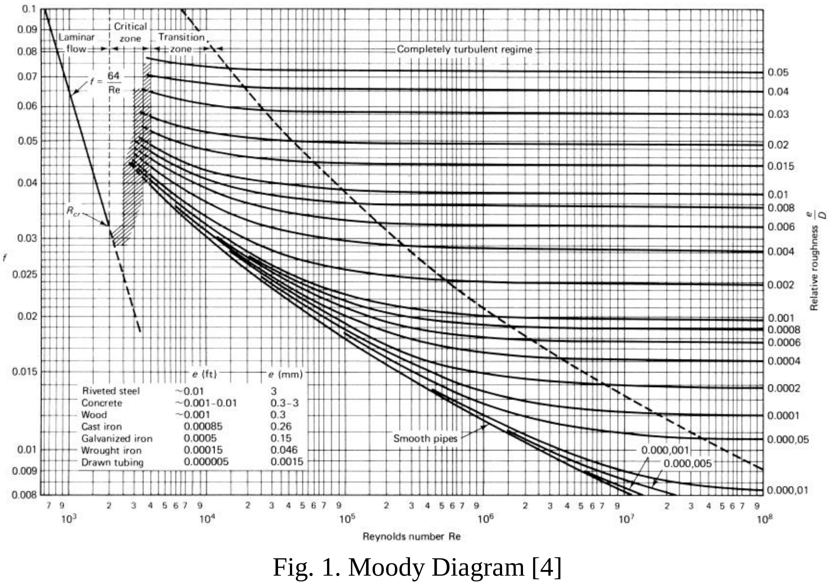

Fig. 1. Moody Diagram [4]

The governing equations for EPANET's water quality solver is based on the principles of conservation of mass coupled with reaction kinetics. The following phenomena are represented [9]:

- Advective Transport in Pipes,
- Mixing at Pipe Junctions,
- Mixing in Storage Tanks,

- Bulk Flow Reactions,
- Pipe Walls Reactions.

The values of the weighted average are calculated based on the values of the age of water calculated for individual pipelines [1]:

$$W = \frac{\sum_{i=1}^{n} (W_i \cdot L_i)}{L} \tag{2.4}$$

where:
W_i - age of water calculated for all pipes of a given diameter d, h,
L_i - length of all pipes of a given diameter, d, m, m,
L - sum of lengths of all pipes in the water supply network, m;
n - number of diameters d of pipes applied in the water supply system.

3. RESULTS

The basis for calculations were models of systems developed using the EPANET program. Input data for calculations are:

- a network graph (accounting for pump stations, reservoirs)
- for nodes: elevation, volume and irregularity of water consumption,
- for pipelines: length, diameters, roughness, local loss coefficient,
- characteristics of pumps,
- parameters of reservoirs and tanks.

The analysed systems are characterized by a mixed layout of the network.
In the Lubin system, the length of the water supply network is approx. 43,300 m, while the pipe dimensions range from φ 50 to φ 315. The graph comprises 72 nodes and 74 segments. It has been presented in Figure 2.

Fig. 2. Graph of the water supply system in Lubin

The length of network in the Głogów system is approx. 132,000 m, while the range of pipe diameters is φ 100 - φ 700. The graph comprises 898 nodes and 1,117 segments. It has been presented in Figure 3.

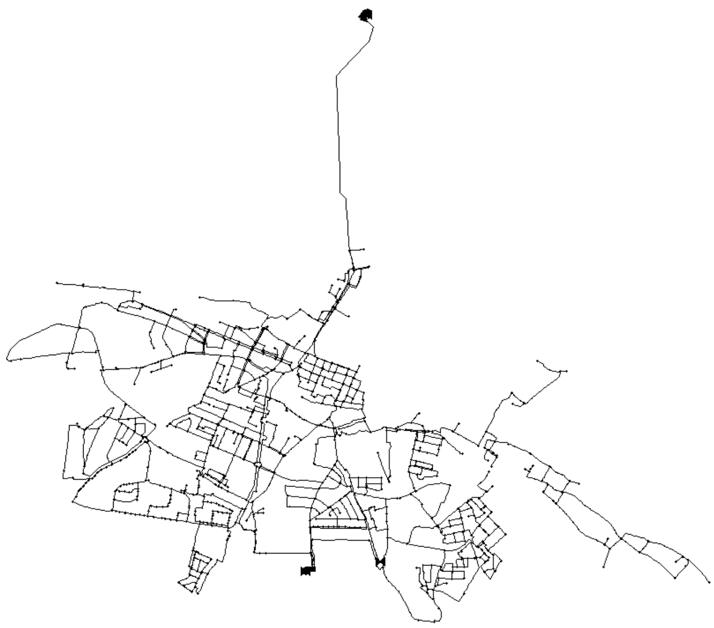

Fig. 3. Graph of water supply system in Głogów

Using the developed models, calculations of hydraulic parameters and the water age in pipes were carried out in the EPANET program for both water supply systems. The duration of the simulation was assumed at 288 hours for the calculations. Ranges of pressure and flow rate at hours with minimum and maximum values of water use have been presented in Table 1. Contours of water pressure in the Lubin system are presented in Figure 4, whereas in the Głogów system - Figure 5.

Table 1. Ranges of pressure and flow rate [7]

System	Pressure Range (m)	Flow Rate Range ($m \cdot s^{-1}$)
Minimum use		
Lubin	32.78-76.46	~0,00-1.09
Głogów	14.98-62.10	~0,00-1.12
Maximum use		
Lubin	25,80-67.45	~0,00-1.02
Głogów	11,19-57.74	~0,00-0.71

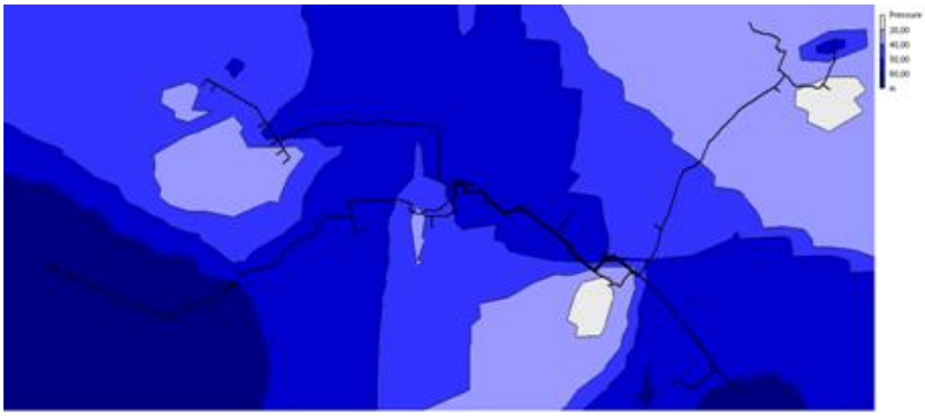

Fig. 4. Contours of water pressure levels in Lubin system during maximum water consumption

Fig. 5. Contours of water pressure levels in the Głogów system during maximum water consumption

Based on the obtained results, the values of weighted averages of water age for individual pipeline diameters. The results have been compiled in Figure 6 and Figure 7.

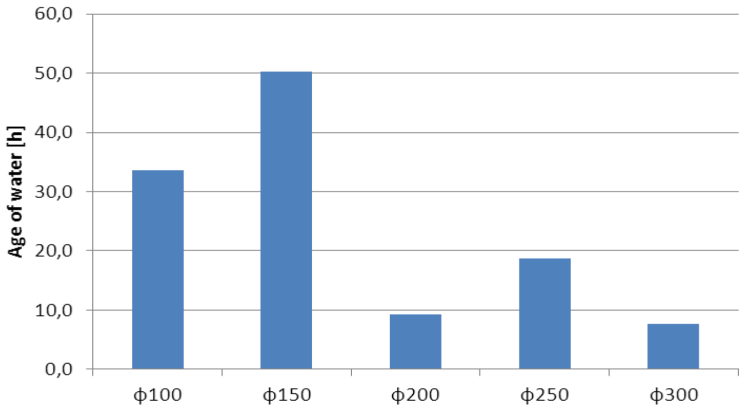

Fig. 6. Values of weighted averages of the age of water for individual pipeline diameters in Lubin

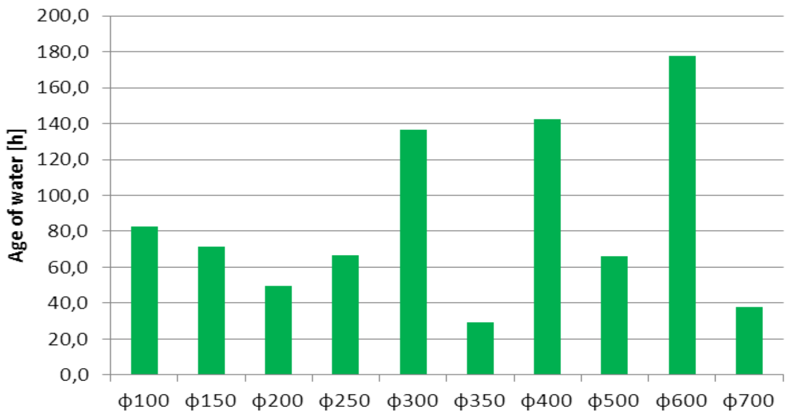

Fig. 7. Values of weighted averages of the age of water for individual pipeline diameters in Głogów

4. CONCLUSIONS

The conducted analysis made it possible to assess the hydraulic conditions in the operating water supply systems. The carried out analyses allowed for establishing the values of such parameters as the pressure for all nodes as well as the flow rate and water age for individual segments of the network.
The following conclusions have been formulated based on the carried out calculations:

- significant variation in the water use over the course of a day and hydraulic parameters exists in the analysed systems, with this resulting from the nature of water consumers,
- irregularity of water pressure in the network is a reflection of the irregularity in water consumption,
- the introduction of pressure regulation systems, making it possible to limit water losses caused by excessive pressure in periods of minimal water consumption ought to be considered,
- industrial and mining companies are characterized by the greatest irregularity of water consumption, which is connected with the schedule of work shifts,
- the carried out simulations indicate the possibility of the occurrence of lowered water quality due to it being stored in the water supply network for an excessive period of time.

The developed models of systems can be the basis for further simulation calculations and for assessing the influence of planned changes on the level of selected parameters.

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MODELOWANIE PARAMETRÓW WYBRANYCH SYSTEMÓW ZAOPATRZENIA W WODĘ W WOJEWÓDZTWIE DOLNOŚLĄSKIM

Streszczenie

W pracy przedstawiono zagadnienie modelowania systemów zaopatrzenia w wodę w kontekście podstawowych parametrów charakteryzujących ich pracę. Oprócz typowych parametrów, takich jak ciśnienie i prędkość przepływu ważna jest ocena wieku wody, jako parametru oceny jakości doprowadzanego medium. Analiza oparta została na dwu obiektach w tym jednego o zróżnicowanym spektrum odbiorców, obejmującym mieszkalnictwo i przemysł. Przeprowadzone symulacje wskazują na możliwość występowania obniżenia jakości wody z uwagi na zbyt długi okres jej magazynowania w sieci wodociągowej. Nie bez znaczenia jest wpływ nierównomierności poboru wody, zwłaszcza w przypadku zasilania różnego rodzaju odbiorców (w analizowanym przypadku zakładów górniczych).

Słowa kluczowe: system zaopatrzenia w wodę, ciśnienie wody, prędkość przepływu, wiek wody, program EPANET

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