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Electrical Energy Management in Industrial Wastewater Treatment Plant

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ABSTRACT

In this study, the energy consumption of Nasirabad Industrial Park (NIP) treatment plant was evaluated. A combination of up-flow anaerobic baffled reactor (UABR) and aerobic integrated fixed-bed activated sludge (IFAS) processes were employed in NIP. To find out the average electrical energy use per m^3 influent wastewater, the rate of energy usage of the plant was calculated by data derived from the monthly utility bills in 2013 and 2014. The energy consumption was estimated to be 10.4 and 10.7 kWh.day^{-1}.m^{-3} in 2013 and 2014, respectively. In addition, the electrical energy consumption of different electromechanical equipment of the plant was separately assessed. The average daily electrical energy consumed by treatment processes (effective energy) in both 2013 and 2014 was estimated at 7.2 kWh.day^{-1}.m^{-3}, while the average energy consumption by other parts of the treatment plant (ineffective energy) was 3.2 and 3.5 kWh.day^{-1}.m^{-3} in 2013 and 2014, respectively. The rate of electrical energy usage per kg COD removal was found to be 4.9 and 5.1 kWh.day^{-1} in 2013 and 2014, respectively. Finally, it was inferred that energy use in NIP was not being managed in a suitable manor. Given the significance of energy, price risings, and the decline of resources by which energy is generated, it is imperative to take effective managerial actions to reduce electrical energy consumption in wastewater treatment plants. Also, the designers of water and wastewater treatment plants should consider less energy-intensive processes to improve their energy efficiency.

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1. INTRODUCTION

In recent decades, public attention has been drawn to the quality standards of wastewater effluents [1]. Energy use is overlooked in designing treatment plants so that they are designed more on the basis of experience than on the basis of the best practices or the latest and the most recent scientific findings.

Wastewater treatment plants (WTPs) are regarded to be among energy-intensive equipment. Most treatment systems consume a great deal of electrical energy, and electricity represents one of the largest parts of their operational costs so that 25-40 % of the operational costs of a wastewater treatment process is accounted for by energy supply [2]. Thus, energy is a critical factor in the costs of treatment plants [3], and the designers of modern wastewater treatment technologies focus on curbing energy use as their main goal [4]. According to Malcolm et al. [5], 50-60 % of energy usage of WTPs is related to the aeration process.

Presently, due to population growth and the improvements of technology and industries, the contaminations that must be treated have augmented on the one hand and more stringent environmental standards have been enforced for the quality of effluent wastewaters and their different applications on the other hand. This has increased energy use of treatment plants. Therefore, it is of paramount importance to optimize energy use and improve the efficiency of treatment plants, their equipment and technologies. Also, more attention should be paid to energy recovery and sound cost management of energy used in water and wastewater sector because the enhancement of energy

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efficiency and productivity in treatment plants means less energy use, less greenhouse gases emission, and lower operational costs [6].

Kusiak et al. [7] report that about 2-4 % of the total electricity of society is consumed by wastewater treatment plants. However, given environmental requirements and population growth in the coming years, the demand for electrical energy will rise. Therefore, necessary actions should be taken to extend energy conservations [8]. Accordingly, electrical energy use seems to be a critical parameter in determining the optimal efficiency of treatment plants. Furthermore, since subsidy reforms and the rise of electrical energy tariffs in Iran have had significant growth, the issue of best electrical energy management practices in sewage treatment plants has attracted more interests. The focus in designing treatment systems should be on the approach of a lower rate and a higher efficiency of electrical energy use. In a study in Sweden, Åmand et al. [9] investigated aeration control to minimize electrical energy use of sewage treatment plants using an activated sludge process. They concluded that the dissolved oxygen level affected the efficiency of the aeration process and, to the same extent, the treatment results. Electrical energy use in WTPs depended on the amount of air consumption and, therefore, oxygen consumption level. Monitoring the concentration of ammonium or ammonia in the input wastewater showed that as nitrogen content of the wastewater was reduced, the rate of oxygen consumption and electrical energy use declined [10]. In a study in Spain, Hernández-Sancho et al. [11] evaluated the factors underpinning electrical energy use in wastewater treatment plants. They came to the conclusion that the average input electrical energy of a plant was a function of the qualitative parameters of input, treatment technology, the quality of effluent wastewater, and the size of the plant. The rate of electrical energy use per unit area was greater in smaller plants than in larger plants. Descoins et al. [12] focused on the electrical energy use of some treatment plants and established a perfect relationship between biological activity and electricity demand. They also derived the effect of primary setting efficiency on electricity use and found that the recycling of ammonia from the anaerobic digester to activated sludge was a factor limiting electrical energy use efficiency of the plants. In an attempt to optimize pumps and aeration in treatment plants, Chae and Kang [13] concluded that pumping stations and aeration process were the most important energy-intensive components of the wastewater treatment plants so that about 22 % of electrical energy was consumed by the pumping station and about 42 % was accounted for by the aeration in the activated sludge process. Therefore, the optimization of pumps and aeration process is crucial to reducing energy use in the treatment plants.

Given the significance of the energy, rising prices and the decline of resources by which energy is generated, it is imperative to take effective managerial actions to reduce electrical energy consumption by wastewater treatment plants [14]. Therefore, the issue of desired aeration and optimization of pumps and blowers in aeration tanks, as well as the management and reduction of the produced sludge, should be seriously considered [15]. Desired operation of aeration unit and sound management of processes such as the use of ultrasonic waves and their distribution into the sewage can make it possible to change the chemical structure and the size of organic particles in wastewater so that the process of biological treatment can be accelerated and the level of wastewater treatment can be increased [16]. A great saving can be achieved in aeration and electrical energy use. In addition, the use of the waves can contribute to reducing the produced sludge to a great extent; then, less electrical energy will be consumed in sludge facilities. If treatment plants can utilize the energy generated in the anaerobic and sludge treatment section to produce electrical energy, the plants can become largely independent of energy issues [17].

The present study focused on the wastewater treatment plant of Nasirabad Industrial Park (NIP), which contains 220 active industrial units. The treatment process in this plant is a combination of up-flow anaerobic baffled reactor (UABR) and integrated fixed-bed activated sludge (IFAS) processes. The aim of this study was to find out the rate of electrical energy consumption of different processes of an industrial wastewater treatment plant. At first, we specified the energy-intensive parts of the plant and then, it was calculated how much electrical energy they needed to remove 1 kg of COD. To the best of our knowledge, this is the first research work on wastewater treatment plants of industrial parks in Iran. According to our findings and the results of other studies on electrical energy consumption and productivity index in the treatment plants of industrial parks, electrical energy use can be considered an effective factor in the design of treatment plants and these plants can be operated much more economically by reducing electrical energy use.

2. MATERIALS METHOD

The statistical techniques were used in this study, and data were collected by observations and fieldwork from the treatment plant of NIP in Tehran, Iran. Figure 1 shows a schematic diagram of the wastewater treatment processes in the NIP plant.

In the Nasirabad treatment plant, influent flows into UABR after passing an equalization tank, and then it flows into IFAS aerobic treatment units. After that, the biomass generated through the aerobic process is settled

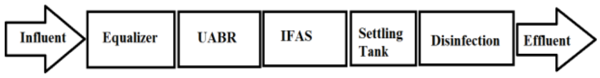

Figure 1. Schematic diagram of the treatment process in NIP

in a clarification tank and finally goes to the chlorination unit and is discharged into the environment. The UABR system is composed of some reactors in which there are rows of baffles. These baffles enable the top-down flow of the wastewater. The bacteria in the reactors may be suspended or precipitated depending on the behavioral characteristics of the flow [18]. The IFAS process is a combination of activated sludge and fixed attached growth along with sludge recycling line. In IFAS systems, both suspended and attached growth microorganisms are effectively and simultaneously used. The IFAS systems have extensive advantages over conventional activated sludge processes. They are more resistant to organic and hydraulic loading shocks because of embedding attached growth media inside aeration tanks [19].

All samplings and assays were performed according to the guidelines provided in standard methods for the examination of water and wastewater [20]. Data were analyzed by drawing the graphs and tables in MS-Excel software package. To check the electrical energy consumption of the studied treatment plant, the utility bills of the plant were assessed for different months of 2013 and 2014. The rate of energy consumption varied at different hours of the day. On the other hand, electrical energy consumption in the bill was divided into three groups: peak hours, semi-peak hours, and off-peak hours. For 24 hours of a day, 12 hours was semi-peak, 6 hours was off-peak, and 6 hours was peak, but their exact time varied with season. Since the measurement periods were different, the average monthly electrical energy consumption was derived from the weighted average of data as shown in Equation (1).

$$E_m = \frac{\sum_{i=1}^{i=n} E_i T_i}{\sum_{i=1}^{i=n} T_i} \tag{1}$$

where E_m represents the average monthly electrical energy consumption, E_i denotes the electrical energy consumption of a certain period, and T_i represents the day count of the period. The amount of electrical energy derived from the utility bill included the electrical energy used by the treatment sections, lighting sections, control rooms, laboratory, and administrative department. We regarded the energy used by the treatment sections as effective energy and the energy used outside the treatment sections as ineffective energy. To specify energy usage of the treatment units, including both effective and ineffective energies, the electromechanical equipment of the treatment sections was checked. So, fieldwork was performed on the treatment plant of NIP and different treatment processes were examined. The treatment plant was composed of eight main sections, including screening unit, pumping station, grit and oil chamber, equalizer, anaerobic unit, aerobic unit, disinfection unit, return sludge line, and filter press. These sections were coded 1 to 8 from the pumping station to filter press as shown in Table 1.

During the site inspection, data were collected from the equipment of these units including the number of pumps and motors operated in different units, as well as their power and working hours. The electrical energy usage of the equipment in each section was separately estimated by Equation (2).

TABLE 1. The electrical equipment used in the WTP of Nasirabad

Unit	Description	Number of units	Equipment	Number of equipment	Power (kW)	Time h.day^{-1}	Q (m^3.day^{-1})
1	Pump Station	1	Pump	2	10	12	620
2	Oil & Grit Chamber	1	Pump	1	1.2	14	620
3	Equalization Tank	1	Pump	2	3.8	12	620
			Dosing pump	1	0.18	12	
			Mixer Dosing	1	0.12	10	
4	Aeration Tank	6	Blower	3	45	12	620
5	Sand Filter	2	Pump	2	5.5	8	300
6	Disinfection Unit	2	Dosing pump	1	0.18	8	200
			Mixer	1	0.18	1	
7	Sludge Storage	2	Pump	2	2.2	8	110
8	Filter Press	3	Compressor	3	4	8	50

$$E = \frac{p \times T}{Q_{ave}} \tag{2}$$

where E is the electrical energy usage in kWh.day^{-1}.m^{-3}, P is the electrical power of pump/motor in kW, T is the operation time in h.day^{-1}, and Q is the total wastewater flow in m^3.day^{-1} [21].

To find out the average electrical energy used to remove 1 kg of COD, COD variation was monitored in different months, which is expressed in mg.l^{-1}. Table 2 illustrates inlet COD (COD$_{in}$) and outlet COD (COD$_{out}$) and the flow rate of wastewater in different months of 2013 and 2014. The flow-rate of wastewater (Q) is expressed in m^3.day^{-1}.

3. RESULTS

3. 1. Total Energy Consumption of Treatment Units

The electrical energy consumptions at each period in 2013 and 2014 were calculated by Equation (1) and illustrated in Figure 2. The electrical energy consumption of each group (peak, semi-peak, and off-peak) was multiplied by the relevant hours and their sum was regarded as the electrical energy consumption of the given period.

The results showed that energy consumption varied significantly across the different months of the years, as expected. This is mainly because of variable quantity and quality of industrial wastewater which directly affects energy consumption in WTP. For example, during the 4th and 6th months of 2013, the average daily energy consumption amounted to 709 and 9904 kWh, respectively. In contrast, in 2014, the lowest and highest average daily energy consumption rates were 3864 and 12717 kWh observed in the 7th and 3rd months, respectively. According to our field assessment, it was due to the changes in the production line of some of the industrial units of NIP which affected the influent of

TABLE 2. COD variation (mg.l^{-1}) and flow rate of wastewater in NTP in different months of 2013 and 2014

Month No.	**2013**			**2014**		
	COD$_{in}$	**COD$_{out}$**	**Q (m^3.day^{-1})**	**COD$_{in}$**	**COD$_{out}$**	**Q (m^3.day^{-1})**
1	2250	160	630	2240	150	620
2	2160	170	620	2310	160	610
3	2320	180	620	2420	170	610
4	2018	145	610	2150	160	620
5	2312	160	620	2460	170	610
6	2415	185	610	2190	150	630
7	2210	160	630	2280	160	610
8	2240	155	620	2510	180	620
9	2025	150	610	2380	160	620
10	2420	180	630	2440	150	610
11	2360	175	620	2010	140	630
12	2280	170	630	2190	160	610

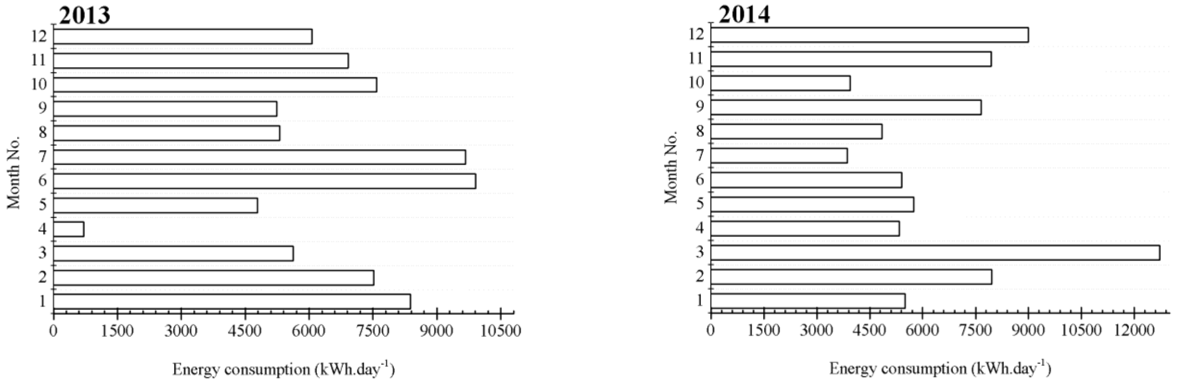

Figure 2. Energy consumption in 2013 and 2014

the treatment plant. Based on the depicted data, the average electrical energy use during 2013 and 2014 was 10.4 and 10.7 kWh.day-1.m-3, respectively. The electrical energy of each unit was calculated by Equation (2) and is displayed in Figure 3. In order to calculate the electrical energy by Equation (2), the average monthly wastewater flow rates in 2013 and 2014 (Qave) was assumed to be 617 and 620 m3.day-1 (based on given data in Table 2), respectively. The efficiency of the pumps/motors was assumed to be 80%.

According to Figure 3, total electrical energy consumption in different sections (effective energy) amounted to 7.2 kWh.day-1.m-3. In addition, the aeration units and filter press consumed the greatest part of electrical energy among all sections of the treatment plant. It can be clearly seen that nearly 45 and 33% of electrical energy use were related to aeration units and sludge treatment section, and the rest of energy was used by pumps, disinfector, and other parts. It confirms that aeration and sludge treatment were two energy-intensive processes in the treatment plant.

3. 2. Ineffective Electrical Energy

According to the utility bill (Figure 2), the mean daily electrical energy consumptions per m3 input wastewater were 10.4 and 10.7 kWh.day-1.m-3 in 2013 and 2014, respectively. The effective electrical energy consumptions of the treatment plant– i.e. the electricity used by the electrical equipment and motors of the treatment – was calculated to be 7.2 kWh.day-1.m-3 according to Equation (2) and Table 2 and the result is depicted in Figure 3. Therefore, we can estimate ineffective electrical energy use– i.e. the electricity consumed by other sections of the plant such as laboratory, control room, and administrative department. This data is illustrated in Figure 4.

As shown in Figure 4, the ineffective energy use of the plant was 3.2 and 3.5 kWh.day-1.m-3 based on input wastewater in 2013 and 2014, respectively. It can be inferred from the data on the total, effective and ineffective electrical energy use that about 32% of the total electrical energy in 2013 and about 33% in 2014 has been consumed by the non-treatment factors of the control room, laboratory, lighting, and administrative department, which were the ineffective electrical use. This implies that the electrical energy efficiency was low in this treatment plant and the consumption of electrical energy was not soundly being managed in the studied plant. This is of crucial importance from an economic perspective because the ineffective electrical energy is priced with industrial tariff too. Therefore, the optimal use of electrical energy in the control room, laboratory, lighting, and administrative department can remarkably reduce electrical energy expenses.

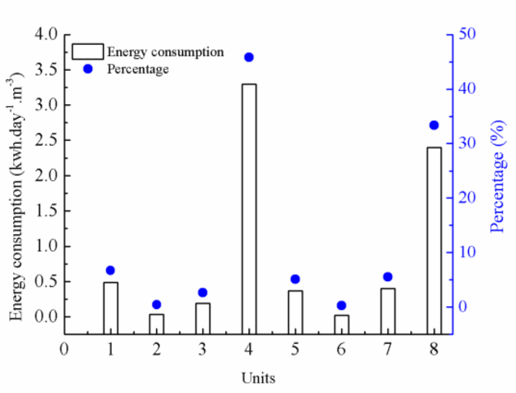

Figure 3. Electrical energy consumption of each unit

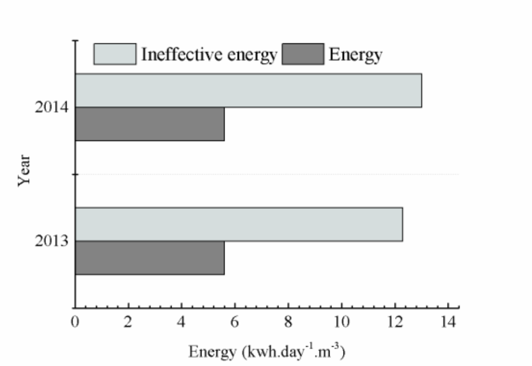

Figure 4. The effective and ineffective electrical energy use of NIP

3. 3. Electrical Energy Use Per COD Removal

The required information is derived from Table 2 to determine the average amount of electrical energy daily consumed to remove 1 kg of COD. Figure 5 shows the average COD removal per month and the amount of electrical energy required for wastewater treatment in 2013 and 2014. It can be seen that in spite of the fact that energy consumption was increased with the increase in COD removal in some months, a different trend was observed in some other months. Therefore, in general, no clear relationship can be drawn between COD and energy consumption. This is due to the impact of various factors on energy consumption and interactions between them. For example, higher temperatures in summer increase the biological activity; thus, without the consumption of additional energy, a higher efficiency would be obtained versus with cold seasons. Also, the effect of pH or toxicity in industrial wastewater is another factor affecting the efficiency of COD removal in the treatment plant. Our results revealed that the average energy consumption per 1 kg COD removal in 12 months of the year was 4.8 and 5.1 kWh in 2013 and 2014, respectively.

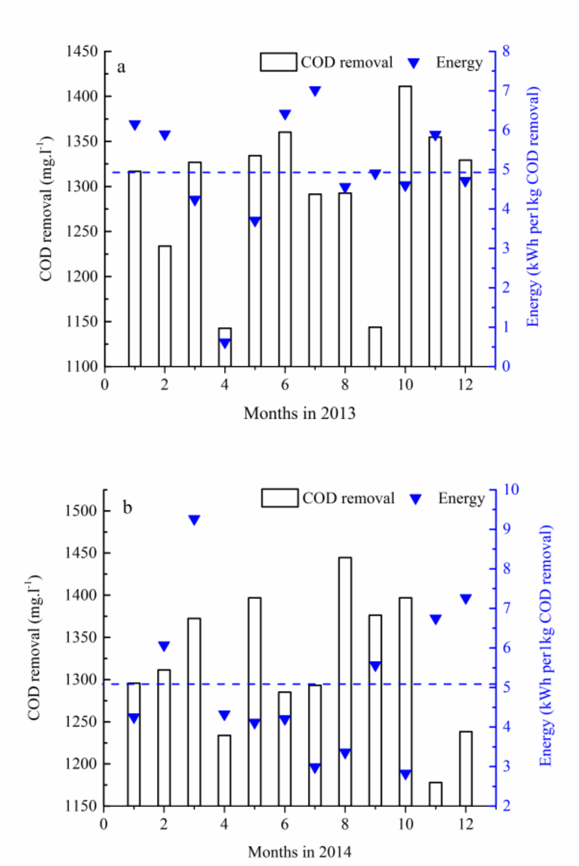

Figure 5. Energy consumption per Kg COD removal in a) 2013, and b) 2014

4. DISCUSSION

According to the results, the aeration sections and filter press are the most electrical energy-intensive parts consuming 3.3 and 2.4 kWh.day-1.m-3 of energy, respectively. The aeration section accounted for 45% and the filter press section for 32% of total electrical energy use of the plant. Also, about 22% of energy was consumed by initial treatment pumps, disinfection section, and the other sections. In a study on energy index of a wastewater treatment plant using activated sludge process coupled with anaerobic digestion in Switzerland, Descoins et al. [12] concluded that 25% of total energy was consumed by pumps and 70 % by compressors that performed the aeration. Chae and Kang [13] investigated a treatment plant in which the activated sludge process was employed and reported that pumping and aeration consumed 22 and 42% of total energy, respectively. The results showed that the rates of electrical energy use of different sections of NIP are reasonable when compared to similar studies. Our previously reported study of the Amol industrial treatment plant (located in the north of Iran) showed similar results [22]. It should be noted that the treatment plant of Amol employs integrated UAFB and IFAS processes. Thus, the aeration sections of both treatment plants consumed a comparable amount of electrical energy. Similar research on treatment plants that use other integrated systems in the industrial parks can contribute to make a comparison among them in terms of their electrical energy consumption to estimate electrical energy use at designing stage of the treatment plants. The rate of ineffective electrical energy use of the Nasirabad treatment plant was 3.2 and 3.5 kWh.day-1.m-3 in 2013 and 2014, respectively. Since it accounted for about 32% of total electrical energy use, it is possible to reduce the energy use of the plant considerably by managing electricity use of the control room, laboratory, and administrative department more soundly.

On the other hand, it is suggested to use separate contours for these sections because the tariff of electricity varies with the purpose for which it is consumed, and hence, ineffective electricity would be priced cheaper than this system. The rate of electrical energy uses to remove 1 kg COD was 4.9 and 5.1 kWh.day-1.m-3 in 2013 and 2014, respectively. However, this was found to be 1.37 and 1.41 kWh.day-1.m-3 in the treatment plant of Amol industrial park reported in our previous work [22]. This means that the treatment plant of Amol industrial park that uses an integrated UAFB-IFAS system coupled with automatic return sludge consumed less electricity than the treatment plant of NIP which uses an integrated UABR-IFAS system with conventional return sludge line using pumps. In conventional return sludge line used in the activated sludge process, the excess sludge is returned from settling tanks to aeration tanks by mechanical or electrical pumps, but this is an important factor of energy use, operational costs, and maintenance in WTPs.

To cope with this problem and reduce the pertaining expenses, the modern methods resort to concentration difference between aeration and settling tanks for the automatic return of sludge. Just a slight change should be made in the structure of settling tanks, and a slope should be created on the bed of the settling tank towards aeration tanks so that these two tanks are separated with a wall containing several holes in one direction and at the same height. In addition, several openings can be mounted at the bottom of the wall to establish an automatic connection between settling and aeration tanks. As such, when it is necessary and the mixed liquid suspended solids (MLSS) concentration rises in the aeration tanks, the sludge can be automatically returned from the bottom of the aeration tanks to the concentration tanks by turning off the blowers [23]. Therefore, it can be concluded that automatic sludge return can be a very useful and effective way to reduce the electrical energy use of treatment plants.

5. CONCLUSIONS

Given the significance of energy, rising prices, and the depletion of energy resources, it is imperative to take more effective managerial actions to curb the use of electrical energy in WTPs. Also, the designers of water and wastewater treatment plants should consider energy-intensive processes and improve their efficiency. Correct and optimal use of electrical energy will contribute to conserving electrical energy as a national resource. As well, it will allow considerable economic saving. Our results showed that priority should be given to sound aeration system, optimization of pumps and blowers in aeration tanks, and the management and reduction of sludge generation. The electrical energy use of pumps and blowers is directly related to the rate of aeration in aeration tanks and the rate of pressure loss. By correct use and management of the aeration section, we can save electrical energy use significantly. Furthermore, ultrasonic waves enable us to reduce exces sludge to a great extent and this will reduce the consumption of electrical energy in sludge facilities. If the treatment plants can utilize the energy generated in the anaerobic section and sludge treatment to generate electricity, they can operate almost independently of energy issues.

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Effective Energy

چکیده

در این مطالعه، مصرف انرژی تصفیه خانه شهرک صنعتی نصیر آباد(NIP) مورد بررسی قرار گرفت. این تصفیه خانه با استفاده از ترکیب فرآیند های راکتور بافل دار بی هوازی با جریان رو به بالا و یک سیستم لجن فعال با بستر ثابت مورد راهبری قرار میگیرد. میزان مصرف انرژی تصفیه خانه با استفاده از داده های حاصل از صورتحساب انرژی برق مصرفی ماهیانه در سال های ۲۰۱۳ و ۲۰۱٤ محاسبه شد تا میانگین انرژی الکتریکی مصرفی به ازای هر متر مکعب فاضلاب بدست آید. مصرف انرژی در سال ۲۰۱۳ و ۲۰۱٤ به ترتیب ۱۰.٤ و ۱۰.۷ کیلووات ساعت در روز به ازای هر متر مکعب فاضلاب تخمین زده شده است. علاوه بر این، مصرف انرژی الکتریکی در بخش های الکترومکانیکی تصفیه خانه به طور جداگانه ارزیابی شد. میانگین انرژی الکتریکی روزانه مصرفی برای فرآیندهای تصفیه (انرژی موثر) در سال ۲۰۱۳ و ۲۰۱٤ به طور متوسط برابر با ۷.۲ کیلووات ساعت در روز به ازای هر متر مکعب تخمین زده شد، در حالیکه میانگین مصرف انرژی در سایر بخشهای تصفیه خانه به منظور رفع نیاز های غیر از تصفیه (انرژی غیر موثر) در سالهای ۲۰۱۳ و ۲۰۱٤ به ترتیب ۳.۲ و ۳.۵ کیلووات ساعت در روز به ازای هر متر مکعب فاضلاب بدست آمد. همچنین، میزان مصرف انرژی الکتریکی به ازای حذف هر کیلوگرم اکسیژن مورد نیاز بیوشیمیایی (COD) در سال ۲۰۱۳ و ۲۰۱٤ به ترتیب ٤.۹ و ۵.۱ کیلووات ساعت در روز به ازای هر کیلوگرم COD حذف شده بوده است. در نهایت بر اساس نتایج بدست آمده میتوان نتیجه گرفت مصرف انرژی در تصفیه خانه مورد مطالعه به درستی انجام نشده است. با توجه به اهمیت انرژی، افزایش قیمت ها و کاهش منابع تولید انرژی، ضروری است اقدامات مدیریتی موثر برای کاهش مصرف برق در تصفیه خانه فاضلاب انجام شود. همچنین طراحان تاسیسات تصفیه آب و فاضلاب باید فرآیندهایی با مصرف انرژی کمتر را برای بهبود بهره وری انرژی در تصفیه خانه ها در نظر بگیرند.

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