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Analyzing the possibility of using the internal energy of part of the Posušje municipality water supply system

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Abstract: Supplying the population with drinking water is an indispensable segment within today's high-quality and sustainable development of human society. The sustainability of water supply systems can be improved by exploiting available renewable energy sources. External renewable energy sources are mostly solar energy, wind energy, water energy, geothermal energy and energy obtained from biomass, hydrogen energy. In contrast, internal renewable energy exists in the water supply system itself. The paper analyzes the possibility of using internal energy by installing a turbine on the main gravity supply pipeline from the Tribistovo reservoir to the water treatment device of the Posušje municipality water supply system.

Key words: water supply, sustainability, renewable energy sources, turbines on water supply pipelines

Analiza mogućnosti korištenja unutarnje energije dijela vodoopskrbnog sustava općine Posušje

Sažetak: Opskrba stanovništva pitkom vodom neizostavan je segment u okvirima današnjeg kvalitetnog i održivog razvoja ljudskog društva. Održivost rada vodoopskrbnih sustava može se poboljšati iskorištavanjem dostupnih obnovljivih izvora energije. Vanjski obnovljivi izvori energije su najčešće energija sunca, energija vjetra, energija vode, geotermalna i energija dobivena iz biomase, energija vodika, dok unutarnja obnovljiva energija postoji u samom vodoopskrbnom sustavu. U radu se analizira mogućnost iskorištenja unutarnje energije postavljanjem turbine na glavnom gravitacijskom dovodu od akumulacije Tribistovo do uređaja za pročišćavanje vode vodoopskrbnog sustava općine Posušje.

Ključne riječi: vodoopskrba, održivost, obnovljivi izvori energije, turbine na vodoopskrbnim cijevnim vodovima

1. INTRODUCTION

The water supply system is a complex of facilities used to supply water from natural sources, purify it, transport it and distribute it to consumers, as shown in Figure 1.

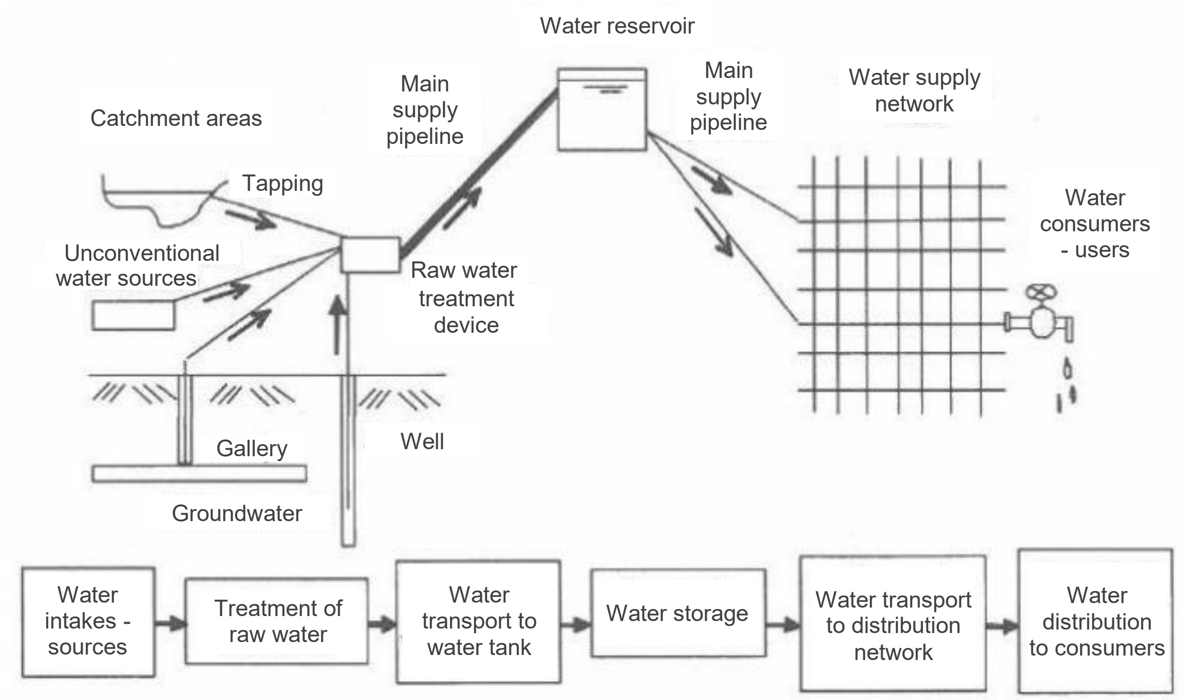


Figure 1. Elements of the water supply system [1]

The task of the water supply system is to provide efficient, sustainable and safe water supply in accordance with drinking water standards and other standards that must be met by water supply systems, which is generated by consumers on the one hand, and provided (limited) by available resources on the other hand. The basic functions of the water supply system are:

- to meet all the needs of consumers with water of drinking water quality
- provide the required pressure in the water supply network
- provide a sufficient reserve of water for all incident situations
- provide water for firefighting at all possible locations (hydrants) while maintaining the set pressure in the system for all other users

In order for the water supply system to meet all these requirements, it is necessary to construct a wide range of facilities. They all form a single whole, the main goal of which is to permanently provide sufficient quantities of high-quality water, under the necessary pressure and in the most economical way.

1.1 Objective of the paper

The objective of this paper is to analyze previous research in terms of achieving the energy sustainability of water supply systems using the system's internal energy. Internal renewable energy exists in the water supply system itself as unused potential energy. The paper analyzes the possibility of using internal energy in the water supply system of the city of Posušje, specifically on the main gravity feed from the Tribistovo reservoir to the water treatment plant immediately before the Posušje reservoir.

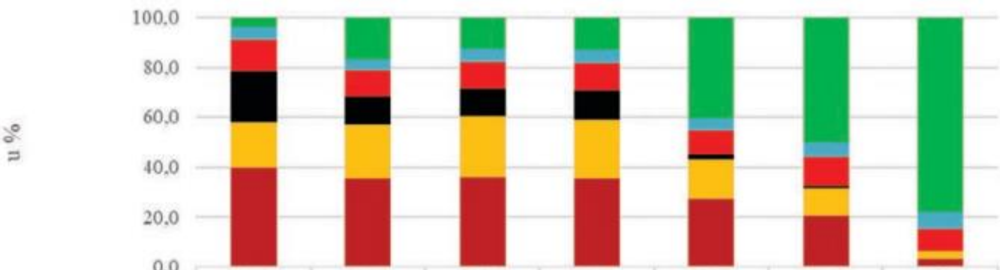
1.2 Research methodology

The paper will first examine previous research related to the use of internal energy in water supply systems by introducing turbines. Based on the past experiences and the analysis of the hydraulic condition on our considered supply pipeline, a place will be proposed to install a turbine for using the internal energy of the system, and the resulting energy will be calculated. This energy can be used for the operation of the treatment plant or for the operation of the monitoring and control system on the water supply system of the municipality of Posušje. In this way, the sustainability of the system would be increased and the allocation of total funds for the necessary energy from the power grid would be reduced.

1.3 Renewable energy sources

The increase in greenhouse gas emissions presents a major threat to climate change, with potentially catastrophic consequences for humans. Renewable energy sources, together with the improvement of energy efficiency in direct use, help reduce primary energy consumption, mitigate greenhouse gas emissions, and in this way mitigate the impact on climate change. Also, due to recent geopolitical events and the need to reduce dependence on conventional energy sources, there is an increased interest in distributed production from renewable energy sources.

According to the net-zero CO2 emission scenario from the March 2022 Outlook publication, the transition from fossil fuels to RES will be accelerated. The share of fossil fuels of 82.3% in 2021 should decrease to 60.9% by 2030 and to 18.7% in 2050. In this scenario, petroleum is at a disadvantage compared to gas. By 2050 petroleum consumption would be reduced to only 3.2% and gas to 3% compared to 84.8% of RES (78%) with hydro sources (6.8%) [2].



	1995.	2019.	2020.	2021.	2030.	2035.	2050.
RES	3,9	16,9	12,5	13,2	40,2	50,3	78,0
Hydro sources	5,1	4,3	5,5	5,4	5,4	5,9	6,8
Nuclear energy	12,4	10,5	11,0	11,0	9,5	11,3	8,7
Coal	20,7	11,2	10,6	11,2	1,8	1,1	0,3
Natural gas	17,8	21,6	24,5	23,8	15,8	10,7	3,0
Oil	40,0	35,5	35,9	35,5	27,4	20,7	3,2

Figure 2. Forecast shares of individual sources
in the total primary energy consumption in the EU27 [2]

Renewable energy sources can be divided into external energy sources (such as solar energy, water energy-hydro power, geothermal energy, wind energy, energy from biomass, hydrogen), and internal energy source, in this case energy within the water supply system itself.

2. WATER TURBINES

Different types of turbines can be used to convert water energy into electricity, among which the best known are: reaction turbines - Francis and Kaplan turbines, and action turbines - Pelton turbines. Micro turbines, pumps as turbines, and the so-called Lucidpipe turbines, which are installed directly on the water supply pipe, are developed and installed in recent times. The field of application of Francis, Kaplan and Pelton turbines depends primarily on the available net head and flow, as can be seen from Figure 3.

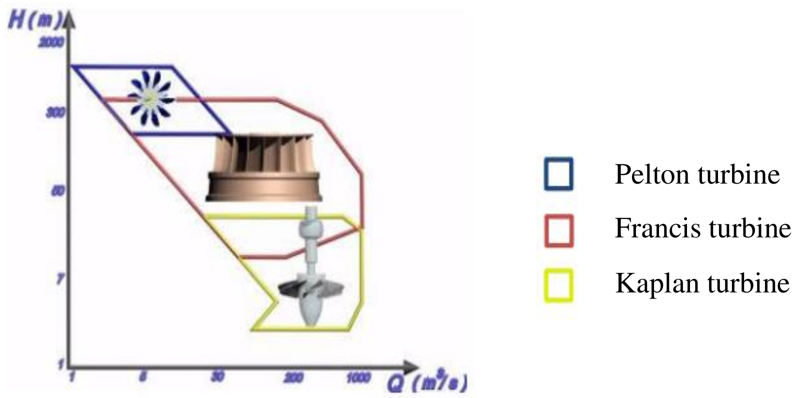


Figure 3. Field of use of Kaplan, Francis and Pelton turbines [3]

Typical efficiencies of Kaplan, Francis and Pelton turbines with regard to their specific speed are shown in the figure (Figure 4). Specific speed is a measure expressing how big the turbine should be in terms of dimensions to produce a certain power at a certain head. For example, as can be seen in Figure 4, the specific speed of the Pelton turbine is low, which means that the Pelton turbine can be used to produce a large amount of energy with a large head at small dimensions, i.e. at a low flow.

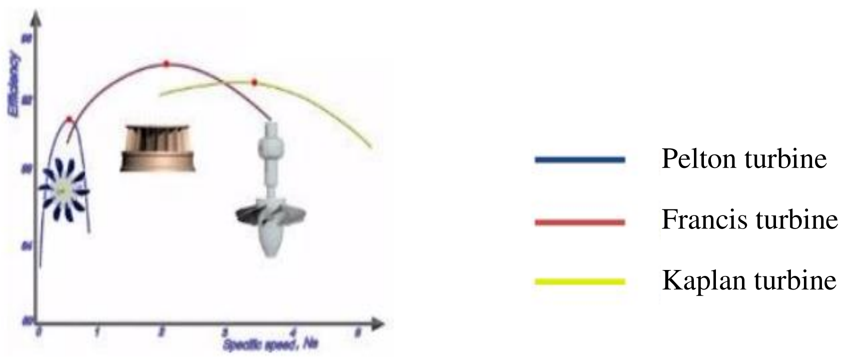


Figure 4. Efficiency of Pelton, Francis and Kaplan turbines [3]

A company named Lucid Energy [4] has developed a water turbine with a vertical axis of lift for a large water supply. This system was developed only for pipelines that are larger than 600mm. Figure 5 shows this type of water turbine with a vertical axis of lift. In order to be able to install this system, the minimum value of the 'excess' pressure in the pipes must be from 0.3 to 0.5 bar. In the case when the turbine is stopped for safety reasons or when there is no flow, it represents a local loss and reduces the pressure by 0.1 bar, while in operating conditions it reduces the pressure by 0.1 to 0.3 bar (Table 1).

Table 1. Characteristics of the Lucidpipe system [4]

LUCIDPIPE diameter [mm]	Expected electricity production [kW]	Expected flow [cm^3/s]	Measured pressure required for expected production [m]	Expected pressure drop [m]	Expected pressure drop when the turbine is out of operation [m]	Coefficient of pressure loss in / out of operation
600	14	1	32	3.7	1.1	6.7-8.4/2.0
1000	50	3	35	4.1	0.9	7.7-10/2.3
1500	100	6	27	3.5	1.0	7.7-10.1/2.3

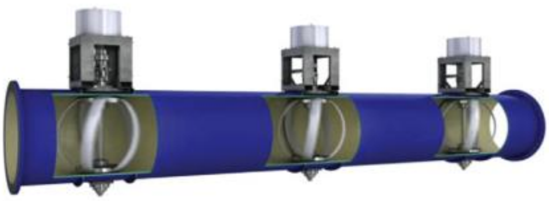


Figure 5. Portland: Lucidpipe system [4]

3. EXAMPLES OF APPLICATION OF WATER TURBINES IN WATER SUPPLY SYSTEMS

In Portugal, for the purposes of scientific research, a turbine was installed in a bypass pipe on the water supply system, and its efficiency in the production of electricity was proven in combination with the electrical power grid and other renewable energy sources [5].

An example of good practice of using the internal energy of water supply systems is the city of Boulder, Colorado. Since 1985, excess pressure in the water supply system has been used to generate electricity. Today, the city has eight facilities where the internal energy of the water from the water supply system is converted into electricity. In each facility there is a turbine to which the water captured at the source flows through the gravity system of pipes, and by turning the turbine, it produces energy that is sent to consumers through the electricity supply system. Pelton turbines are installed in places with a pressure higher than 24 bar. In places where the water pressure is between 3 and 24 bar, Francis turbines are installed to ensure the minimum pressure required to supply consumers downstream [6].

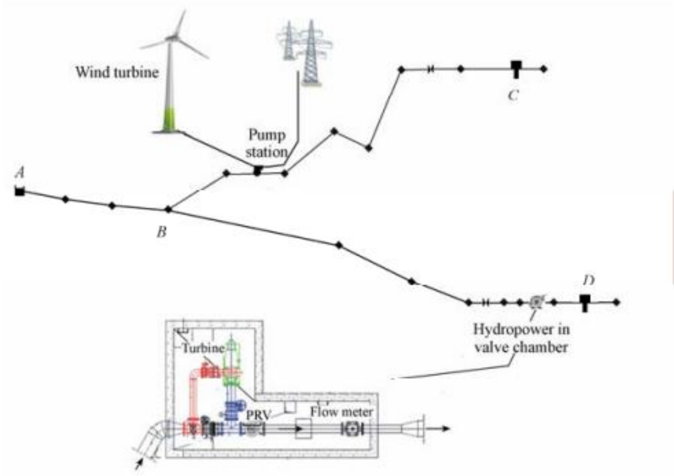


Figure 6. Illustration of the case study in Portugal and installation of a turbine in a bypass pipe in the chamber of the pressure reducing valve (PRV) [5]

Figure 7. Locations of constructed facilities with Pelton turbines (marked in yellow) and Francis turbines (marked in blue) on the water supply system, Boulder, Colorado [6]

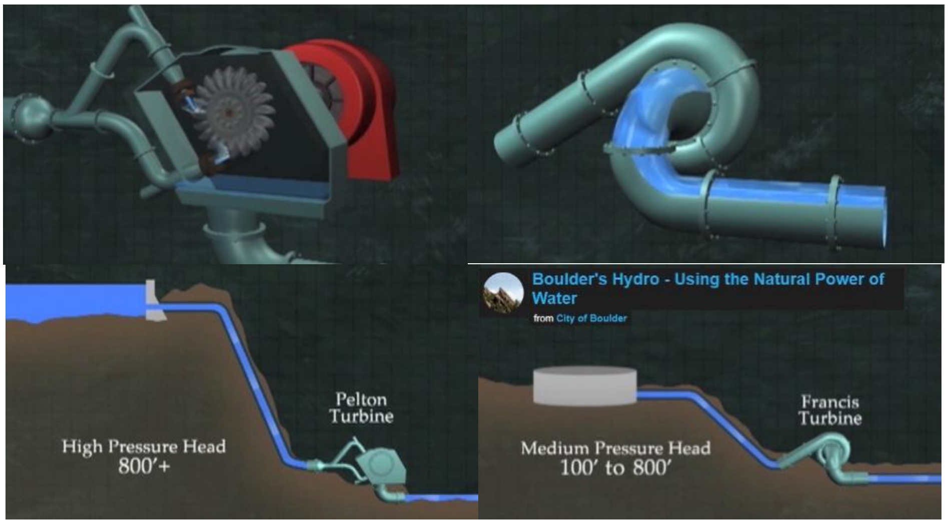


Figure 8. Principle of operation of Pelton (left) and Francis turbine (right) [6]

Installation of the mentioned Lucidpipe system is shown on the water supply system in the city of Portland, Oregon in Figure 9. Due to its design, the system can operate in a very wide range of flow conditions, volumes and speeds. It can be configured to efficiently generate electricity within a wide range of pipe diameters, ranging from 600mm to 2400mm. Lucidpipe turbines are not installed in bypass pipes, but directly in the water supply pipes of the gravity pipeline, which is their biggest advantage over other similar systems. The flow of water inside the pipe causes the turbine rotation, which is converted into electricity via a generator. They are constructed so as to minimally disrupt the flow of water. In the event that there are already installed pressure reduction valves, these turbines can be placed before the valve, and then their main role is to reduce pressure on the section upstream of the valve, reduce pipe wear caused by high pressures, and thereby extend the service life of the valve itself. On sections of the gravity pipeline where pressure reduction valves are not installed, and pressure reduction is required, we use the Lucidpipe system to gradually reduce the pressure in the pipes and at the same time produce electricity [7].

Figure 9. Delivery and installation of the Lucidpipe system on the water supply system of the city of Portland, Oregon [8]

Micro turbines are developed and tested in the world, and so is the justification for using micro turbines in contrast to pumps as turbines (PAT), and their performance and cost-efficiency are tested, which was also carried out in the case of the water supply system of the city of Funchal in Madeira, Portugal [9].

4. WATER SUPPLY SYSTEM OF POSUŠJE MUNICIPALITY IN BIH - MAIN SUPPLY PIPELINE

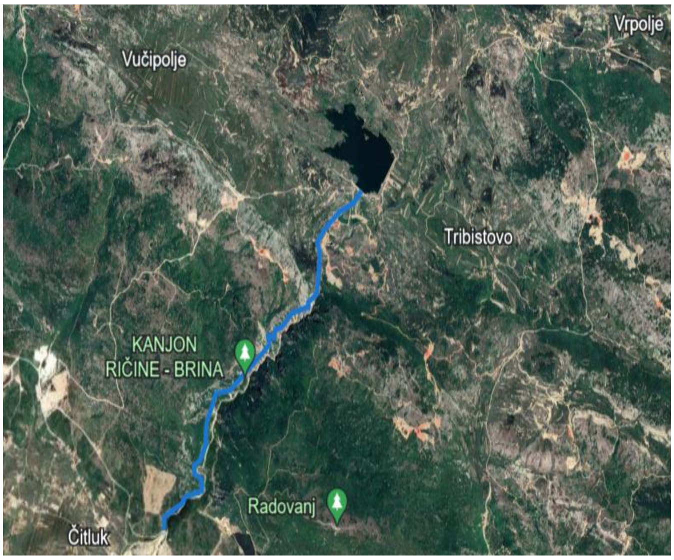


Figure 10. The layout position of the Tribistovo reservoir and the canyon of the temporary watercourse of Ričina, where the water supply pipeline is located

4.1 Tribistovo reservoir

The multipurpose reservoir Tribistovo was formed on the Ričina watercourse and has a water surface area of 700,000 m². Lake levels range from 906 m a.s.l. to the designed water level in the reservoir of 913.5 m a.s.l. + depth of water flowing over spillway of 0.5 m. The absolute highest water level so far was recorded in 2005 and was 913.99 m a.s.l. It is planned to be used for the purposes of water supply, irrigation, energy industry and flood wave control.

4.2 The main supply section: Tribistovo reservoir – treatment plant

The main supply pipeline has a total length of 5748.7 m and consists of:
- the first and second section of the previously constructed pipeline in a length of 833 m, i.e. profile DN 800 mm was installed in a length of 106 m, and profile DN 600 mm was installed in a length of 727 m
- the third newly constructed section with a length of 4,915.70 m profile DN 600 mm

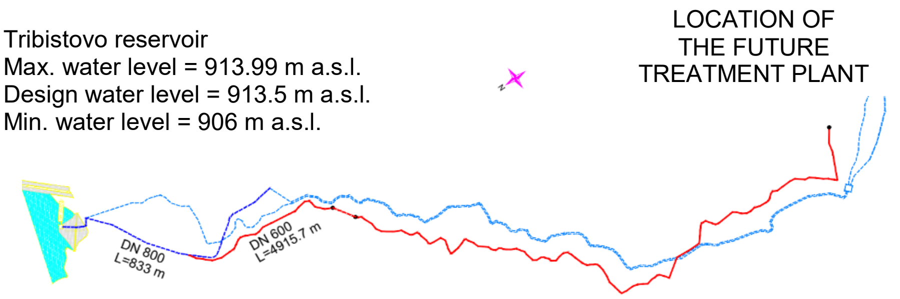


Figure 11. Schematic view of the position of the main supply pipeline from the Tribistovo reservoir to the treatment plant

<u>Calculation of steady states</u>

The piezometer line at the beginning of the designed part of the pipeline was calculated based on data on the existing (constructed) section. The piezometer line was calculated for two operating conditions: normal operating conditions (NOC) and limit operating conditions (LOC).

Table 2. Determining the piezometer line at the beginning of the pipeline for normal and limit operating conditions for the first and second section with a total length of 833 m [10], [11]

Parameter			**Normal operating conditions section**		**Limit operating conditions section**	
Meaning	**mark**	**unit**	**1**	**2**	**1**	**2**
flow	Q	[l/s]	300	300	500	500
pipeline profile	DN	[mm]	800	600	800	600
pipeline roughness	k	[mm]	0.25	0.25	0.25	0.25
velocity in pipeline	v	[m/s]	0.597	1.061	0.995	1.768
pressure line drop	I	[m/km]	0.38	1.64	1.02	4.44
section length	L	[m]	106	727	106	727
friction losses	ΔH	[m]	0.04	1.19	0.11	3.23
velocity head	$v_R^2/2g$	[m]	0.018	0.057	0.05046	0.1593
coeff. of res. – intake str.	ξ_{UL}	[-]	0.5		0.5	
local losses		[m]	0.0091		0.025	
total losses - section			**0.05**	**1.19**	**0.14**	**3.23**
piez. line elev. - beginning of the sect.	H_0	[m a.s.l.]	905.00	904.95	903.00	902.86
piez. line elev.- end of the sect.	H_1	[m a.s.l.]	904.95	903.76	902.86	899.63

Table 3. Determining the piezometer line on the third section of the pipeline from chain. 0+000 to 4+915.70 for normal and limit operating conditions [10], [11]

parameter			**operating conditions**	
Meaning	**mark**	**meas. unit**	**NOC**	**LOC**
Flow	Q	[l/s]	300	500
pipeline profile	DN	[mm]	600	600
pipeline roughness	k	[mm]	0.25	0.25
velocity in pipeline	v	[m/s]	1.061	1.768
pressure line drop	I	[m/km]	**1.64**	**4.44**
section length	L	[m]	4,915.7	4,915.7
total losses on the section	ΔH	[m]	**8.06**	**21.83**
elevation of the piezometer line at the beginning of the section	H_0	[m a.s.l.]	903.76	899.63
elevation of the piezometer line at the end of the section	H_1	[m a.s.l.]	895.70	877.80

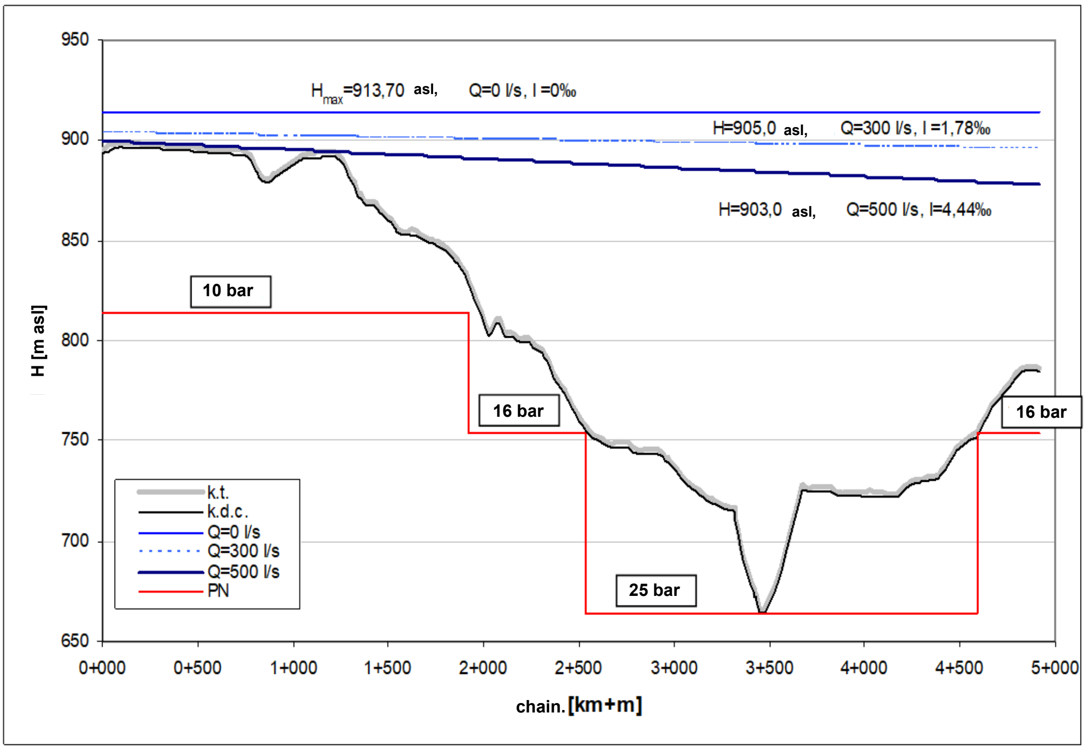


Figure 12. Hydraulic longitudinal profile of the third section with hydrostatic and hydrodynamic line for normal and limit operating conditions [10], [11]

<u>Calculation of non-steady states</u>

The calculation of non-steady states in the system caused by the closing or opening of the valve at the end of the pipeline (i.e., decreasing or increasing the initial velocity), which results in a sudden increase in pressures in the system, was performed for two states [10], [11]:

- Calculation of water hammer according to **Joukowsky-Alliévi** with the assumption of instantaneous flow stop and the assumption of elastic deformations of the pipeline.

Table 4. Calculation of maximum pressure change - complete hammer

pipe diameter (m)	**D**		0.6
pipe area (m²)	**A**	= D² × ∏/ 4	0.283
initial flow (m³/s)	**Qₒ**		0.3
initial velocity (m/s)	**vₒ**	= Qₒ / A	1.061
final flow (m³/s)	**Q₁**		0
final velocity (m/s)	**v₁**	= Q₁ / A	0
closed/open velocity difference (m/s)	**Δv**	= ± (vₒ-v₁)	± 1.061
pressure change (m WC)	**Δp**	=± c*Δv/g	± 117.4
pipeline length (m)	**L**		5749
oscillation cycle (s)	**Tc**	= 2L/c	10.60

In the event of a complete water hammer of a deformable pipeline, the maximum pressure change will be 117.4 m WC. This pressure will occur every time the valve is closed/opened, where the maneuver time is shorter than the oscillation cycle of the water mass in the pipeline (hydraulic sudden maneuver), which in this case is 10.6 s. In order to protect the system from water hammer, or to reduce the pressure change, it is necessary to achieve a hydraulic gradual maneuver, which is achieved by extending the valve maneuver time.±

- Calculation of water hammer according to **Michaud**-extended valve closing time. The maximum pressure that occurs at the end of the pipeline (immediately next to the valve) with extended valve closing time is:

$$\Delta p_{\max} = \frac{2 \cdot \rho \cdot L \cdot v_0}{T_z} = \rho \cdot c \cdot v_0 \cdot \frac{2 \cdot L}{c \cdot T_z} = \rho \cdot c \cdot v_0 \cdot \frac{T_c}{n \cdot T_c} = \frac{1}{n} \cdot \Delta p \tag{1}$$

where:

$\Delta p_{\max}$	is the maximum pressure immediately next to the valve
ρ	water density (1000 kg/m³)
L	pipeline length
v_0	initial velocity in the pipeline
$T_z = n \times T_c$	valve closing time (set as a multiple of the water mass oscillation time)
c	velocity of hammer propagation in the medium
T_c........................	water mass oscillation time
Δp	maximum pressure for complete hammer

For a cross section along the pipeline route, the maximum pressure is even lower and is:

$$\Delta p_{\max}^{s} = \frac{2 \cdot \rho \cdot (L - s) \cdot v_0}{T_z}, \tag{2}$$

where *s* is the distance of the cross section from the end of the pipeline, or from the valve.

The ratio of the maximum pressure along the route to the maximum pressure at the end of the pipeline can be set:

$$\frac{\Delta p_{\max}^{s}}{\Delta p_{\max}} = \frac{L-s}{L} = 1 - \frac{s}{L} \Rightarrow \Delta p_{\max}^{s} = (1 - \frac{s}{L}) \cdot \Delta p_{\max} \quad (3)$$

From the above formula, it can be seen that the maximum pressure decreases linearly with increasing valve closing time (T_z) and is as many times lower as the closing time is longer than the duration of the oscillation cycle of the water mass. The obtained results are presented in Figure 13.

a) b)

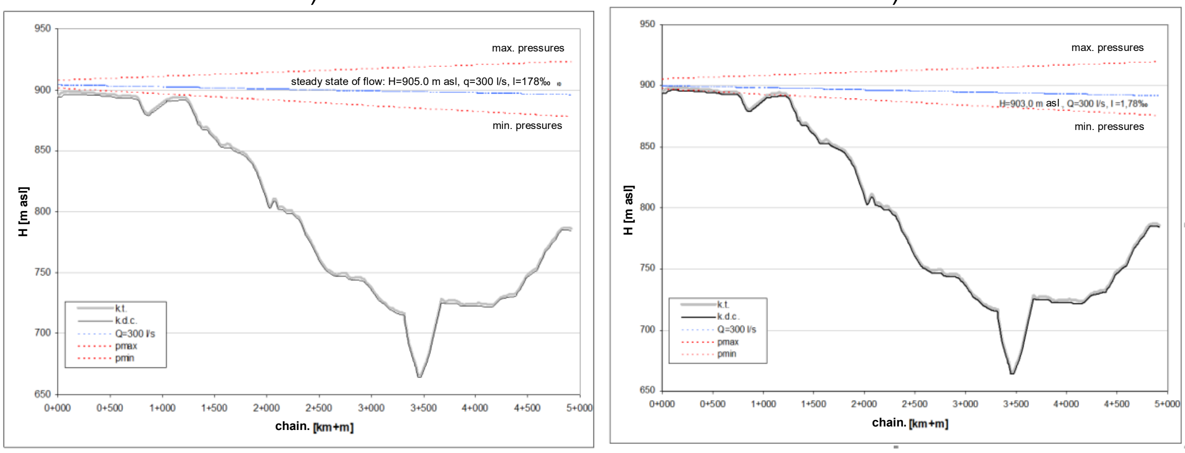


Figure 13. a) Envelope of maximum and minimum pressures for the case Q = 300 l/s and H = 905 m a.s.l. - valve closing time T_z = 68.9 s; b) Envelope of maximum and minimum pressures for the case Q = 300 l/s and H = 903 m a.s.l. - valve closing time T_z = 127.1 s [10], [11]

5. ELECTRICITY GENERATION FROM THE INTERNAL ENERGY OF THE SYSTEM

Installation of the turbine on the gravity pipeline from the Tribistovo reservoir to the water treatment plant is planned just before the inlet to the treatment plant. In this way, all available energy on the supply pipeline will be used. It will be converted into electrical energy using a water turbine, generator and transformer. The electrical energy generated from this renewable energy source can be used for the operation of the monitoring and control system or for the operation of the treatment plant, thus reducing the total amount of energy needed to be taken from the electrical power grid.

Basic turbine calculation [12], the output electrical power P is defined as:

$$P = \rho \cdot Q \cdot g \cdot H \cdot \eta_c \cdot \eta_t \cdot \eta_e \cdot \eta_{tr} \ [W] \quad (4)$$

where:

ρ = is density of water 1000 [kg/m^3]
Q = flow [m^3/s] – for normal operating conditions
g = gravitational constant [m/s^2]
H = net head [m]
η_c = pipeline efficiency ≥ 90% for nominal flow
η_t = turbine efficiency 88% ≤ η_t ≤ 94% for nominal flow
η_e = generator efficiency ≥ 92% for nominal flow
η_{tr} = transformer ≥ 97%

The total efficiency ($\eta_c \cdot \eta_t \cdot \eta_e \cdot \eta_{tr}$) was taken in the amount of 0.7 for the purposes of this analysis.

The turbine is planned to be installed before the treatment plant as shown in Figure 14. The pipe invert elevation before the inlet to the treatment plant is 784.3 m a.s.l. [10], [11]. The turbine power is calculated for normal and limit operating conditions, as follows:

For normal operating conditions:

P = 1000x0.3x9.81x(895.70-(784.3+10))x0.7 = 1000x0.3x9.81x101.4x0.7 = 208894.14 W = 208.894 KW

For limit operating conditions:

P = 1000x0.3x9.81x(877.80-(784.3+10))x0.7 = 1000x0.3x9.81x83.5x0.7 = 172018.35 W = 172.018 KW

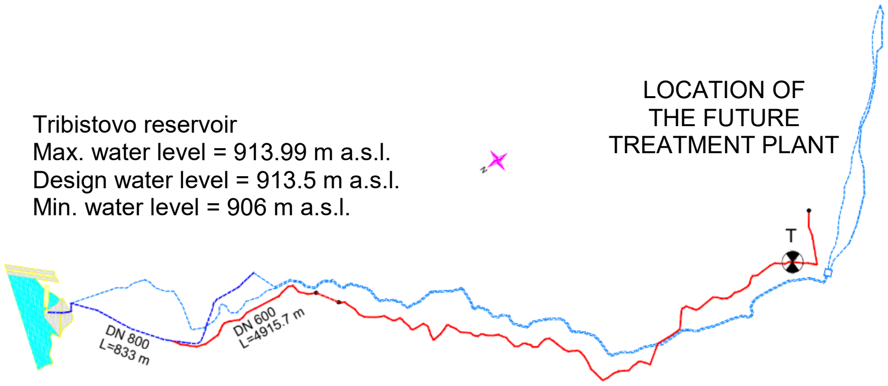


Figure 14. Layout view of the turbine location before the treatment plant

The total amount of energy that would be generated for the limit operating conditions on an annual basis, on the condition that there is a constant inflow of water in the amount of 500 l/s through the water supply pipe, would be: P_{tot} = 365daysx24hx172 KW = 1 506 720.00 KWh/year

In the event that the inflow is limited to 12 hours a day, and there is no inflow the rest of the time when the main water supply tank is full and the treatment plant is not operating, the total energy generated on an annual basis would be half as much, i.e. 753,360.00 KWh/year. For normal operating conditions this amount would be higher.

6. CONCLUSION

The price of electricity is in the range from 0.1286 KM/kWh for the consumption of working electricity according to the higher tariff system to 0.0268 KM/kWh for the lower tariff system. Not considering the energy consumption measurement point and the capacity cost during periods of higher tariffs, and various fees, but observing only the average price of electricity of 0.0455 KM/kWh and assuming the limit operating conditions in the water supply pipeline, the water supply company would have a bill for consumed electricity for the needs of the system reduced by 34 277.88 KM on an annual basis.

We can conclude that installing a turbine in the water supply pipeline and using the internal energy of the system is a possibility that needs to be considered and that has already come to life in practice, as shown in the conducted research on turbines installed so far on similar water supply systems presented in section 3, which was also one of the primary tasks throughout this paper. Based on the conducted study, using the available data and maps [10], [11], the idea is to see that the same can be implemented in the water supply system of Posušje and use the internal energy of the system, which is now basically being wasted.

A feasibility analysis for the use of this system would require an investment assessment of the procurement, installation and maintenance of the turbine, and its correlation with profit through one of the investment methods, such as present value method, internal rate of return, etc., which were not the scope of this analysis.

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