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Effect of collection tank level on energy consumption of lifting pumps in drinking water distribution systems

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ABSTRACT

Submersible pumps and lifting pumps are among the indispensable elements of drinking water supply systems. The operational costs and the investment costs of this mechanical equipment are essential for the operating institutions. Most of the energy consumption costs, which have an important place in the expenditure budgets of the water and sewerage administrations, arise from the pumps in the system. Therefore, the efficiency of this system's elements has a significant role in terms of energy costs for the water and sewage administrations responsible for supplying drinking water to the public in our country. Today, dependence on energy and increasing energy consumption necessitate measures to reduce costs on energy. Lifting pumps pump water from a mid-level collection tank, where water is drawn from the wells by submersible pumps to an upper feed tank. This study aimed to investigate the effect of collection tank level on the energy consumption of lifting pumps in drinking water distribution systems. For this purpose, an experimental setup consisting of a borehole, a collection tank, a lifting pump, and a distribution tank was established in an independent laboratory in Kayseri. A SCADA system was integrated into the experimental system to monitor and evaluate energy consumption. The results showed that the pump efficiency increased with the tank level, thus reducing energy consumption.

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1. INTRODUCTION

Water will be a strategic resource in the future due to increasing threats, and that excessive water use and high loss rates have social, economic, cultural and political reasons, and the cost of water from the source to the tap should be an essential issue be addressed. The purpose of drinking water supply and distribution systems is to provide a population with water of satisfactory quality and sufficient quantity. The system consists of water intake structures, transmission lines, tanks, main pipes, primary and secondary distribution pipes, pressure boosting pumps, valves, fire hydrants, pressure breakers, stabilizer valves, and subscriber connections [1].

Energy costs comprise a significant component of the operating costs of Water Supply Systems (WSS). Water pumping stations usually consume the most considerable quantity of energy. The overall operational cost associated with a particular pump station depends on the following factors: the pumps, the distribution system, the pump drivers, and the governing energy rate schedule [2]. Water companies/administrations use various water treatment and transport processes, which are high electricity consuming. It is estimated that means of water distribution absorb from 3% to 7% of electricity worldwide [3-5]. According to Watergy [6], approximately 2% to 3% of the worldwide electricity consumption is used for pumping in WSS, while 80%–90% of this consumption is absorbed by motor-pump sets [7]. Copeland and Carter [8] states that 67% of energy consumption in WSS comes from tap water pumping, 14% from water treatment, 11% from raw water pumping, and 8% from in-plant water pumping (e.g. backwash water of filters). According to Vilanova and Balestieri [3], 80-90% of electricity consumption, due to water distribution, comes from

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the running of pumping stations. The researchers mentioned here and many other researchers point out that pumping stations make a significant contribution to electricity consumption. Therefore, any efficiency improvement in the relevant processes is substantial [5].

Several methods positively affect the reduction of energy consumption in WSS [4-21]. Coelho and Andrade-Campos [4] provides several strategies to improve the energy efficiency of the WSS. According to Zimoch and Bartkiewicz [5], the main improvements in energy efficiency can be achieved with: (a) implementation of control and monitoring systems Supervisory Control and Data Acquisition (SCADA), (b) installing higher efficiency pumps, motors and drives, (c) generating energy in WSS using alternative energy sources. Feldman [10] states that the significant improvements in energy efficiency can be achieved using the following methods: (a) improvement of pumping stations and system design; (b) Variable Speed Drives (VSDs) installations; (c) efficient operation of pumps and (d) minimizing of water losses through pressure control. According to Luna et al. [11], to improve the efficiency of the water supply system operation, two optimization approaches are generally considered, namely optimization of the water levels in the storage tanks and optimising the pumping operations' scheduling. Both methods may be relatively successful depending on the case study.

A slight increase in inefficiency caused by pumping optimization may cause significant savings in electric energy and expenses [22]. Sarbu [7] presented several comparative studies of energy efficiency in water distribution systems considering distinct configurations of the networks and considered implementing the variable-speed pumps. The improving energy efficiency of water pumping is briefly reviewed by presenting a representative real case study. Four strategies are described to improve the energy efficiency of water pumping: using control systems to vary pump speed drive according to water demand, pumping to storage tanks, using intermediary pumping stations integrated into the network, and using elevated storage tanks floating on the system. He concluded that it is possible to achieve significant savings in operating costs. According to Grundfos [23], one of the world's largest pump manufacturers, two-thirds of the currently used pumps, energy savings of up to 60% are possible. Nowak et al. [23] presented an optimization process and an extended decision support process for the design and operation of water supply systems, emphasizing the use of variable speed pumps. It was applied to a model of the water supply system at Worms, Germany. Different scenarios were compared using an optimization process that predicted energy savings of up to 18% annually. Georgescu and Georgescu [24] used a Honey Bees Mating Optimization Algorithm to optimize pump schedules for four pumping stations, three tanks, and a constant level water source using a simplified model of the piping network. Case studies indicated that pumping energy savings vary widely depending on the circumstances, but overall savings of between 5 and 30% of current energy demand appeared achievable [25]. The more considerable savings will be mainly due to improving maintenance, and closer matching pumps to their duties. Energy efficiency gains from new pumping technology will probably be less than 5% since the technology is generally mature. However, more significant improvements should be feasible in submersible and borehole pumps where hydraulic and electrical configurations are more complex. The case studies and examples tend to focus on these two areas, but there is a broad range of activities worldwide, from leakage reduction to renewable energy [25]. Luna et al. [11] developed a hybrid genetic algorithm to optimize the pumping scheduling of a water supply network, aiming to minimize energy consumption and costs. They found that optimizing pump planning can improve energy efficiency by an average of 15% (maximum 25%) than the actual operation. Literature review shows that there are significant energy-saving opportunities and viable potential in WSS [26]: (a) pumps and pumping (standard potential ranges): 5-30%; (b) improving existing pumps: 5-10%; (c) improvement to new pumping technology: 3-7%; (d) maintenance improvement and closer matching of pumps to their duties (such as using VSDs): up to 30%.

Lifting pumps water from a mid-level collection tank, where water is drawn from the wells by submersible pumps, to an upper feed tank. This study investigates the effect of collection tank level on the energy consumption of lifting pumps in drinking water distribution systems. An experimental setup consisting of a borehole, a collection tank, a lifting pump, and a distribution tank was established in an independent laboratory in Kayseri. A SCADA system was integrated into the experimental system to monitor and evaluate energy consumption. Energy consumption and energy cost characteristics are determined. Suggestions are made to reduce energy consumption and improve energy efficiency in drinking water distribution systems.

2. MATERIAL AND METHOD

2.1. Experimental System

An experimental system was set up in an independent laboratory in Kayseri to examine the effect of collection tank level on the energy consumption of lifting pumps in drinking water distribution systems. The experimental design is shown in Figure 1 and Figure 2. The practical system consists of 3 main parts: Part A, Part B, and Part C. Part A consists of well (1), deep well pump (submersible pump) (2), power panel with frequency converter (3), level sensor (4), bullock check valve (5), manometer (6), output pressure sensor (7), sliding valve (8), promotional line (9), SCADA control panel (10), electromagnetic flowmeter (11) and line pressure sensor (12). The essential elements of Part B are collection storage tank (1), inline centrifugal pump (2), power panel with frequency converter (3), SCADA control panel (4), bullock check valve (5), manometer (6), pressure sensor (7), sliding valve (8), vacuum meter (9), promotional line (10), and electromagnetic flowmeter (11). Part C consists of a 100 m^3 distribution storage tank. Figure 3 shows a general view of the experimental setup.

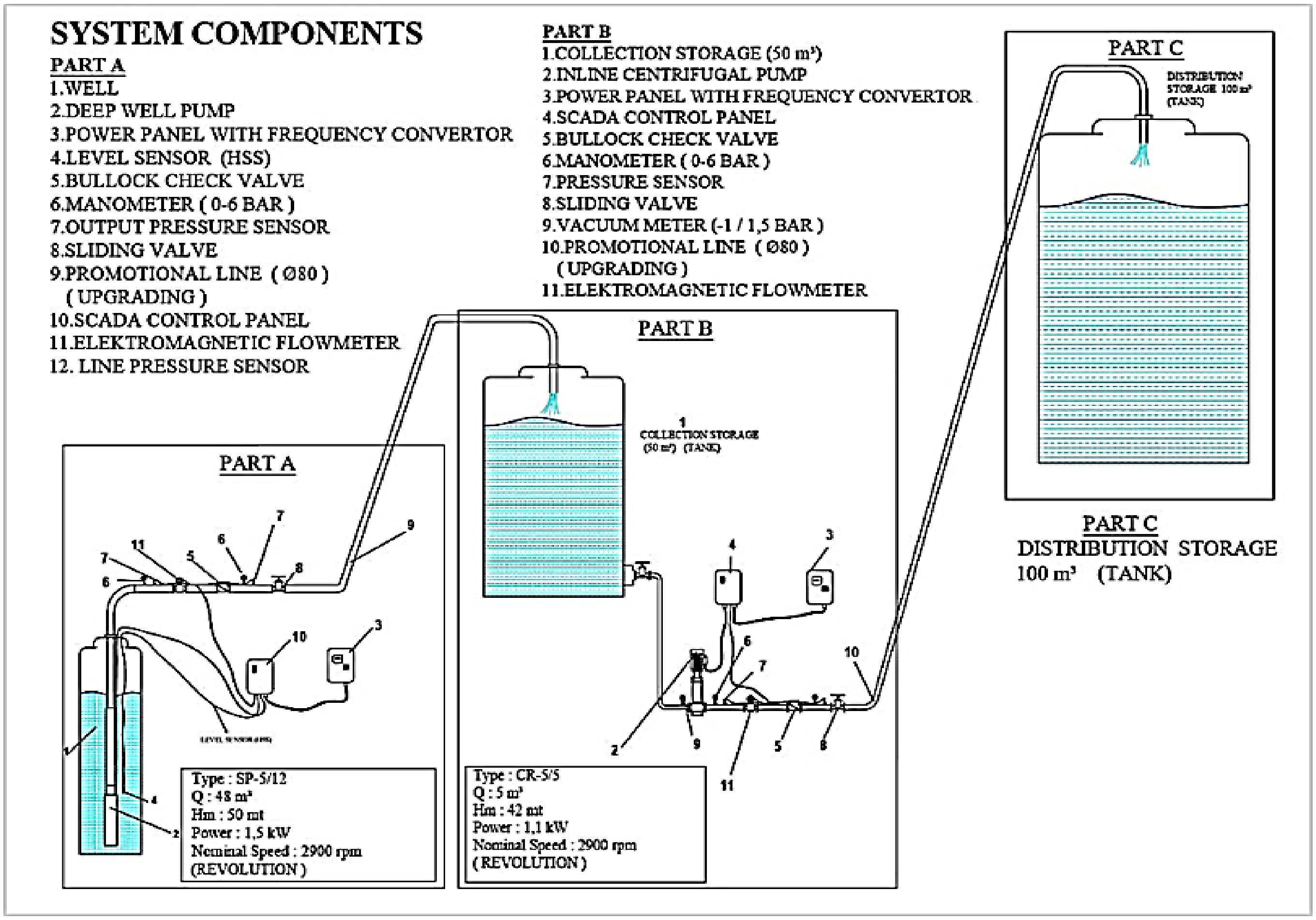

Fig. 1. A schematic diagram of the experimental setup.

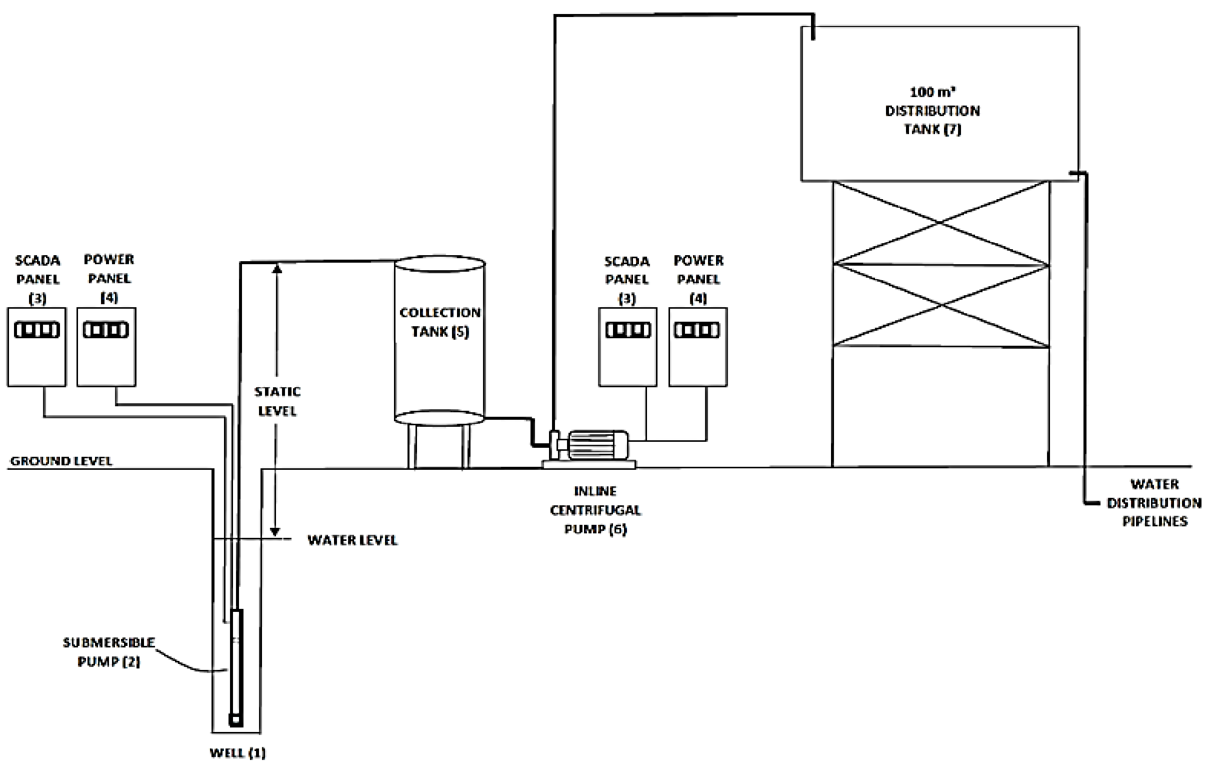

Fig. 2. A schematic diagram of the experimental setup.

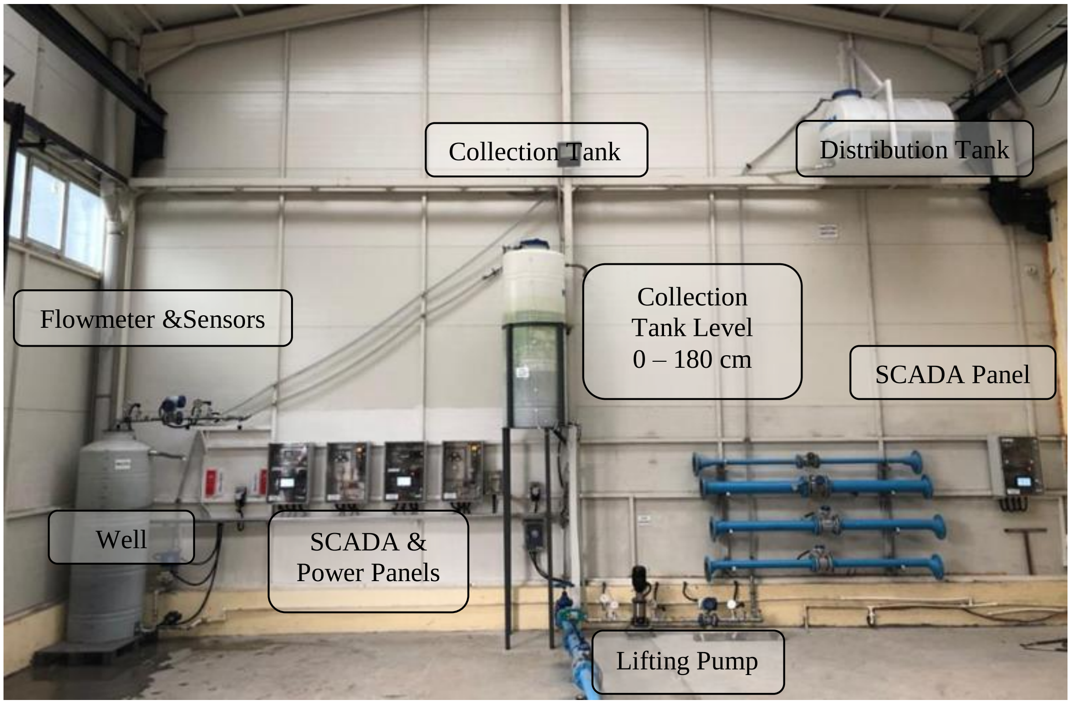

Fig. 3. A general view of the experimental setup.

A SCADA system was integrated into the experimental system to monitor and evaluate energy consumption. Using the SCADA system, the instantaneous measurement values measured by the measuring devices were recorded. Using the measuring instruments, the following data were taken:

(a) Well: water level, outlet flow rate, outlet pressure, line pressure, energy information (voltages, currents, power),

(b) Collection tank: inlet pressure, outlet pressure, outlet flow rate, energy information (voltages, currents, power),

(c) Distribution tank: water level, outlet flow rate.

Data was transferred from the system every 10 seconds via servers, and the received data were recorded. Using these data, characteristics of the well part, collection storage part, and distribution storage part were evaluated. Energy consumption and cost characteristics were calculated.

2.2. Method

This study aimed to examine the effect of collection tank level on the energy consumption of lifting pumps in drinking water distribution systems. The experiments were carried out in an experimental system established in an independent laboratory in Kayseri. Five different levels of 40, 80, 120, 160, and 180 cm were used for the collection tank. Measurements were taken for 2 hours for each level of the collection tank. Energy consumption and energy costs were analyzed at different collection tank levels, and savings were calculated.

The power absorbed by a pump in a water supply system P, in W, and the electricity consumption W, in kWh, can be calculated using the following equations [7, 24]:

$$P = \frac{\gamma Q H_p}{\eta} \tag{1}$$

$$W = P T_p \tag{2}$$

where γ is the specific weight of water, in N/m3; Q is the pump discharge, in m3/s; Hp is the pump head for the operating point, in m; η is the global efficiency of the pumping station; and Tp is the operation period, in h.

3. RESULTS AND DISCUSSIONS

3.1. Results for System Established in an Independent Laboratory in Kayseri

This study was carried out to examine the effect of collection tank level on the energy consumption of lifting pumps in drinking water distribution systems. Experiments were carried out for five different levels of the collection tank: 40, 80, 120, 160, and 180 cm. The specific energy and specific cost were determined.

The effect of collection tank level on specific energy is shown in Figure 4. While the collection tank level is 40 cm, the specific energy is 0.08129 kWh/m^3. When the tank level is 120 cm, the particular energy decreases to 0.07699 kWh/m^3; when the tank level is 180 cm, the specific energy decreases to 0.07257 kWh/m^3. These results show that the tank level has significant effects on particular energy. The regression equation that gives the relationship between the specific energy and the water level is given below equation:

$$E = 0.08427 - 0.00657h \tag{3}$$

E is the particular energy consumed to generate 1 m^3 of drinking water, in kWh/m^3; h is the collection tank level, in m.

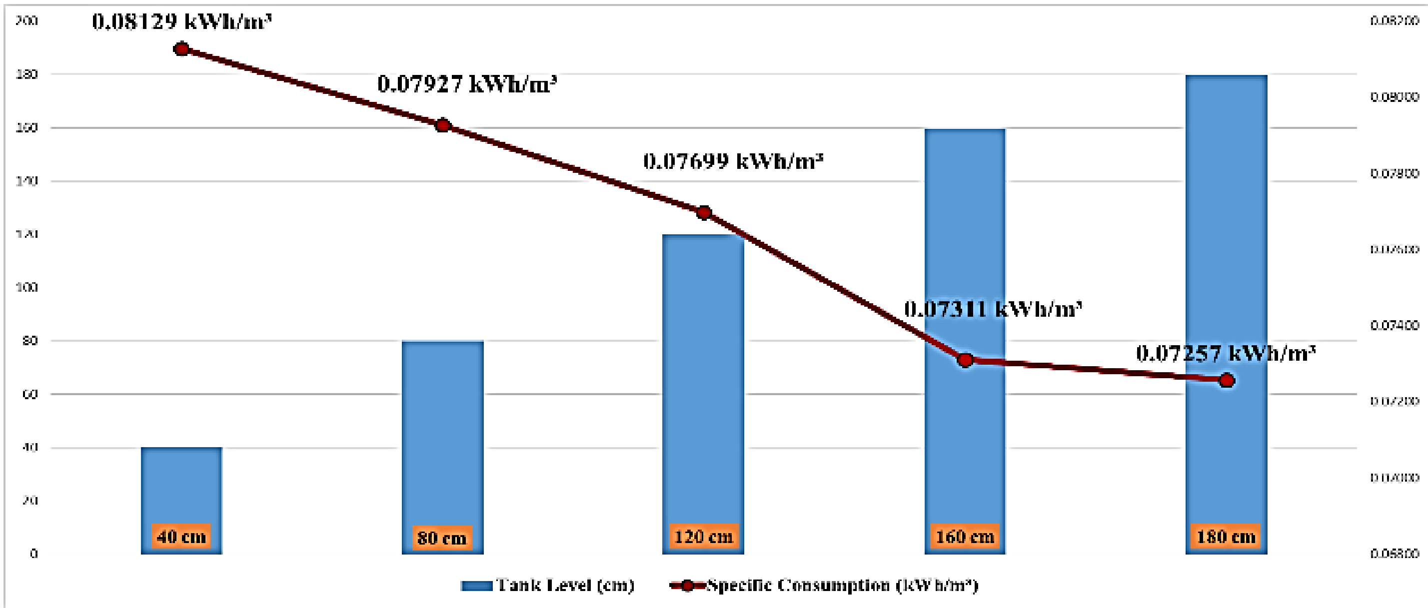

Fig. 4. The effect of collection tank level on specific energy.

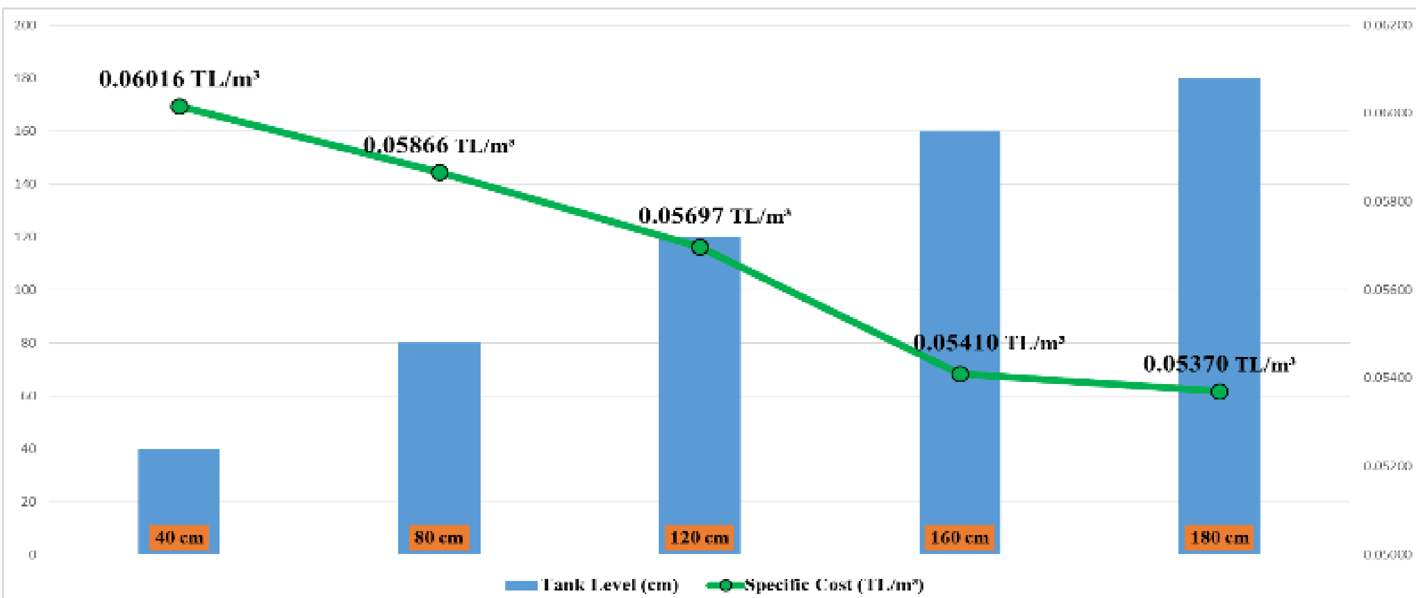

Fig. 5. The effect of collection tank level on specific cost.

Figure 5 shows the effect of collection tank level on the specific cost. While the collection tank level is 40 cm, the special price is 0.06016 TL/m^3. When the tank level is 120 cm, the specific cost decreases to 0.05697 TL/m^3; when the tank level is 180 cm, the particular cost decreases to 0.05370 TL/m^3. These results show that the tank level has significant effects on specific expenses.

The effect of the tank level on both the specific energy and the particular cost is given in Figure 6. The examination of the figure reveals that both specific energy and specific cost decrease with increasing tank levels. Table 1 presents specific energy and specific cost savings when the water level in the collection tank increases. The minimum water level in the tank is taken as 40 cm. When the water level is increased to 80 cm, 2.48% saving in specific energy occurs. When the water level is 120 cm, 160 cm, and 180 cm, a special energy savings of 5.29%, 10.06%, and 10.73% occur, respectively, relative to the 40 cm water level. All these results show that with the increase in the water level, significant savings will be achieved in the energy consumed by the lifting pumps. These results reveal the importance of making the height of the collection tanks as high as possible when building collection tanks in water catchment areas. However, in this case, simulations involving all three essential elements (submersible pumps, collection tanks/lifting pumps, and distribution tanks) must be made to determine the adequate saving amount of energy consumed by the pumping stations.

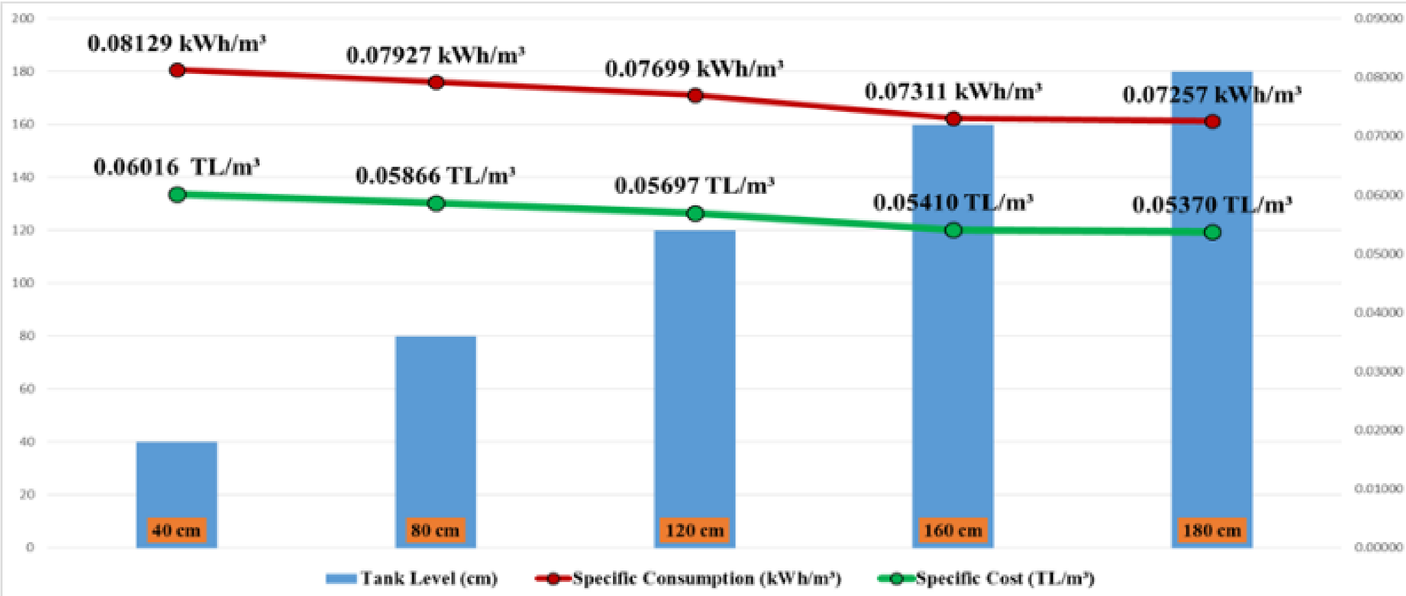

Fig. 6. The effect of collection tank level on specific energy and specific cost.

Table 1. Comparison of the effect of the collection tank level on specific energy and specific cost.

Tank Level (cm)	*Specific Energy (kWh/m³)*	*Specific Cost (TL/m³)*	*Saving (%)*	*Total Saving (%)*
40	0.08129	0.06016	-	
80	0.07927	0.05866	2.48	2.48
120	0.07699	0.05697	2.88	5.29
160	0.07311	0.05410	5.04	10.06
180	0.07257	0.05370	0.74	10.73

3.2. Evaluation for central pumps group of Kayseri Water and Sewerage Directorate (KASKİ)

In this study, a demo was created by simulating the well, collection tank/lifting pump, and distribution tank, which are the essential elements of drinking water supply systems. The operating performances of the lifting pumps with the water level of the collection tank have been examined. It is observed that if the collection tank has 180 cm of water instead of 40 cm, the lifting pump saves approximately 10.73% energy.

There are 12 drinking water catchment areas in the KASKİ responsibility in Kayseri city centre (Table 2). The annual water production and energy consumption in these catchment areas are given in Table 2 and Figure 7. Figure 7 is drawn using the amount of water produced and energy consumed by the KASKİ central group pumps between 01.01.2019 and 31.12.2019. These data were taken from the KASKİ SCADA system. As seen, 96 622 443 m^3 water is promoted annually in the city centre of Kayseri, and 21 720 354 kWh energy is consumed.

Table 2. Lifting stations water production and energy consumption in KASKİ for the city centre.

	Catchment Area	*Water Production (m^3)*	*Energy Consumption (kWh)*
1	Beştepeler	15 859 770.00	3 715 705.00
2	Germiraltı	17 666 991.58	2 338 626.06
3	Karpuzatan	10 313 356.00	2 411 265.00
4	Keykubat	12 247 152.66	3 796 873.84
5	Mahrumlar	8 803 192.18	2 479 551.81
6	Dokuzpınar	5 657 216.00	819 042.00
7	Eğribucak	6 187 519.00	1 952 352.00
8	Gediris	3 394 392.00	756 182.00
9	Konaklar	6 303 890.00	607 356.00
10	İldem	3 606 256.00	999 024.00
11	Çaybağları	4 320 438.00	1 758 171.00
12	Talas	2 262 270.00	905 248.00
	Total	**96 622 443.42**	**21 720 354.71**

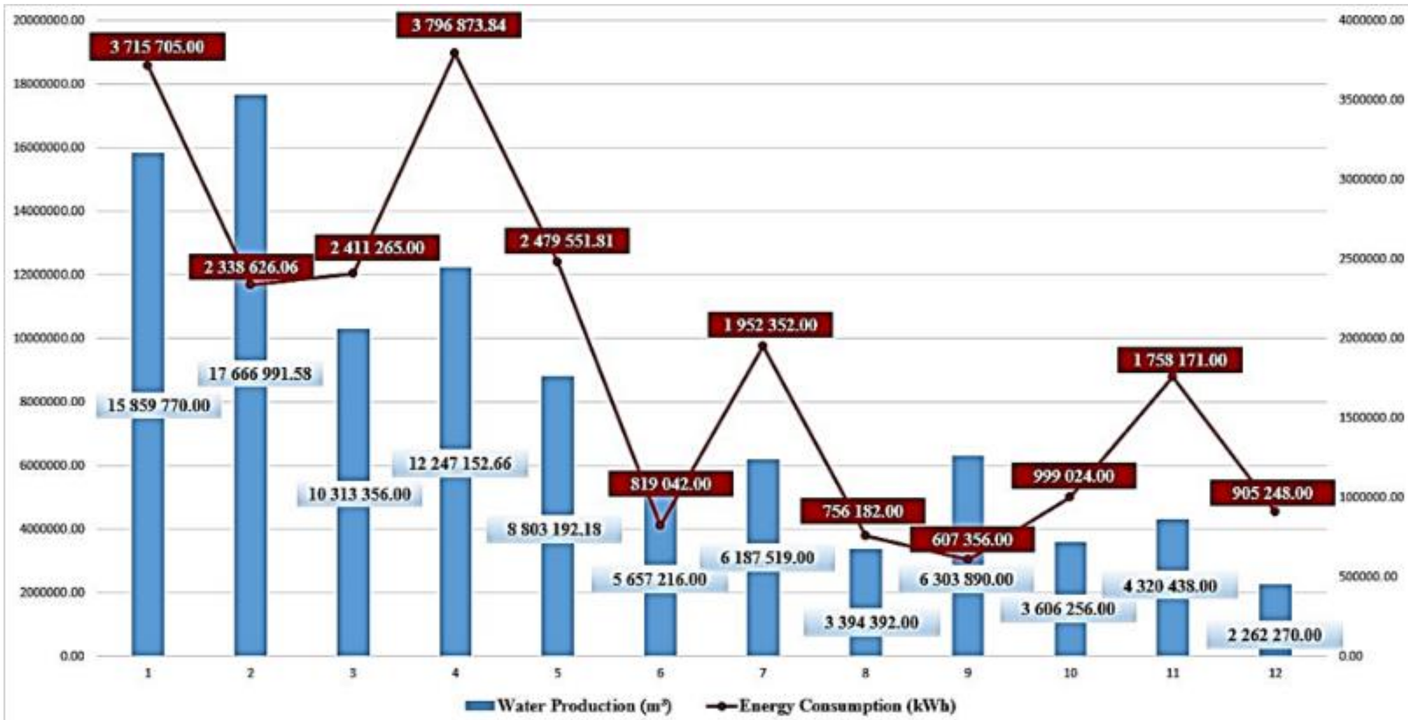

Fig. 7. Lifting stations water production and energy consumption in KASKİ for the city centre.

Figure 8 shows the Germiraltı drinking water catchment area, whose altitude is 1095 m. There are 18 deep wells in the Germiraltı catchment area, 16 of which are active. In the Germiraltı catchment area, the average static levels of drinking water wells, whose depths are around 200 meters, are 34 meters, and their dynamic levels are about 36 meters. The drinking water in the catchment area, at 1060 elevation underground, is promoted to the collection tank with a size of 9.5x15.50x3.40 m and a capacity of 500 m³ at 1095 elevation by submersible pumps. The drinking water collected here is promoted to distribution tanks at higher elevations by three centrifugal pumps. Technical features of the lifting pumps are given in Table 3.

Fig. 8. Germiraltı catchment area.

Table 3. Technical specifications of the lifting pumps in the Germiraltı catchment area.

	Flow Rate (m^3/h)	*Discharge Head (m)*	*Revolutions Per Minute (rpm)*	*Power (kW)*
Pump - 1	1 080	34	1 500	132
Pump - 2	400	101	1 500	200
Pump - 3	100	90	2 900	37

As a result of the demonstration study, it is determined that the water level in the collection tank should be kept as high as possible to save energy. If an analogy is made to this result, it is concluded that the water level of the collection tank in the Germiraltı catchment area must be kept high to save energy. Due to the high water production and high-energy cost in the catchment area, significant financial savings will be achieved by keeping the water level in the collection tank high. On the other hand, since twelve submersible pumps are feeding the collection tank, it should be decided by making an optimization study which pumps to be used while filling the collecting tank.

4. CONCLUSION

In this study, the energy consumption behaviour of the lifting pumps used in drinking water supply systems was examined for different tank levels. Significant findings of this study are concluded as follows:

(a) The tank level has significant effects on specific energy. The specific energy of the lifting pump decreases with increasing tank level.

(b) The tank level has significant effects on specific costs. The particular cost of the lifting pump decreases with increasing tank level.

(c) The increase in the water level creates significant savings in the energy consumed by the lifting pumps. If the collection tank has 180 cm of water instead of 40 cm, the lifting pumps save approximately 10.73% of energy.

(d) To reduce the energy consumed by the lifting pumps, the height of the collection tanks in the catchment areas should be made as large as possible.

(e) The water levels in collection tanks built in the catchment areas should be kept as high as possible to reduce the energy consumed by the lifting pumps.

(f)Simulations involving all three essential elements (submersible pumps, collecting tanks/lifting pumps, and distribution tanks) should be conducted to determine the actual amount of savings that can be made in the amount of energy consumed by pumping stations.

(g) Since many lifting pumps are used in water supply systems of provinces, significant energy savings can be achieved by sizing collection tanks appropriately and keeping the water level in the tanks high.

(h) Since the water production and energy consumption of the lifting stations in KASKİ for the city centre are very high, significant financial savings may be achieved by keeping the water level in the collection tanks high.

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