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Implementation of hydraulic modelling for site selection of pump as turbines for pressure reduction and power production in water distribution networks

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ABSTRACT

Inefficient management of water distribution networks (WDNs) causes a serious problem of water losses in many countries. Excess water pressure is one of the main factors that increases leakage in WDNs. Pressure management is an efficient and economically feasible method to reduce physical water losses in WDNs, and is generally achieved by installing pressure reducing valves (PRVs). Recently, pump as turbine (PAT) has become a viable option to replace PRVs. In this study, water losses reduction, power production potential, CO_2 emissions reduction and payback period were investigated for Konyaalti WDN, which is composed of 18 district metered areas (DMAs), with implementation of PAT. Population, water demands and flow rates were forecasted for the years 2020, 2025 and 2035. A hydraulic modelling study was conducted to determine the optimum pressure levels to be maintained at the entrance of each DMA. Temporal and spatial variations of water pressure and excess water pressure levels were obtained for minimum and maximum water consumption periods. The investigation revealed that DMA-6 was the best site for implementation of PAT with a payback period of 0.85 year. Long-term analysis of hydraulic parameters (water demand, flow rate, excess water pressure) and evaluation of environmental benefits and payback period are necessary for optimal site selection of PAT.

Keywords: Pump as turbine; Energy recovery; Hydraulic modelling; Water distribution network; Water losses

1. Introduction

Due to industrialization and population increase, urban water demand has increased in many countries, causing a high pressure on water resources. Therefore, sustainable management of water resources has become more crucial. Management of water distribution networks (WDNs) has a great impact on sustainable management of urban water systems. Sustainable management of WDNs covers a variety of issues such as improvement of energy efficiency, reductions in water losses, energy needs and CO_2 emissions. Water losses, defined as the difference between System Input Volume (SIV) and authorized consumption, have become a common problem worldwide. Water losses consist of physical water losses and apparent water losses. Pressure management is an efficient and economically feasible method to reduce physical water losses in WDNs [1,2]. The problem of water losses is not only a revenue problem but it also results in wasting of valuable sources such as water, energy and chemicals. 2%–3% of global energy is consumed for urban and industrial water supply but it can be reduced at least 25% by implementing cost-effective actions [3].

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Pressure management is generally achieved by installing pressure reducing valves (PRVs) which facilitate dissipation of energy [4–6]. Recent studies showed that microturbines or pump as turbines (PATs) could be used to reduce pressure and to recover energy from excess water pressure [2,3,7–11]. Microturbines have higher capital costs than PATs that prevent them from having a widespread implementation in WDNs. Recently, several research studies were conducted for investigating the use of pumps in reverse mode, as hydraulic turbines [12,13]. Studies showed that centrifugal pumps can operate as turbines at various flow rates and heads [14,15]. PAT systems help to improve the efficiency of WDNs by reducing pressure, water losses, pipe failures and CO_2 emissions in addition to energy production at picoscale or microscale. Water demands in WDNs show wide hourly, daily, weekly and monthly variations. Therefore, water pressures exhibit wide temporal and spatial variations. Prediction of water pressures can be achieved only by a well calibrated and verified hydraulic model. In this respect, hydraulic models are integrated in research studies to compare alternatives for improving operational efficiency of WDNs [1,16,17].

Theoretical, experimental and numerical investigations of PAT system applications are presented in the literature [18–20]. Furthermore, several research studies are focused on cost analysis for evaluating economic feasibility [2,13,16,21–26]. Energy production potential in WDNs is usually at microscale (<100 kW) and the possibility of using turbines with high capital cost is not a viable choice. Due to their low operational and capital costs, use of PATs is commonly advised [20,26]. Some of the presented cases indicate good opportunities for actual implementations with relatively short payback periods and environmental benefits [9,27]. As an example, PAT systems at picoscale (<4 kW) were recommended as viable options with payback periods of 4–22 months [28].

A number of research studies were conducted on optimization techniques for optimal location of PRVs and PATs for hydropower generation [9,29–33]. However, prediction of long-term water demand, flow rates and pressure are very crucial for evaluation of microhydropower energy recovery potential in WDNs as future changes in flow rates and pressure levels could render an installed PAT unsuitable [34]. There is limited research study in the literature for detailed hydraulic analyses of real WDNs to examine the potential for implementation of a PAT system considering the long-term forecasted population and flow rates. This paper presents an analysis of the potential for power generation, energy saving, reductions in physical water losses and CO_2 emissions by implementation of a PAT system in district metered areas (DMAs) of Konyaalti WDN (KWDN) in Antalya City, Turkey. For this purpose, projection of population was realized for the years 2020, 2025 and 2035 and based on the forecasted population values; future water demands and flow rates were estimated. A hydraulic modelling study was conducted to determine the level of excess water pressure at the entrance of each DMA of KWDN for the future years. Based on the results of hydraulic modelling study and consequent analysis of environmental benefits and payback period, alternative sites for implementation of PAT system were compared.

2. Materials and methods

2.1. Pilot study area

Antalya City is located in the south-west of Turkey, along the Mediterranean coast. The topography of Antalya City varies from sea level to around 300 m above sea level. Therefore, Antalya WDN was divided into seven pressure zones and subnetworks for better management of water supply system [1]. KWDN pilot study area (PSA) is one of the major-subnetworks of Antalya WDN and it is operated independently from the rest of the water supply system. KWDN was divided into 18 DMAs to improve efficiency of WDN. Fig. 1 shows water supply system of Antalya City, the main components and DMAs of KWDN. The region is supplied by raw water extracted from five wells at Bogacay Pumping Station. Hurma Balancing Reservoir with a capacity of 15,000 m^3 is the only balancing reservoir in the PSA. The PSA serves about 60 thousand people by around 200 km pipe network with different pipe materials (polyvinyl chloride [PVC], high-density polyethylene [HDPE] and steel) and diameters (in the range of 32–250 mm). The number of junctions and total pipe length vary widely in the DMAs. The number of junctions was between 22 and 161 whereas total pipe lengths in the DMAs were in the range of approximately 1.9–11 km. The PSA has an efficient supervisory control and data acquisition system (SCADA) for online continuous monitoring of flow rates and water pressures at the entrance of each DMA [1,35].

2.2. Modelling approach

The PSA covers residential and tourism areas where population is expected to increase in the forthcoming years. For this purpose, populations for the years 2020, 2025 and 2035 were forecasted. Future water demands and flow rates in the PSA were also forecasted based upon the forecasted population. Increase in water demand was assumed the same as population increase rate, calculated by Turkish Statistical Institute (TSI). Minimum and maximum water consumption profiles of the years 2020, 2025 and 2035 were calculated by multiplying the observed water consumption profiles in 2010 by the rate of population increase. WaterGEMS (Water Distribution Analysis and Design Software) hydraulic model was applied to the PSA to predict spatial and temporal changes in water pressures. WaterGEMS is a comprehensive hydraulic and water quality simulation model for WDNs. The model could be applied for steady-state and extended-period hydraulic simulations, water loss analysis, energy and capital cost analysis. Details of hydraulic model calibration and verification studies of the PSA were given elsewhere [1,36]. Flow rates and water pressures at the entrance to each DMA of the PSA were obtained from the SCADA system for the year 2010.

Hydraulic model was used to predict optimum pressure values at the entrance to each DMA in the PSA for each simulation year. Consequently, excess water pressure levels at the entrance to each DMA were determined using the hydraulic model results for the years 2020, 2025 and 2035. Additionally, temporal and spatial changes of water pressure were predicted for all the DMAs that have potential for pressure reduction. The temporal and spatial variations of water pressure were analyzed for minimum and maximum flow rate

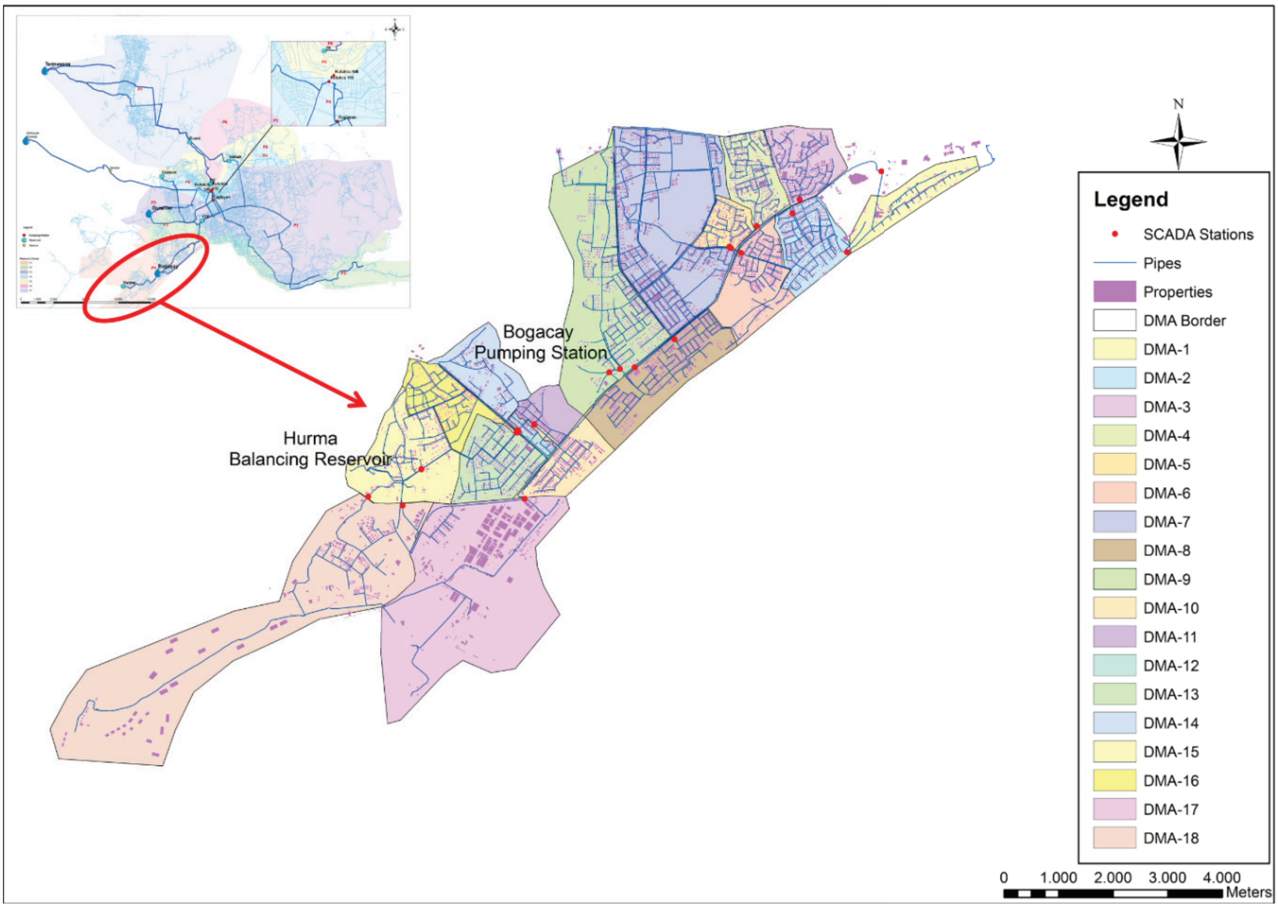


Fig. 1. Water supply system of Antalya City and DMAs of KWDN (updated from [1,35])

conditions: (i) for the years 2020, 2025 and 2035, (ii) for the scenarios of "no PAT" and "PAT installed".

Hydraulic model was also used to predict water savings due to pressure reductions. Excess water pressure in WDNs is one of the major factors that results in leakage. Leakage estimation from a node is possible by application of emitter coefficients in hydraulic modelling [37]. Physical water losses in the PSA were accepted as 80% of minimum night flow of the PSA according to the operational experiences of the responsible water authority [1]. Physical water losses were distributed homogenously to each node by adapting Eq. (1):

$$q = C.P^{\gamma} \quad (1)$$

where P is nodal pressure, C is emitter coefficient, q is flow rate and γ is pressure exponent.

Pipe material is important for leakage behavior of pipes [38]. Pressure exponent for PVC pipes (round hole/circular hole) was determined as 0.52 from experimental investigations while it was determined as 0.5–1.0 for PE pipes [39]. Water distribution pipes in the PSA consist of PVC, HDPE and other materials such as steel, iron, etc. Therefore, a conservative value of 0.5 was assigned to pressure exponent in this study. Emitter coefficient was estimated through a trial and error method for each DMA considering the maximum and minimum flow rates, separately for each simulation year.

2.3. PAT configuration and efficiency

A recent full-scale PAT system, with 10 kW capacity, was implemented at Aksu district of Antalya City for energy production and pressure reduction [40]. This full-scale PAT system was installed on a by-pass line of the main distribution pipe and operated in parallel with a PRV, as shown in Fig. 2. The installed system, being in operation since January 26, 2016, reduces the excess pressure of approximately 1 bar and works efficiently in a wide range of inflows [41]. The components, operational details and characteristic curve of the installed PAT system were presented elsewhere [40]. Similar configuration and design is suggested for the investigated DMAs in this study as the suggested capacities are very close to 10 kW. According to the monitored operational data sets of the implemented full-scale PAT system for the period between May 18, 2016 and June 13, 2016, 93.5% of the total flow rate passed through the PAT line, on the average. Additionally, efficiency of the full-scale PAT system was observed to vary considerably according to the variations in flow rate and when flow rate deviates from the best efficiency point. The average efficiency of the full-scale PAT system was computed as 60% for the same operational period. Similar operational characteristics and efficiency value were accepted as reference for the suggested PAT systems in this study.

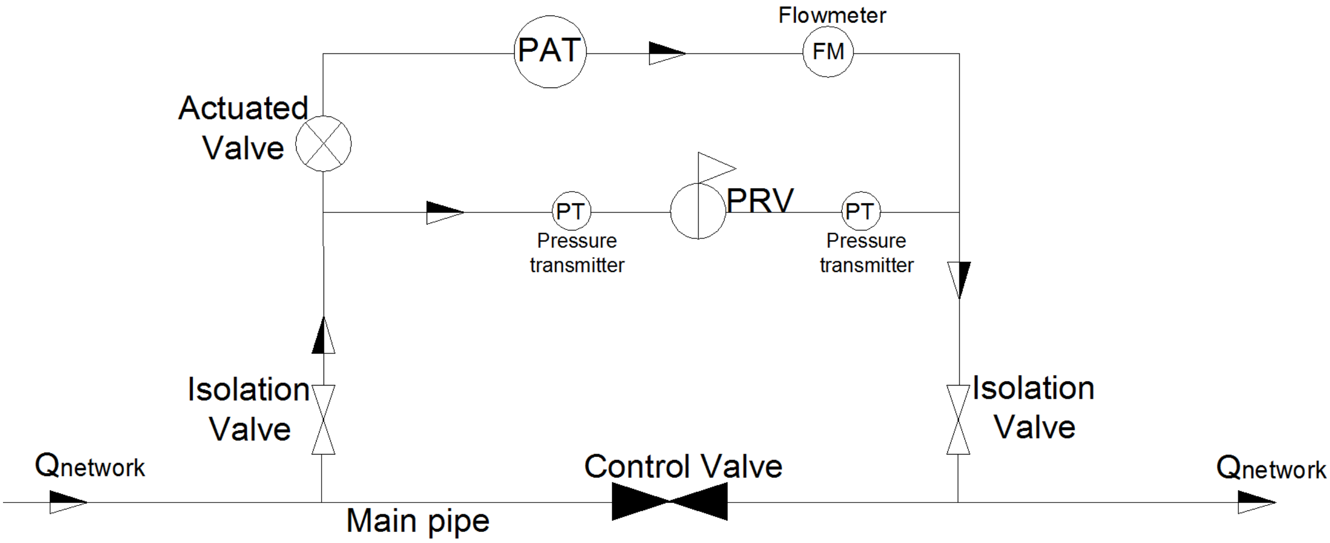


Fig. 2. Installation scheme of by-pass line for the installed PAT system and PRV [40].

2.4. Recovery of excess water pressure, reduction in CO_2 emissions and payback period

Excess water pressure is the difference between the existing water pressure and the optimum pressure level. Excess water pressure in WDNs can be recovered by application of turbines or PAT systems. Power generation from recovery of excess water pressure can be calculated by Eq. (2):

$$P = Q.\rho.g.H.e_o \tag{2}$$

where P is produced power (watt), Q is flow rate (m^3/s), ρ is water density (kg/m^3), g is acceleration due to gravity (m/s^2), H is excess water head (m) and e_o is efficiency of system.

Excess water pressures at the entrance to each DMA were calculated by subtracting the optimum pressure from the existing pressure values. DMAs exhibiting reasonable excess water pressure were chosen as potential PAT installation locations. Power generation by implementation of PAT was estimated using Eq. (2) where efficiency of PAT system was assumed as 60%. Additionally, 93.5% of the total flow rate was assumed to pass from the PAT line. The mentioned values were obtained from the operational data sets of a similar full-scale PAT application in Antalya, as described above.

Reduction in CO_2 emission is achieved by hydropower production and energy saving where CO_2 emission reduction was calculated based on the reference value of the unit emission equivalence for energy production in Turkey which is 0.53426 kg CO_2/kWh [42]. The value of recovered energy and water saving were calculated using the average unit price of electricity (0.1144 €/kWh) and water (0.78 €/m^3) in Antalya, respectively. Energy saving was calculated based on the energy consumption for water production, pumping and distribution which is 0.6 kWh/m^3 for the PSA [35].

The payback period calculation was based on the implementation cost of the installed full-scale PAT system in Antalya with 10 kW capacity. The capital cost included electrical and mechanical equipment, construction costs for the underground by-pass room and the above-ground protection house, assembling and installation of all electrical and mechanical parts. Total cost of the installed full-scale PAT system, as covered by a national research project, was approximately €38,210 [41]. Other construction works (by-pass line inlet and outlet connections from the main water distribution pipe, final reorganization of the area, arrangement of the SCADA station connections, etc.) were realized by Antalya Water and Wastewater Authority (ASAT) and they were not accounted here.

3. Results and discussion

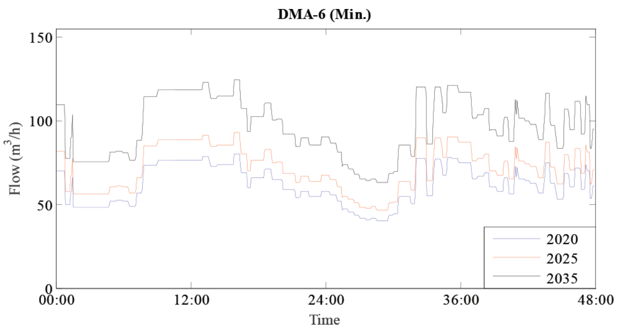
3.1. Population projection and water demand estimation

Population projection of Antalya City was calculated till 2035 utilizing arithmetic, geometric and semilog projection methods by using present and past population records starting from 1935. Population increase rates were calculated as 30.9‰ and 29.4‰ for the years 2012–2013 and 2013–2014, respectively, by TSI [43]. Population projection results showed good agreement with the calculated population increase rates by TSI. Therefore, the annual population increase rate in the PSA was assumed as 30‰. Increase in water demand was also assumed the same as population increase rate. By analyzing the available online measurements of flow rate at the SCADA stations, located at the entrance to each DMA of the PSA, periods of maximum and minimum flow rates were examined for the PSA and were found as July 20–21 and December 1–2, respectively. The estimated water demands of minimum and maximum consumption periods are illustrated in Fig. 3 for the years 2020, 2025 and 2035 for DMA-6, as an example.

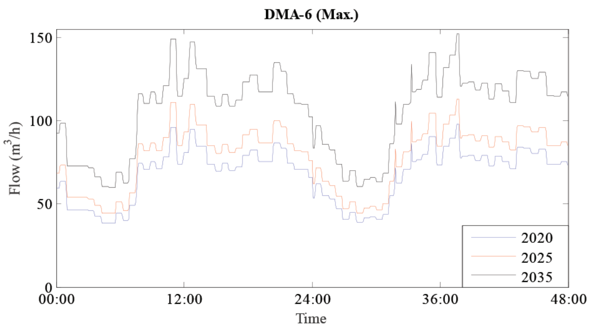
3.2. Pressure management and prediction of water savings due to pressure reduction

Excess water pressure levels at the entrance to each DMA of the PSA were predicted using the hydraulic model for the years 2020, 2025 and 2035. Some of the DMAs in the

PSA (DMA-1, DMA-2, DMA-6, DMA-10, DMA-11, DMA-12, DMA-15 and DMA-16) exhibited excess water pressures whereas the rest of the DMAs (DMA-3, DMA-4, DMA-5, DMA-7, DMA-8, DMA-9, DMA-13, DMA-14, DMA-17 and DMA-18) were not suitable for pressure reduction in the forthcoming years. Consequently, a series of pressure management scenarios were tested to find out the optimum water pressures at the entrance to each DMA considering minimum and maximum water consumption periods. The strategy was to maintain a minimum water pressure level of about 20 m water head at all the nodes of the DMAs at maximum and minimum flow rates. Temporal and spatial changes of water pressure were predicted for all the DMAs that have potential for pressure reduction. Prediction of spatial changes of water pressure in DMA-6 is presented in Fig. 4 for minimum and maximum flow rate conditions for the years 2020 and 2035 and for the scenarios of "no PAT" and "PAT installed", as an example. In case of "no PAT" scenario, there is no pressure management in the DMA to reduce excess water pressure whereas "PAT installed" scenario applies pressure management by implementation of PAT system at the entrance of the DMA. As a result of pressure reduction, physical water losses are reduced in WDN which results in water and energy savings. Estimations of leakage, water and energy savings were conducted for each scenario and all DMAs where pressure management was possible. The emitter coefficients were calculated through a trial and error method for leakage simulations. Emitter coefficients, optimum and excess water pressures, water and energy savings are presented in Table 1 for each of the studied DMAs and scenarios.



(a)

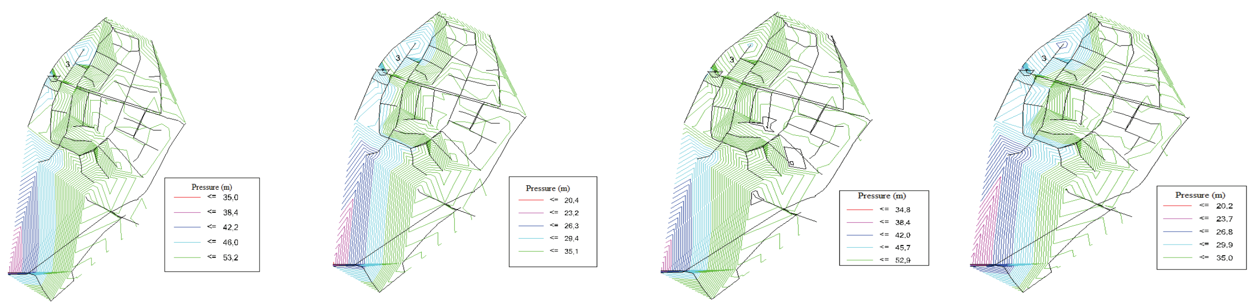


(b)

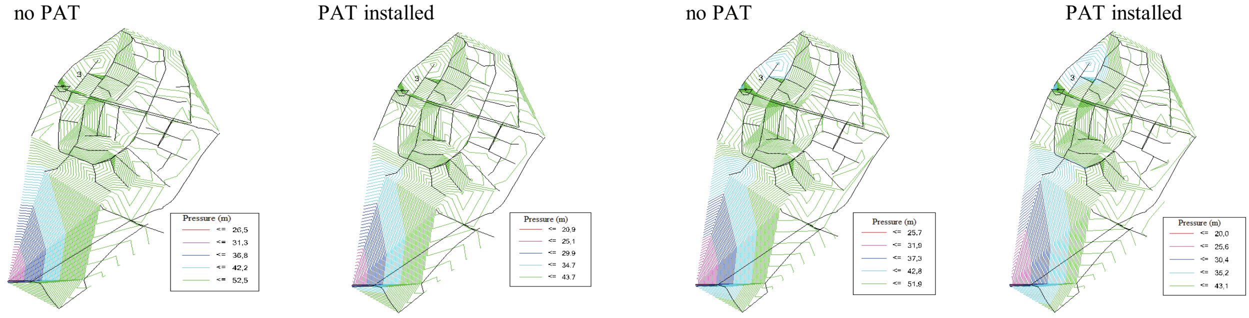
Fig. 3. Estimated 48-h water profiles for DMA-6, (a) minimum consumption period and (b) maximum consumption period.

3.3. Potential power generation by reducing excess water pressure and reduction in CO_2 emissions

Excess water pressure, which is usually associated with high physical water losses, can be recovered by



a) Year 2020, min flow rate, no PAT
b) Year 2020, min flow rate, PAT installed
c) Year 2020, max flow rate, no PAT
d) Year 2020, max flow rate, PAT installed



e) Year 2035, min flow rate, no PAT
f) Year 2035, max flow rate, PAT installed
g) Year 2035, max flow rate, no PAT
h) Year 2035, max flow rate, PAT installed

Fig. 4. Prediction of spatial changes of water pressure in DMA-6 for the years 2020 and 2035 at minimum and maximum flow rates in cases of "no PAT" and "PAT installed".

Table 1
Summary of pressure management strategies for all DMAs

Year	Flow rate passing through PAT (m^3/h)		Emitter coefficient		Average water pressure (m)		Optimal water pressure (m)		Excess water pressure (m)		Average power generation (kW)		Average water saving (m^3/h)		Average energy saving (kWh)		CO^2 emission reduction (kg CO_2/h)		Payback period (year)
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	
2020	16.66	17.38	0.0225	0.0208	53.90	54.03	23.60	24.10	30.30	29.93	0.83	0.85	4.51	4.03	2.71	2.42	1.89	1.75	
2025	19.30	20.11	0.0262	0.0238			24.10	24.60	29.80	29.43	0.94	0.97	5.12	4.58	3.07	2.75	2.14	1.99	1.27
2035	26.08	26.16	0.0360	0.0323			25.10	26.60	28.80	27.43	1.23	1.21	6.69	5.68	4.01	3.41	2.80	2.47	
2020	58.20	95.04	0.0307	0.0375	50.60	50.60	34.20	37.70	16.40	12.90	1.56	2.00	7.50	5.89	4.50	3.53	3.24	2.96	
2025	67.60	110.34	0.0362	0.0447			36.70	41.70	13.90	8.90	1.54	1.61	8.27	4.76	4.96	2.86	3.47	2.39	[a]
2035	112.30	[a]	0.0509	0.0641			45.60	[a]	5.00	[a]	0.92	[a]	2.89	[a]	1.73	[a]	1.41	[a]	
2020	57.78	63.35	0.0348	0.0330			29.20	29.70	18.22	18.01	1.72	1.89	6.48	6.05	3.89	3.63	3.00	2.95	
2025	67.11	73.12	0.0406	0.0380	47.42	47.71	31.50	31.70	15.92	16.01	1.75	1.91	6.50	6.11	3.90	3.67	3.02	2.98	0.85
2035	90.12	98.65	0.0549	0.0520			38.50	38.90	8.92	8.81	1.31	1.42	4.72	4.41	2.83	2.65	2.21	2.17	
2020		24.55		0.0310		53.09		21.00		32.09		1.29		4.78		2.87		2.22	
2025		28.48		0.0360				21.00		32.09		1.49		5.55		3.33		2.58	–
2035		38.26		0.0490				21.00		32.09		2.01		7.48		4.49		3.47	
2020		8.41		0.0027		52.85		21.50		31.35		0.43		0.28		0.17		0.32	
2025		9.73		0.0031				22.00		30.85		0.49		0.32		0.19		0.36	–
2035		13.09		0.0042				22.00		30.85		0.66		0.43		0.26		0.49	
2020	6.38	9.86	0.0130	0.0195	51.63	52.17	21.80	21.80	29.83	30.37	0.31	0.49	0.72	1.09	0.43	0.65	0.40	0.61	
2025	7.38	11.19	0.0150	0.0210			21.80	22.00	29.83	30.17	0.36	0.55	0.83	1.17	0.50	0.70	0.46	0.67	5.77
2035	10.04	15.30	0.0210	0.0300			22.00	22.80	29.63	29.37	0.49	0.73	1.15	1.61	0.69	0.97	0.63	0.91	
2020	18.71	23.80	0.0190	0.0205	52.16	52.59	32.30	32.30	19.86	20.29	0.61	0.79	1.82	2.01	1.09	1.21	0.91	1.07	
2025	21.77	27.64	0.0223	0.0240			32.80	33.30	19.36	19.29	0.69	0.87	2.08	2.23	1.25	1.34	1.04	1.18	2.76
2035	29.18	37.11	0.0300	0.0326			34.80	35.30	17.36	17.29	0.83	1.05	2.48	2.69	1.49	1.61	1.24	1.42	
2020	28.25	29.29	0.0188	0.0142	51.40	52.44	34.90	34.90	16.50	17.54	0.76	0.84	2.97	2.38	1.78	1.43	1.36	1.21	
2025	33.01	34.18	0.0222	0.0168			35.40	35.40	16.00	17.04	0.86	0.95	3.39	2.72	2.03	1.63	1.55	1.38	2.00
2035	43.99	46.13	0.0295	0.0230			36.90	36.90	14.50	15.54	1.04	1.17	4.04	3.37	2.42	2.02	1.85	1.71	

Note: "Min." refers to the minimum consumption period, while "Max." stands for maximum consumption period. Flow rate data for minimum consumption period was not available.
[a]Pressure management is not suitable. Hence, hydraulic model was not utilized to predict water/energy savings, power generation, reduction in CO_2 emissions and payback period.

implementing turbine or PAT systems. In this study, potential power generation was estimated for each of the studied DMAs and scenarios in case of PAT installation to reduce excess water pressure. For each scenario, the optimum pressure head at the entrance to each DMA was predicted by the hydraulic model. Decrease in flow rates due to pressure reduction in the DMA was also considered and estimated by the hydraulic model. The average power generation values calculated for each of the studied DMAs and scenarios are presented in Table 1. As an example, estimated power generation in DMA-6 is presented in Fig. 5 for minimum and maximum flow rate conditions for the years 2020, 2025 and 2035. Additionally, CO_2 emissions are reduced due to power generation from a renewable source and energy savings. In this respect, reductions in CO_2 emissions due to potential power generation from PAT system and energy saving due to water saving are presented in Table 1.

The proposed PAT systems could generate power in the range of 1–2 kW and even smaller. For the calculation of power generation, the efficiency of the proposed PATs was taken as 60% based on the measured performance of a 10 kW PAT system. In this respect, the most important parameters for PAT performance are specific speed, flow and head conditions. Different specific speeds, flow and head conditions require different PATs with different characteristic curves. Taking the performance of one PAT and assuming it applies to all others is a limitation in this study.

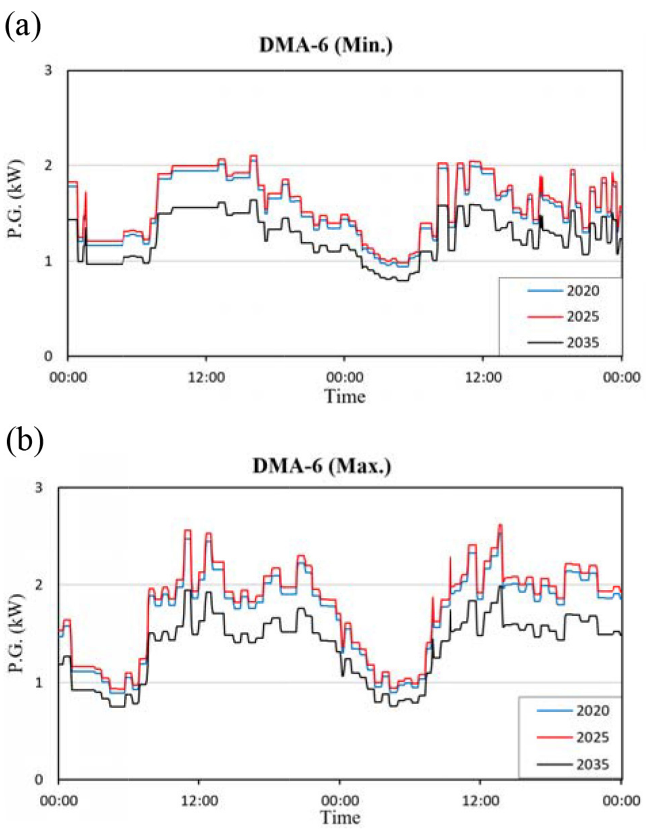


Fig. 5. Potential power generation (P.G.) in DMA-6 by implementation of PAT (a) minimum consumption period and (b) maximum consumption period.

3.4. Site selection of PAT system based on potential environmental benefits and payback period

Environmental benefits of power generation, water saving, energy saving, CO_2 emission reduction and payback period were evaluated for all potential DMAs, considering minimum and maximum flow rate conditions and future years, as presented in Table 1 and Fig. 6. The payback period was calculated by dividing the total implementation cost of PAT system (€38,210) by the total annual amount of revenues from produced energy and saved water. The findings of this evaluation are very helpful for optimal site selection of PAT system among the potential DMAs where pressure management could be practiced. The details of the environmental benefits (annual recovered energy, saved water, saved energy and reduced CO_2 emissions) and payback period of DMA-6 is presented in Table 2. In the PSA, environmental benefits of PAT system implementation were highest for DMA-6 with the shortest payback period of 0.85 year. Consequently, this DMA is prioritized as the best location for PAT system implementation.

4. Conclusions

Excess water pressure in WDNs results in high physical water losses, increases the frequency of pipe bursts and operational and maintenance costs. Consequently,

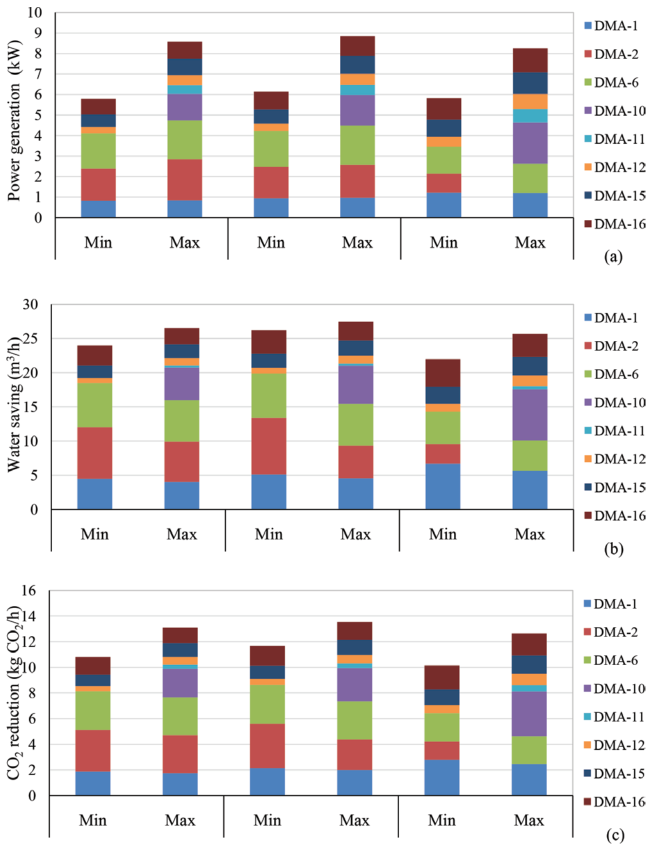


Fig. 6. (a) Power generation, (b) water saving and (c) CO_2 emission reduction for all potential DMAs considering minimum and maximum flow rate conditions and future years.

Table 2
Environmental benefits and payback period of PAT system implementation in DMA-6

Years	2020	2025	2035
Predicted flow rate (m^3/h)	61.80 (minimum) 67.75 (maximum)	71.78 (minimum) 78.20 (maximum)	96.38 (minimum) 105.51 (maximum)
Flow rate passing through PAT system (m^3/h)	57.78 (minimum) 63.35 (maximum)	67.11 (minimum) 73.12 (maximum)	90.12 (minimum) 98.65 (maximum)
Average power generation (kW)	1.81	1.83	1.37
Annually recovered energy (kWh)	15,856	16,031	12,001
Value of recovered energy (€/year)	**1,814**	**1,834**	**1,373**
Average water saving (m^3/h)	6.27	6.31	4.57
Annually saved water (m^3/year)	54,925	55,276	40,033
Value of saved water (€/year)	**42,842**	**43,115**	**31,226**
Average energy saving (kW)	3.76	3.79	2.74
Annually saved energy (kWh)	32,938	33,200	24,002
Value of saved energy (€/year)	3,768	3,798	2,746
Average CO_2 emission reduction (kg CO_2/h)	2.98	3.00	2.19
Annually reduced CO_2 emission (kg/year)	26,105	26,280	19,184
Total benefits from recovered energy and saved water (€/year)	**44,656**	**44,949**	**32,599**
Payback period (year)	**0.85**		

Note: The bold values show the value of environmental benefits in terms of money to calculate the payback period.

pressure management is vital for reducing physical water losses and improving efficiency of WDNs. Installation of PRVs is an effective way to reduce excess water pressure by dissipation of energy. However, recovery of energy from excess water pressure is possible by implementing turbine/PAT systems. In the literature, there are several research studies which focus on experimental and possible real case applications of PAT systems for reduction of excess water pressure in WDNs. PAT systems help improving hydraulic efficiency of WDNs by reducing excess water pressure, physical water losses and frequency of pipe bursts in addition to reduction in CO_2 emissions, energy production and saving. In this study, site selection of PAT system was investigated for all DMAs of the PSA, KWDN, considering minimum and maximum water consumption periods and future years up to 2035. In this analysis, hydraulic modelling study was conducted to determine excess and optimum water pressure levels in each DMA, to analyze areal pressure distributions and to estimate leakage volumes with respect to pressure. Environmental benefits of PAT implementation (potential power generation, water and energy savings, CO_2 emission reductions) and payback period were assessed for the potential DMAs where pressure management could be practiced. Based on the presented results, DMA-6 of KWDN was prioritized as the best location for PAT system with a payback period of 0.85 year. In this study, hydraulic model was effectively used for site selection of PAT system considering changes in future water demands and excess water pressure levels. Long-term analysis of hydraulic parameters (water demand, flow rate and excess water pressure) and evaluation of environmental benefits and payback period are necessary for optimal site selection of PAT.

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