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THE TECHNOLOGICAL ALTERNATIVES FOR ENERGY AND HYDRAULIC IMPROVEMENTS

The problem of converting attenuated hydraulic energy into power energy in an artificial local resistance unit placed on a gravity drinking water pipeline (outlet control valve, pressure regulator) without disrupting the hydraulic regime of the water pipeline is examined. It is recommended to replace the regulator with the same resistance hydraulic turbine, and thus, with its corrective device, automatically adjust the consumption outlet of the water pipe. The energy and economic data of the hydraulic turbine unit to be built on the «Arzakan-Yerevan» drinking water main pipelines have been presented as an example of proposal implementation. According to estimations, the small hydroelectric power plant on the Yerevan water pipeline could produce 90 million kWh of electricity per year. It should be noted that the water supply system in Yerevan has around 300 half-open valves and pressure control devices, and in case of conversion of many of them, it is possible to apply the suggestion given in the article.

Keywords: *hydraulic resistance, attenuated energy, hydraulic turbine, corrector, water pipe, energy efficiency indicator, renewable energy, pressure management.*

Introduction

The traditional non-renewable sources of primary energy with limited resources continue to dominate. The overexploitation of fossil energy brings about severe pollution issues, including air pollution, water resource shortage, soil contamination, and ecosystem degradation [1]. Therein, taking into account the population growth in the country, the continuous increase of household and industrial energy supply, the further quantitative (extensive) development of the energy, which is based on traditional raw materials is inadvisable in Armenia. From the point of view of sustainable development and environment protection, the use of renewable energy resources in the energy balance is becoming essential. Water and energy resources are critical to human survival, and they are constantly under economic, technical, demographic, and societal pressures. Pumping in water supply systems (WSSs) is projected to account for 2–3% of global power usage [2], with motor-pump sets accounting for 80–90% of this demand. It is one of the most significant operational expenditures connected with WSSs [2].

Promotion of the efficient and rational use of water and electricity in WSSs plays a strategic role in the quest for the sustainable development of nations as well as in the mitigation of and adaptation to the causes/consequences of climate change. The high potential for the application of water and electricity rational use actions in WSSs has been attributed to poor infrastructure and operational procedures, particularly in developing countries. Moreover, according to the Millennium Development Goals (MDGs) [3], there is a need for more sustainable alternatives in the expansion and implementation of new systems by the year 2015, further, according to the MDGs, there is a target to halve the proportion of people without sustainable access to safe water and basic sanitation. Small hydroelectric power stations (SHPS) should be recommended as a renewable energy source for domestic drinking water and water delivery networks in the places where the local hydraulic resistances, half-open valves, or pressure regulators are available. Simultaneous use of the above-mentioned systems is economically feasible for electrical energy production and water delivery, and in principle, is an example of total water resource usage [4]. Although in past decades the use of hydropower was one of the main sources of energy, today the vector of action has changed, the sector is viewed as a direct consumer of electricity, which affects the distribution of water resources in the context of energy consumption and use of energy [5]. According to Frijns et al. [6], the high consumption of energy affects water industries around the world, been associated with climate change issues. According to Dias [7], the rational use of energy aims to provide sustainable development through the correct use of energy resources at all stages of conversion.

Hydropower recovery. The hydropower potential of water supply systems has been known for a long time, however, it has not been adequately explored worldwide. Cases of micro turbines used for power generation in water supply systems have been reported in the literature (e.g., [6]). Systems installed in areas with high topographic gradients, in which water is transported by gravity, tend to offer high pressures in the water mains and distribution networks, making these systems capable of hydroelectric power generation. In addition to generating electricity, turbines installed in water distribution networks can act as pressure control systems, replacing the pressure-reducing valves (PRVs), which are important tools in the management of water losses/leakages [8,9]. While PRVs reduce the pressure through the dissipation of energy, water turbines can convert this excess pressure into useful electricity [9]. The main benefits of hydraulic energy recovery in WWSs, according to Vieira and Ramos, include increases in the energy efficiency of the system through the use of local sources and decreases in the dependence on external /grid energy, additionally, hydraulic energy recovery favors overall reduced operational costs. Vieira and Ramos [10] also emphasize that the implementation of small hydro plants in WSSs presents a considerably reduced implementation cost because many of the necessary components are already present in typical WWSs.

To assess the applicability of the proposal, the possibility of building a SHPP on the Arzakan-Yerevan drinking water pipeline is presented.

Main part

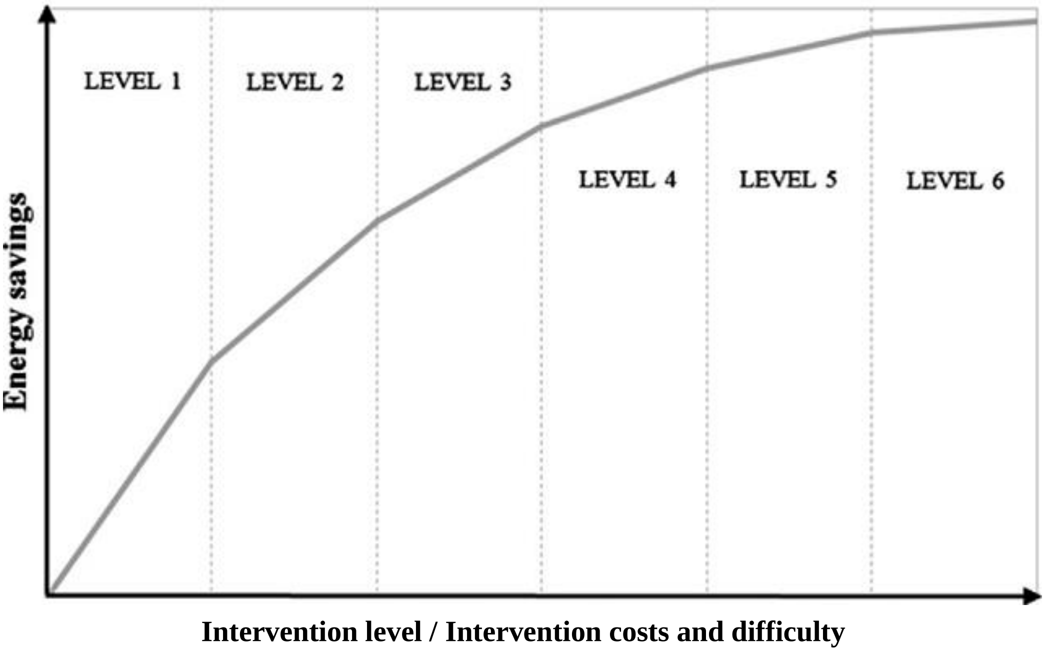
According to Dias [7], the rational use of energy aims to provide sustainable development through the correct use of energy resources at all stages of conversion. Based on the author's description, the efficient use of energy can be systematized into the following six intervention levels.

- Level 1, the elimination of waste: waste elimination is the most evident level of intervention. In the context of water supply, the most emblematic example of intervention level 1 is the elimination of water losses due to leakages.
- Level 2, increasing the efficiency of power-consuming units: this level includes energy efficiency measures aimed at the technological improvement of processes, which involve, for example, the replacement of old motor-pump sets by high efficiency sets.
- Level 3, increasing the efficiency of power generation units: this level aims to adjust and harmonize the energy production units with the energy consumption units, preferably a posteriori with respect to the level 1 and level 2 interventions. In the context of the present work, we can cite the following examples of level 3 interventions in WSSs, such as the use of renewable sources for water pumping and hydropower recovery.
- Level 4, the reuse of natural resources by recycling and reduction of the energy content of products and services: Dias [7] describes level 4 interventions as those related to the recycling and recovery of energy from waste generated in the considered production process as well as the use of technologies and inputs with reduced energy intensities throughout their lifecycles. Although outside the scope of this paper, both waste water recycling and the energy efficiency of wastewater treatment plants are associated with the reuse of resources, which are characteristic of level 4 interventions [12–15]. Attention should be paid to the fact that the reuse and recycling of wastewater are generally considered energy intensive (as described in Section 1), which can mischaracterize these processes as alternative technologies for enabling energy efficiency and conservation. The typical analysis of a WSS energy lifecycle considers the energy intensities of the chemicals used in water treatment in addition to the materials and components of the physical systems (e.g., pipes). Energy analyses considering life cycle assessments of

WSSs are presented, among others, by Lundinand Morisson [16], Filion et al. [17], Racoviceanu et al. [11], and Stokesand Horvath [18].

- Level 5, discussion of the center/periphery relations: in the context of water supply, level 5 interventions can be obtained, for example, through the decentralization of supply and incentives toward the enhanced use and management of local water sources in the form of distributed water infrastructures [19,20]. Physically, the center/periphery relationship influences the energy efficiency of a WSS once the relative position between the water sources, the treatment plants and the consumers influences the amount of energy needed for water transport as well the head losses along the network and water mains. Filion [21], for example, describes the influence of city shape on the energy consumption of water distribution systems. Level 5 interventions are strongly related to urban planning and zoning and can be effectively implemented through proper and optimized system designs. This occurs because the location of natural water sources (e.g., rivers, springs) cannot be changed, and the layout of water mains and the distribution networks depend on the local topography and other types of infrastructure (mainly the streets and roads).
- Level 6, changes in ethical and esthetic paradigms: level 6 involves changes in opinions, consumer choices and consumer behavior and, therefore, represents the most difficult energy efficiency action that can be implemented.

The energy saving impact of each intervention level can be associated with the specific intervention's difficulty and/or cost of deployment. This nonlinear relationship ideally grows and asymptotically tends to the maximum energy saving potential; that is, when applying the above interventions by following the levels in ascending order, the closer the interventions move toward the higher-levels, the greater the difficulty and/or implementation cost become. Further, in this manner, the cumulative energy savings are present in continuously decreasing increments. This model is shown in Fig. 1, in which all levels were denoted with the same dimension for the purpose of illustration because it is very difficult to establish the actual dimensionality of a level. Although in past decades the use of hydropower was the most evident relation between water and energy, today the focus of this relationship has turned to the role of water as a consumer of electricity, which has turned water distribution into an important stage in terms of the consumption and use of energy [5]. According to Frijns et al. [6], the high consumption of energy affects water industries around the world, been associated with climate change issues.



Intervention level / Intervention costs and difficulty

Fig. 1. *The relationship between the energy efficiency intervention level, its cost and difficulty, as well as the cumulative energy savings*

In the paper, we have studied some of the third-level options for improving the efficiency of water supply and drainage systems and energy-economic indicators of the hydraulic turbine unit that will be installed on the "Arzakan-Yerjan" drinking water main pipeline. Many areas of Yerevan (Arabkir, Malatia-Sebastia, Achapnyak, Erebuni villages) and other nearby settlements are served by the «Arzakan-Yerevan» water supply system (Zovuni, Kanakeravan, Nor Hajn, Nor Geghi, Eghvard, etc.). The water supply starts from the Arzakan spring, and in Getamedj administrative region it is separated between two water pipelines with different pressure regimes. On one of the branches supplying the northwestern and western parts of Yerevan city, the development of a SHPP is being proposed. The so-called "compression valve" is currently installed on the considered branch of the water supply system for regulating the volume of water in the dividing junction, as well as to provide the needed water supply pressures in numerous settlements next to Nor Hajn. The valve provides a local hydraulic resistance on the water pipe (the pressure in the water pipe is about 33 meters before the valve, and it is about 13 meters after the valve). The proposed solution is to use a SHPP instead of a "pressing valve" to avoid disrupting the water pipeline's main hydraulic regimes. The site plan created by the Google Earth program is presented below in Fig. 2, and the actual pressure values of the continuous pressure recorders registered by the loggers are presented in Table 1.

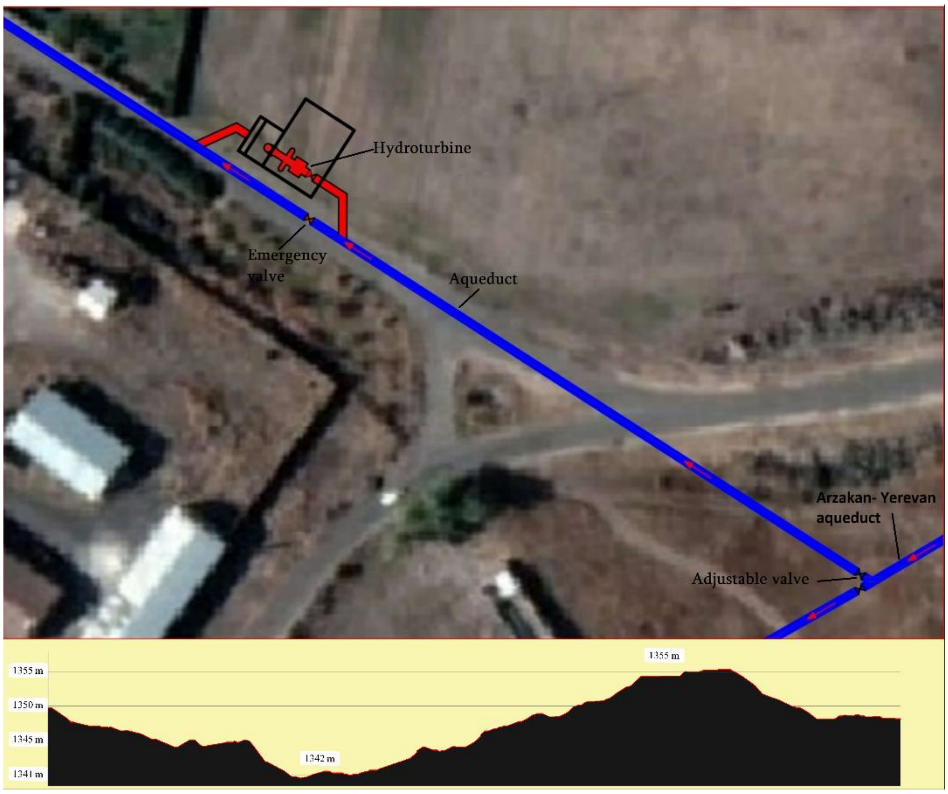


Fig. 2. *The site plan created by the Google Earth program*

The proposal aims to convert the attenuated hydraulic power into electrical energy in an artificially created local resistance unit. There are favorable conditions to use the energy potential for complex purposes at the SHPP construction site (on the branch of the «Arzakan-Yerevan» drinking water main pipeline). At this junction, the average annual outlet of a turbine water pipeline is 1.15 m^3/sec. An outlet controlling valve is fitted on the water pipeline, with throttling providing the outlet. As a result of this regulation, a pressure difference of 20.3… 21.4 m is formed on different sides of the valve (Table 1). The proposed solution solves the problem of efficient utilization of the energy of this water flow. It should be noted that there are many so-called "hidden" places of energy on the drinking water pipelines in the Republic of Armenia, the use of which for electricity generation is justified. In this case, it is recommended to replace the regulator on the water pipeline with the same resistance hydraulic turbine, and thus, with its corrective device, automatically adjust the consumption outlet of the water pipe.

Table 1. Data from pressure loggers installed in the research area

Date of survey	Hour	Recorded pressure, *m*	
		Before the local resistance	After the local resistance
15.09.2020	20:00	32.8	13.0
15.09.2020	21:00	33.2	12.6
15.09.2020	22:00	33.3	13.0
15.09.2020	23:00	33.3	13.0
16.09.2020	00:00	33.5	12.8
16.09.2020	01:00	33.8	12.4
16.09.2020	02:00	33.9	13.2
16.09.2020	03:00	33.9	13.1
16.09.2020	04:00	33.9	13.6
16.09.2020	05:00	33.8	13.3
16.09.2020	06:00	33.8	13.2
16.09.2020	07:00	33.7	12.6
16.09.2020	08:00	33.4	13.0

Table 2 shows the average monthly outlet of water pipelines.

Table 2. Hydraulic turbine unit outlet parameters

Month	Water supply outlet, m^3/sec		
January	1.20	July	1.30
February	1.10	August	1.30
March	1.10	September	1.05
April	1.00	October	1.05
May	1.10	November	1.10
June	1.30	December	1.20

According to the data in Table 1 and Table 2, the SHPP design pressure will be $H = 20m$, and the estimated outlet - $Q = 1.15m^3/\sec$.

The water flow capacity N_1 in the case of estimated hydraulic parameters will be [6]:

$$N = \rho gQH = 1000\cdot 9.81\cdot 1.15\cdot 20 = 225632\ w \approx 225Kw.$$

Hydraulic turbine selection options. In the case of low water pressure and a substantial annual fluctuation in the outlet, the following two possibilities for hydraulic turbine class selection are reasonable: a. reactive type and b. active type. At low pressures, reaction turbines are preferable over high-speed turbines (Kaplan). However, this turbine efficiency coefficient is sensitive to changes in the outlet. Among the active type turbines, for the given pressure front, preference is given to the Osberger type low-speed turbine (Banki), where the efficiency coefficient is practically unchanged, regardless of the change in outlet. The basic structure of the Banki-type turbine provides an advantage in terms of turbine procurement, cost, and ease of operation. It should be noted that the country has experience in the construction and operation of such low-power turbines. However, there is one criterion to consider: the surplus pressure at the exit of the "Banki" type turbine is zero. As a result, it will only be applicable on the pressure front, where after the turbine installation, the exceed in water pipe endpoints will provide accounting outlet in gravity mode. The turbine must be placed near the pressure reduction chamber of the water pipe. It means that using an active type turbine in a water pipeline is excluded.

The pressure levels, the outlet flow rates, and the above criteria should be considered when selecting a turbine for each pipeline unit.

It is necessary to include a hydraulic unit in the pressure front, which will perform the regulating valve function, that is, to ensure a consistent drop in the pressure. On the other hand, hydraulic turbine aggregate operating in the united electrical network, must be regulated according to network requirements, i.e., it must have an opportunity to change the water output.

In the case of low pressure, an axial (Kaplan) or double-regulated adjustable-blade turbines are used. In the case of low water flow capacity, such as drinking water gravity pipelines, it is advisable to use an axial turbine with an adjusting apparatus. The hydraulic turbine aggregate must be installed on a pipe bypassing the regulating valve, with turbine inlet and outlet mounting valves.

The adjusting apparatus of the hydraulic turbine and the hydraulic resistance of the pipe bypassing the regulating valve are used to ensure the required pressure drop.

The regulating valve is closed during the SHPP operation, as can be seen.

It is recommended to install the turbine on a pipe that runs parallel to the water pipe, ensuring that the water pipe continues to operate even in case of station failure. Pressure sensors will be installed at the turbine intake and outlet sites to monitor the SHPP's operation. It will deliver the required pressure from the station following the water supply company's regulations. At the same time, the station must be installed on the drinking water supply system, therefore the equipment and the project must meet specific standards[1,2] [22], such as avoiding contamination of the water with lubricating oils and other materials. A water supply system is a set of structures, facilities, and services that produces and distributes water to consumers the distributed water must be compatible with the needs associated with the domestic consumption, utilities, and other industrial consumption in both quantity and quality.

Energy indicators of SHPP. For the elements of a hydraulic turbine unit, let’s consider the following average values for efficiency coefficients: $\eta_m = 0.86$ and $\eta_{gen} = 0.94$.

The power on the turbine shaft will be:

$$N_m = \eta_m \quad N = 0.86 \cdot 225 = 193.5\ kW\ ,$$

and at the generator outlet:

$$N_{gen} = \eta_{gen} \quad N_m = 0.94 \cdot 193.5 = 184\ kW\ .$$

In Table 3, the average capacity of the SHPP and the corresponding average monthly electricity outlet are presented.

It should be noted, that the use of SHPP turbine at a negative outlet height (in our example $h_S = -13\,m$), in our opinion, is proposed for the first time in world practice. In this case, on the one hand, the occurrence of cavitation is excluded [22, 23], which is a positive factor, and on the other hand, the effect of high-pressure drop on the efficiency coefficient on the turbine exit is unknown, so, in our calculation understated indicators were applied.

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[1] Sanitarakan Kanonner yev Normer N2-III-A2-1, Khmelu jur: Jramatakararman kentronats’vats hamakargeri jri vorakin nerkayats’vogh higiyenik pahanjner, Voraki hskoghut’yun, Yerevan, 2002, p. 11 (in Armenian).

[2] Sanitarakan Kanonner yev Normer N2-III-A2-2, Khmelu nshanakut’yan jrmughineri yev jramatakararman ardyunk’neri sanitarakan pahpanut’yan gotiner, Yerevan, 2002, p.14 (in Armenian).

Table 3. SHPP capacities and outlet per month

Month	Capacity, *kW*	Outlet, *kWh*
January	190	141360
February	174	116930
March	174	129456
April	158	113760
May	174	113456
June	206	148320
July	206	153264
August	206	153264
September	166	119520
October	166	123504
November	174	125280
December	190	141360
	Total	1.573.474

Financial analysis

As a power plant with a guarantee of purchasing electricity, the electricity produced by the SHPP (Table 3) is planned to provide to the general energy system of the Republic of Armenia at prices regulated by the Public Services Regulatory Commission[3].

Table 4 summarizes the main financial indicators, based on the expenses of SHPP construction and continuous operation, as well as the provisions of the current legislation of the Republic of Armenia[4].

Table 4. Cost-effectiveness indicators

Names of indicators	U/M	Indicator
IRR (Internal Rate of Return)	percent	10.4
PB (Payback Period)	year	9.0

Conclusion

Based on the approaches presented in the article, it can be confirmed that the inclusion of renewable energy resources in the energy balance is becoming the imperative of the period. In terms of the peculiarities of the mountainous relief of the territory of the Republic of Armenia, to regulate the pressures in the water supply system intended for drinking and economic needs, measures for creating local resistance are often carried out by the water supply organization using half-open valves or pressure control equipment. Equipping these units with a specially designed hydraulic turbine with the same hydraulic resistance and automatic operation through the corrective device will allow the conversion of attenuated mechanical energy into electricity production during artificially created local resistance. It should be noted that Yerevan water supply system has over 300 half-open valves and pressure control devices, and in case of conversion of many of them, it is possible to apply the suggestion given in the article.

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