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MINIMAL ENERGY PRINCIPLE IN WATER SUPPLYING SYSTEMS

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Abstract

One of the crucial problems of the functions of water supplying system is often very large electrical energy consumption and therefore the providing the means for its payment. The process of reduction of energy consumption in water supplying systems usually takes place gradually, so we encounter specially defined things such as efficiency of pumps and their aggregate, friction losses in pipelines, water losses in systems, etc. This is obviously a complex process with different parameters that do not fit in easily. Operative applying requires establishing a simpler methodology, which would describe energy component of each system in a unique way. That is the reason for propose the indicators, based on which it would be possible to evaluate the system's condition simply and quickly, and to recommend measures that should be taken in order to improve its energy efficiency..

Key words

energy; indicator; water losses; water supply system

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1 INTRODUCTION

Energy consumption in water supplying systems depends on the system types above all. In other words, it depends on its configuration [1]. Water source location, compared to drinking area, represents the main point of it. If the source lies above the consumption place, water transport requires either very small or no additional energy at all. Whenever the source is lower than the consumption place, water transport requires more energy for maintaining the functions of the pump plants in the first place. Normally used specific energy indicators of consumption (kilowatt hour per cubical metre of elevated water) say very little or almost nothing about how efficiently the energy is used in the system. [2, 3] These issues are quite present in the water supply systems of Montenegro. This was one of the reasons to investigate the basic indicators of energy use in these systems. In this way creating opportunities for providing recommendations for their more efficient work have been created.

2 MINIMAL ENERGY CONCEPT

Minimal energy required for water supplying system can be defined as the least energy amount theoretically required for the water transport from production place to the consumer place, [1] for some operative level of pressure (in our condition, it is usually 5-6 bar). Let's take a look at the pumping system presented on Figure 1. Let's assume that the consumption place consists of 5,000 inhabitants who usually spend 300 litres per inhabitant per day, so the annual consumption of this place is $547.5 \cdot 10^6$ litres. Height difference that has to be overcome is 200+60=260m. Minimal energy is calculated in the following way: water mass multiplied by gravitational acceleration multiplied by height difference and in this specific example, it amounts 387,902 kWh, which means that the consumed quantity of elevated water is 0.71 kWh/m^3. [2]

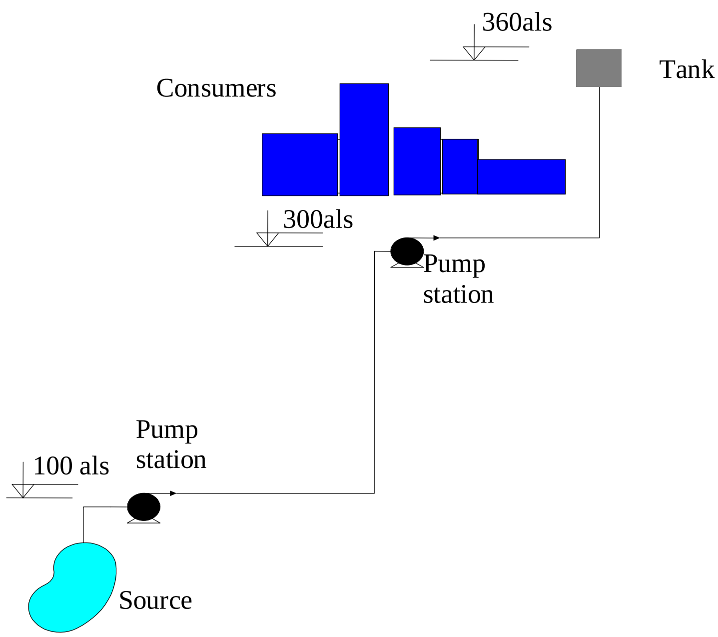

Fig. 1: Scheme of water systems pumping to consumption

It's not always possible to calculate minimal energy in such a way. In many systems, there are more sources, more reservoirs, the consumption categories are not uniform, etc. In order to overcome these difficulties, we can use the term of potential energy, which is actually water elevation theoretically required from the grip place to the ultimate consumers. In other words, the subtract between potential energy of 1m^3 water at the consumer's level and on the level of source is the energy of water elevation. According to that, minimal energy can be calculated as a subtract between potential energy of water amount annually spent per consumer and potential energy of the same water amount per source, plus energy required for enabling operating pressure in system (usually 5÷6 bar) [4]. Formula for minimal energy can be written as:

$$\mathrm{E}_{\min} = E_{CONS} - \mathrm{E}_{\mathrm{S}} + E_{OP} \tag{1}$$

Where:

E_{CONS} is the sum of potential energy of water annually spent per consumer(kWh);

E_S is the sum of potential energy of water annually spent per source (kWh);

E_{OP} is the energy required for enabling operating pressure of a system (kWh).

Formulas for mentioned values can be approximately written as:

$$E_{CONS} = 0.00273 \cdot \left(Q_{k1} \cdot H_{k1} + ... + Q_{kn} \cdot H_{kn} \right) \tag{2}$$

$$E_S = 0.00273 \cdot \left(Q_{ws1} \cdot H_{ws1} + ... + Q_{wsm} \cdot H_{wsm} \right) / \left(1 + \frac{G_s}{100} \right) \tag{3}$$

$$E_{OP} = 0.00273 \cdot 60 \cdot \left(Q_{k1} + ... + Q_{kn} \right) \tag{4}$$

with:

Q_{ki} amount of water spent by *i*-consumer (m^3);

H_{ki} the altitude of the consumer (m);

Q_{ws} the amount of water gripped at sources (m^3);

H_{ws} the altitude of the source (m);

G_s water losses in system (the estimation *t* of water produced but not used by the ultimate consumers).

The value of loss G_s represents approximate losses in the system or special pressure zone. Having that in mind, ES value can't be precisely determined, and it always depends on the accuracy of loss estimation. However, for calculating value of E_{min}, we usually have enough data (amount of water pumped, amount of water sold, altitudes etc.) which can be enabled in great percentage of water supplying systems.

3 BASIC INDICATORS OF USING ENERGY IN WATER SYSTEM

If we are familiar with minimal energy values, it is possible to introduce some certain indicators, based on which it is possible to evaluate and compare specific systems and their conditions. [5]

Structural indicator – minimal energy term enables introducing new term, so-called structural indicator that we use to describe energy features of water supplying systems, in other words, the influence of differences in height of the ultimate users and the source on the energy spent. It can be further defined as:

$$SI = E_{\min} / Q_c \tag{5}$$

Where Q_c is annual water consumption per consumer. Normalisation of Q_c causes the value of structural indicator to be independent of the sum of water supplying system. Theoretically, it is possible of structural indicator value to be negative, which means that the energy produced is of a raw water. In that case, potential energy of the source is far greater than the consumption of water in system. [6]

Qualitative indicator – this terms shows if the energy required for water supplying systems is used economically, or if we use it to compare the real energy consumption in a minimally required system for its functioning. If we assume that total raw water amount is pumping, then the qualitative indicator can be defined as:

$$QI = E / E_{\min} \tag{6}$$

Where E represents energy really consumed during a certain period of time (one year).

If the energy used equals theoretical minimum, then the value of QI would equal 1. However, such a case has never occurred in practice, because every water supplying system functions with losses, and the efficiency of pump plants is always less than 100%. High KP values mean the possibility of energy reduction under certain circumstances. This indicator is also independent of the system quantity and does not depend on the energetic systems in practice.

For practical applying, the qualitative indicator can be calculated as:

$$QI = E / E_{\min} = \frac{K \cdot (1 + G_s / 100) \cdot \left[(H_R - H_S) / (H_C - H_S + 60) \right]}{\eta} \tag{7}$$

With:

K the ratio of pressure gauge heights of pump elevation and subtract H_R -H_S;

Gs loss percent;

H_R the reservoir altitude (m);

H_S the height of a well, underwater source (m);

Hc average altitude where the consumers reside (m);

η pumps efficiency.

Qualitative indicator can be calculated for one consumption zone or for the whole area supplied. The estimations for one consumption zone requires the exact data of energy consumption for each part of equipment incorporated in it, far more precise than when it is about the whole system level. Complex systems that do not enable unification way of supplying often require that kind of estimation, for each zone separately. Forming the basic zones of balancing, usually suggested as a measure in preventing losses in water systems, can lead to more precise determination of qualitative indicator at the same time.

Approximate values of qualitative indicator, with the system condition estimation, are given in the Tab. 1.

Tab 1. Values of qualitative indicators and evaluation of system for them [1]

Qualitative indicator (QI)	***Energy consumption (economical evaluation)***
< 2	Very good
2 – 2.5	Good
2.5 – 3.0	Economically acceptable
3.0 – 4.0	Require changes
> 4.0	Require immediate changes

Minimal energy of water pumping – if raw water is partially supplied from the sources of the altitudes up above the settlement, and partially from the well, minimal energy has to be substituted with the term of minimal energy for water pumping and it is calculated similar to previously explained E_{min}. Numerous water systems have mixed type of supplying, gravitational and water pumping supplies. That's why, for the purpose of calculating minimal energy, it is required to separate the amount of water coming to the ultimate consumers one way or another:

$$Q_t = Q_{pw} + Q_{gw} \tag{8}$$

Where:

Q_{pw} is the annual water supply by pumping (m^3);

Q_{gw} is the annual water supply by gravity (m^3).

Minimal beneficial energy in this case equals:

$$E_{\min C} = E_S \cdot \frac{Q_{pw}}{Q_t} \tag{9}$$

Minimal energy required for supplying operating pressure in system per user is:

$$E_{\min OP} = E_{OP} \cdot \frac{Q_{pw}}{Q_t} \tag{10}$$

While minimal potential energy at the source level $E_{\min S}$ equals potential pumping energy at each source, divided by losses factor $\left(1+\frac{G_s}{100}\right)$.

Therefore, the total minimal energy of water pumping equals:

$$E_{\min P} = E_{\min C} - E_{\min OP} + E_{\min S} \tag{11}$$

It is obvious that, if the whole amount of water is being pumped, minimal water pumping energy equals the total minimal energy assuming that:

$$E_{\min C} + E_{\min S} > E_{\min OP} \tag{12}$$

4 QUALITATIVE INDICATOR OF SOME WATER SUPPLYING SYSTEMS IN MONTENEGRO

The estimation of qualitative indicators of some water supplying systems in Montenegro (table 2) has been executed based on the most thorough and the most precise review of the water supplying system condition in Montenegro so far, described in the study case „Projection of long-term water supplying in Montenegro“[7]. Qualitative indicator is calculated for some systems in which the whole water amount is pumped or pumping is a part of partial supplying from the source. Just like when the study case was created, there are some unknown things even nowadays, in almost each system that does not enable entirely correct estimation of the mentioned indicator. Here, in the first place, we think of operating efficiency lack of pumping plants and of imprecise height boundaries in pressure zones through systems. That’s why in this process there were required some simplifications and assumptions for unavailable data. On that way, in estimation for all pumps, the assumed efficiency degree of 65%, which certainly doesn’t have to be correct for each and every system, suits some usual operating conditions. However, thorough fullness and precision of the rest of the data used in this estimation lead to the conclusion that the values achieved are genuinely plausible and practical.

The estimation has shown that the least qualitative indicator value is in two biggest cities, Podgorica and Nikšić, or that the energy used in these two cities is the most efficient. Practice has proved it right, because these two systems, especially Podgorica water supplying system, are taking precautionary monitoring and loss sanation for longer period of time. Additionally, they are applying new technologies, rationalized consumption etc., which leads to energy efficiency of these systems. Other analysed water supplying systems have the QI values which require alterations in their work. The main reason for relatively high QI values of other water supplying systems is a high percentage of water loss in systems themselves in the first place. This analysis is confirmed through practical steps that some of the mentioned water supplying systems have already taken, because their ordinary work has shown the requirement for alterations which would enable more efficient using of all the system resources (for example, maritime water supplying systems).

Tab 2. Qualitative indicator (QI) of each water supplying systems in Montenegro

Ordinal numer of municipality	***City water supplying system***	***Water produced***				***Losses***	***Quality indicator (QI)***
		Total		***Quantity transported from source (m³/annually)***		***% from amount produced***	
		m³/ annually	***l/s***	***GRAV.***	***PUMP.***		
1	Andrijevica	1,261	40	1,261	-	72.00	
2	Bar	7,726	245	4,257	3,469	65.00	3.35*
3	Berane	4,600	146	4600	-	50.00	
4	Bijelo Polje	4,730	150	4730	-	56.00	
5	Budva	4,680	148	1368	3,312	46.00	2.88*
6	Danilovgrad	4,257	135	788	3,469	70.00	3.42
7	Žabljak	598	19	536	62	46.00	
8	Kolašin	2,027	70	2,207	-	57.00	
9	Kotor	7,569	240	1,262	6,307	65.00	3.60*
10	Mojkovac	630	20	630	-	45.00	
11	Nikšić	11,258	357	-	11,258	38.00	2.52**
12	Plav	876	28	876	-	44.00	
	Gusinje	780	25	780	-	70.00	
13	Plužine	420	13	420	-	50.00	
14	Pljevlja	4,493	142	2,286	2,207	54.00	3.20*
	Gradac	66	2	33	33	40.00	
15	Podgorica	26,183	830	-	26,183	35.00	2.40*
	Tuzi	572	18	-	572	55.00	
16	Rožaje	3,564	113	3,564	-	72.00	
17	Tivat	2,522	80	-	2,522	50.00	2.95*
18	Ulcinj	5,489	174	2,066	3,423	62.00	3.10*
19	Herceg Novi	11,574	367	9,461	2,113	60.00	
20	Cetinje	3,050	97	200	2,850	52.00	3.05*
	Rijeka Crnojevića	160	5	160	-	54.00	
21	Šavnik	138	4	138	-	50.00	
TOTAL m³/annually		109,403		41,623	67,780	54.32	
AVERAGE l/s		3,469		1,320	2,149		

* - water supplying systems with more sources, pumping stations and reservoirs, value given represents average value

** In chart, there is labeled that all the water gripped is being transported into the area of pumping consumption, even though water from the source to the PS "Duklo" is brought by gravity. Considering that total water amount elevates over that pumping station, impartially speaking, the issue is not gravitational water supplying (because water elevation is necessary), and pumping station could be located at the very source. [7]

5 RECOMMENDATIONS FOR IMPROVING QUALITATIVE INDICATORS

Improving qualitative indicators of water supplying systems in Montenegro can be accomplished by process of designing new systems (parts of the existing ones) or by altering existing and their maintaining and controlling their work. By taking precautions of lowering qualitative indicators, the positive effects would certainly take place, which can lead to extending exploit period of the source and systems themselves, and systems can gradually be transferred into the state of efficient functioning according to market principles [8].

Savings in designing process

This category includes selection of colours, position and capacity of a reservoir, number and type of pumps and traces and diameters of leading suppliants in designing process [9]. Height position of a reservoir determines energy spending in system, and that's why a thorough analysis has to be obligatory in designing process. [10] Great height differences should be eliminated by dividing into two or more zones. The activation of a new source (if possible) on higher altitudes above the reservoirs can significantly reduce energy expenses, but it can also show that the expenses of that act are greater than savings accomplished.

System fixing

Rehabilitation and update of the existing systems should be a main thing in the process of improving qualitative indicators of water supply systems. On that way, system losses are reduced, supplying security increases etc. Examination and replacement of dilapidated pipelines, pumps and fasteners are required for proper managing of existing systems. Energy saving can be accomplished by optimisation of pump operating and controlling compatibility of their work, but also charging and emptying of reservoir, especially in multiple pumps systems and reservoirs and developed supplying network. Optimisation of operating pumps and reservoirs can be adjusted and connected with electrical energy different rate structure during the day as well as changes of the consumption of the ultimate consumers. If is often a very hard process, but savings accomplished justify it. [11]

Water pressure in distribution network and energy conservation are intertwined so that they are practically synonymous. Any reduction in the pressure level in water distribution network will automatically result in a reduction of the use of energy (tab. 3).

Tab. 3: Examples of pressure reductions in facilities and the saving effects achieved [10]

Type of facility supplied by water	**System pressure before the reduction (bar)**	**System pressure after the reduction (bar)**	**Savings**	
			Water	**Energy**
			m^3 / month	**kWh/month**
Educational institution, 5 floors, 3600 m^2	7.0	4.0	1,925	2,090
Administrative – business facility, 6 floors, 2500 m^2	7.5	4.0	2,512	2,696
Residential building, 9 floors, 450 consumers	7.0	5.0	1,179	1,964
Complex of residential buildings, 1420 consumers, 5 floors	7.0	4.5	2,284	2,446

Programme of rehabilitation and pipeline substitute improves energy efficiency of the whole system, even through reduction of the roughness of pipeline walls. Previous analyses have shown that increasing the pipeline roughness causes the growth of energy consumption in water supplying system [3]. One study case of eight different water supplying systems in European cities has shown that from 2,3 to 26,8% of total system energy requirements is overcoming losses due to roughness, including vents and faucets at ultimate consumers [6].

Changes of existing pipes diameters can also affect energy balance of the whole system but, generally speaking, the greatest influence has the change of the roughness, or its decreasing.

CONCLUSION

Water distribution systems in Montenegro consume a significant quantity of energy to transport water. Pumping stations are usually most responsible for a high percentage of energy losses in water distribution systems. Improving hydraulic and energy efficiency in water distribution systems can be aided by knowledge of systems qualitative indicators. A simple analysis of these indicators in Montenegro shows that water systems are on the borders of sustainability and they require significant and rapid changes. In all systems there are large reserves and the potential to increase their energy efficiency. Given recommendations and guidelines aim at desired changes for the better further acceleration and contribute to improving the indicators and thus reducing the consumption of expensive energy in water supply systems.

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