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ENERGY EFFICIENCY IN WASTEWATER TREATMENT PLANT EMPHASIZING ON COD REMOVAL: A CASE STUDY OF AMOL INDUSTRIAL ZONE, IRAN

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ABSTRACT

In the present investigation, the wastewater treatment plant (WWTP) of industrial zone of Amol which works with anaerobic system using Up flow Anaerobic Fixed Bed (UAFB) and aerobic system using Integrated Fixed Activated Sludge (IFAS) was studied. In order to measure the amount of energy consumed by the treatment plant, the electricity bills for the different months of 2012 and 2013 were checked and the average daily consumption of electric energy per 1 cubic meter of effluent calculated during these years was 6.62 kwh and 6.24 kWh, respectively. Furthermore, the electromechanical equipments of the plant in each unit were examined separately. The effective daily electrical energy that is the energy used in the treatment process was 4.45 kWh. In addition, the amount of electrical energy per 1 kilogram removed chemical oxygen demand (COD) was obtained. Regarding the energy consuming treatment plant equipments and the rapid increase in energy (electrical energy) prices, the energy management should be more seriously concerned.

Keywords: Industrial zones, consumption of electrical energy, wastewater treatment.

INTRODUCTION

In the wastewater treatment industry, the general notice is mostly given to the effluent quality standards. Regardless of energy consumption, the treatment plants have been designed based on experience rather than the latest scientific findings (Metcalf and Eddy, 2003). The treatment plants are considered as a part of energy equipments which largely consumed electrical energy and thus electricity is the great part of the costs of plant utilization so that 25-40% of the total costs of the wastewater treatment process is related to energy supplies. Therefore, energy is regarded as an important factor in treatment plant costs (Rojas *et al*., 2010). This has caused designers to adopt new methods to reduce energy consumption (Zhang *et al*., 2012). The study in 2010 indicated that 50-60% of energy consumed by treatment plants is related to the aeration process. Nowadays, due to the rapid population growth along with recent advances in technology and industry, the amount of pollution has been increased. In addition, environmental standards for effluent quality and its recycling process for different utilization have become much stricter. What was mentioned above increases energy consumption, hence energy efficiency, effectiveness of the plan and the utilized equipments and technologies, energy recovery processes and effective cost management have been recently considered more seriously. Additionally, enhancing energy efficiency which means a further reduction in energy consumption, greenhouse gases production and operation costs of wastewater treatment plants have become more important (Malcolm *et al*., 2010). A study Kusiak *et al*. (2013) suggested that 2 - 4% of total energy consumption is related to the wastewater treatment plants. A study was conducted in 2012 in Sweden on WWTPs energy consumption in which aeration was controlled to reduce energy consumption in a treatment plant employing activated sludge which affected the amount of dissolved oxygen, the efficiency of the aeration process and equally the results from treatment process. The amount of energy consumed by treatment plants depends on air flow rate and consequently the rate of oxygen consumption. The rate of oxygen consumption in activated sludge system is changed by changing the concentration of ammonium or ammonia in the effluent so that by reducing the amount of ammonium in the effluent, air flow rate and consequently the rate of oxygen and the amount of electricity consumption have been reduced (Åmand and Carlsson, 2012). A study in 2011 in Spain performed on the factors affecting the plant energy

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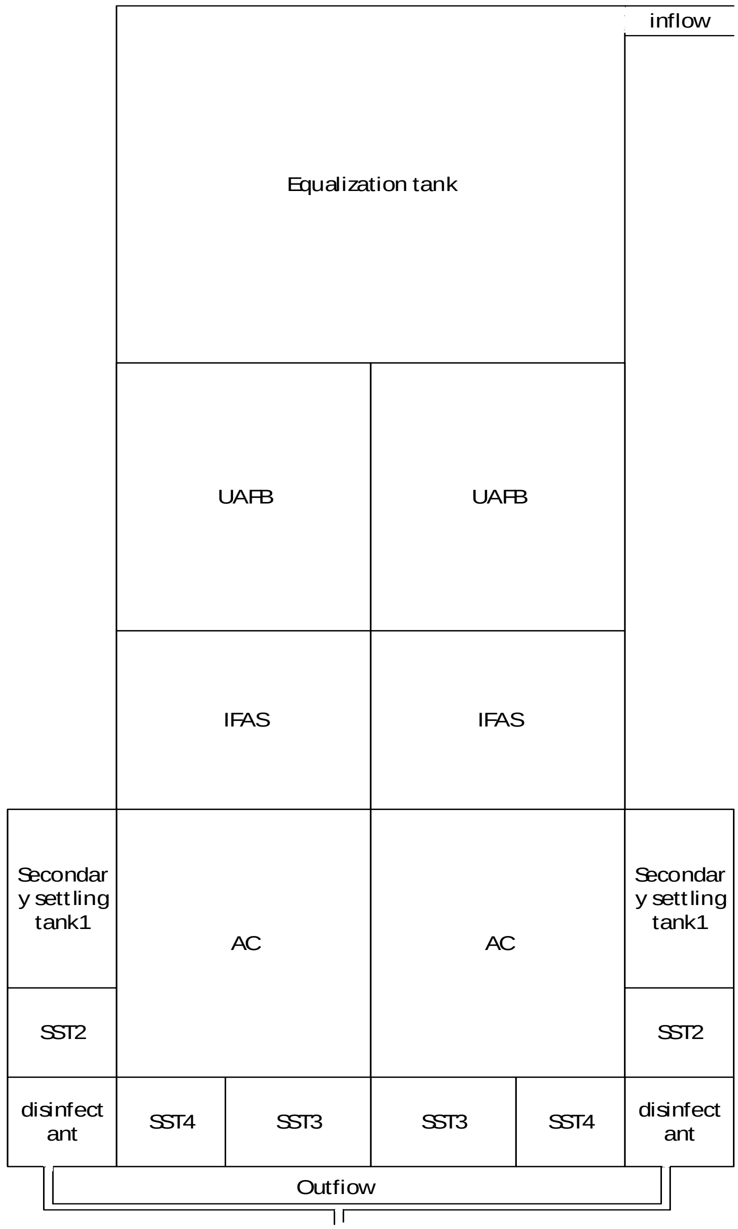

Fig. 1. The treatment process of the WWTP of Amol.

consumption. The results indicated that the average amount of energy consumed by WWTPs depends on the input quality parameters, treatment technology, effluent quality and the size of the plant. Furthermore, the amount of energy consumed by smaller plants per unit area is higher compared to the larger plants (Hernández *et al*., 2011).

In an article in 2012, the amount of energy consumption was studied in each physical unit which led to finding a strong relationship between biological activity and demand for electricity (Descoins *et al*., 2012). In 2013, a study conducted to optimize pumps performance and aeration process in treatment plants. The results suggested that the pumping stations and the aeration in activated sludge process are the most energy consuming parts in treatment plants which consume 22 and 42% of electrical energy, respectively. Thus, in order to reduce energy consumption, the pumps performance should be improved and aeration processes should be optimized (Chae, 2013).

In the present study, the wastewater treatment plant (WWTP) of industrial zone of Amol was studied which works with a combination of Up flow Anaerobic Fixed Bed (UAFB) system and Integrated Fixed Activated

Sludge (IFAS) (Iranian small industries and industrial towns company, 2013). Amol industrial zone collecting all the wastewater from several industrial plants such as poultry processing plant, meat and fruit juice processing plant, paperboard factory, dairy farm products, glass factory, tomato cannery and many more small plants which are located in 20 hectares of pasture land, generating a discharge flow rate of 350 to 400 m per day (Sadeghpoor *et al*., 2009).

MATERIALS AND METHODS

The present study was conducted using statistical methods and data collecting through observation and field study of wastewater treatment plant of industrial zone of Amol. Data was analyzed through drawing tables and charts in Excel along with making Engineering judgment. In order to study electrical energy consumption in treatment plant of industrial town of Amol, the electricity bills of the plant in different months of 2012-2013 were got from the town's Board of Trustees and analyzed. Energy consumption varies at different times of day, thus electrical energy falls in three categories namely Peak Load, Medium Load, and Low Load periods. According to the table of Peak Load which was set up by the Electricity Distribution Company of Mazandaran province, Iran, 12 hours out of 24 hours a day is considered to be the Medium Load, 6 hours is considered to be the Low Load and the remaining 6 hours is considered to be the Peak Load period. However, the beginning and ending time of the each group varies from season to season. The electrical energy consumption relating to each group (Peak Load, Medium Load, and Low Load periods) is multiplied by related times and the sum is considered as the electrical energy consumption relating to the period. The electrical energy consumption for each period in 2012 and 2013 is presented in table 1. Due to the fact that the measurement periods varies from one to another, in order to obtain the monthly average amount of energy consumption, the weighted average represented in equation 1 was used (Adel and Momeni, 2006).

$$Em = \frac{\sum_{i=1}^{i=n} Ei \times Ti}{\sum_{i=1}^{i=n} Ti} \qquad (1)$$

Where *Em* is the monthly average electrical energy, *Ei* is the electrical energy in a period and *Ti* is the days of the period. The results were presented in table 1. The electrical energy obtained from electrical bills includes the energy consumed by the WWTP equipments, control room, laboratory, and electrical lighting. In this study, the energy used in the treatment plant units were considered as effective energy and the one used in the sections outside of the units was considered as ineffective energy. In order to exactly specify the energy consumed by the units (the effective energy) and ineffective energy, the electro mechanic equipments should be examined. Therefore, the field study on the WWTP of the industrial zone of Amol was conducted and different treatment processes were examined. The inflow discharge entered into the second phase of the treatment plant was approximately 1100 m^3/day. Figure 1 shows the schematic map of the treatment plant. By conducting an inspection, full details of the equipments operating in these units such as the number of pumps and engines working in different units as well as their power and working hours were obtained. The electrical energy consumed by the equipments in each unit was calculated by the equation 2 (Singh *et al.*, 2012). The results were presented in figure 2.

$$Ep = \frac{P \times T}{Q} \qquad (2)$$

Where *Ep* is the electrical energy in Kwh/m^3, the electrical power is in Kw and the pumps and engine operating time is in h/day, the total amount of effluent is in m^3/day. In order to measure the amount of electrical energy used to remove one kilogram COD, the input and output COD were achieved in mg/lit. The entire procedure of the sampling and testing were performed according to the instructions and guidelines provided in the standard methods for examination of water and wastewater (Eaton and Franson, 2005). Considering the fact that the average inflow discharge was in m^3/day, the removed COD was defined in kg/day and the effective energy was in kWh/ m^3, the amount of energy per 1 kilogram COD is in kWh.

RESULTS AND DISCUSSION

Estimating the Electrical Energy Consumed in WWTPs Units

In the second phase, the average monthly amount of Amol WWTP effluent was 1100 m^3/day and pumps efficiency was assumed 80%. Each unit of treatment plant (from Bar screen to filter press) was specified with numbers from 1 to 8 which were presented in table 2. The amount of electrical energy of each unit was obtained from equation 2 and is shown in figure 2. The energy consumption for each plant's unit is in kWh and per 1 cubic meter of effluent. Furthermore, the energy consumption percentage of the different plant's units was indicated in figure 3.

Concerning the obtained figures in figure 2, the total amount of electrical energy which is consumed in different units of the treatment plant is equal to 4.83 kWh. In a study in 2012, an energy analysis was conducted on

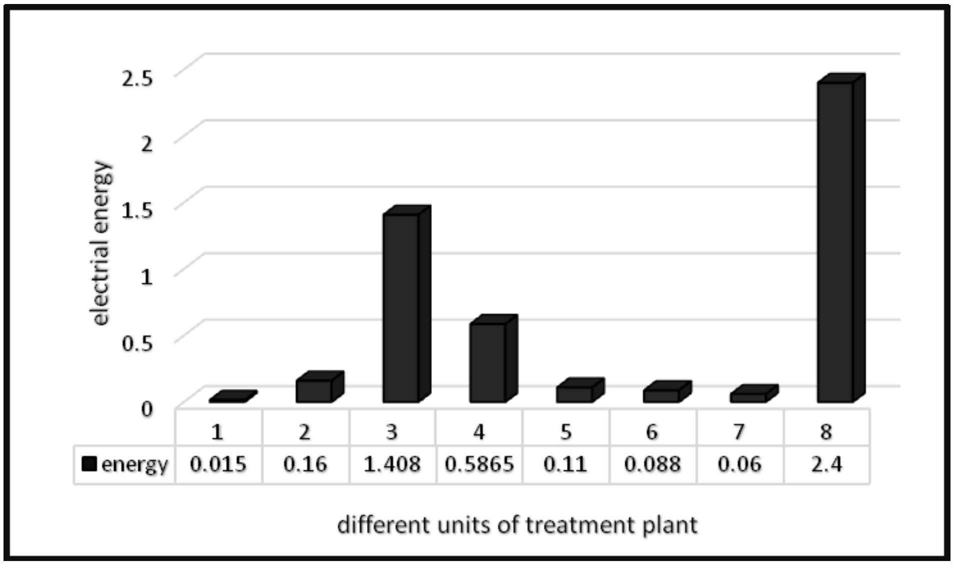

Fig. 2. The electrical energy consumption of plant's units in Kwh.

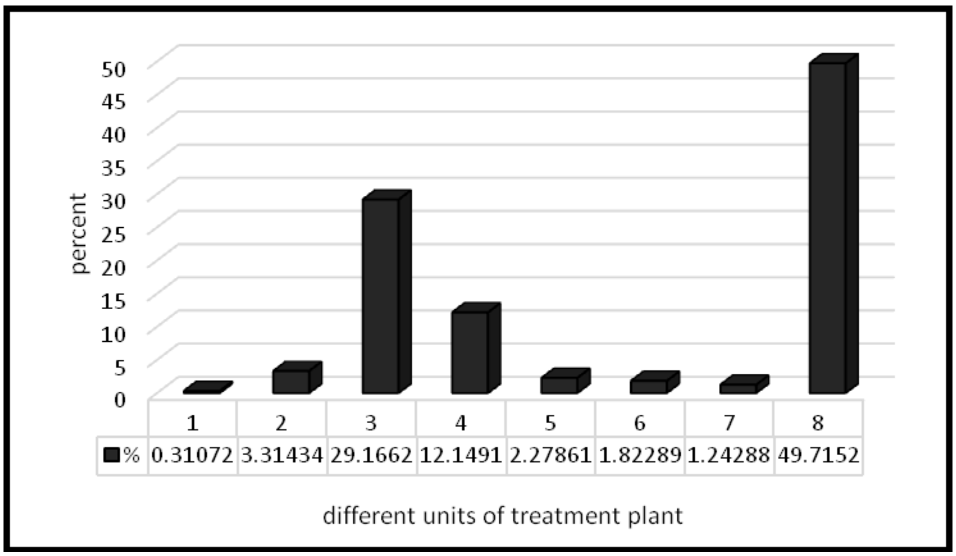

Fig. 3. The percentage of electrical energy consumption in WWTP units.

wastewater treatment plant in India with rotating biological contactor (RBS) aerobic system which has primary and secondary sedimentation and the energy consumption per 1 cubic meter of effluent was 0.8 kWh (Singh *et al*., 2012). Such a figure is much lower than the energy consumption of AMOL treatment plant due to the difference exists in types of electrical energy consumption processes it worth mentioning that some parts of the differences was due to the lack of energy management in design and utilization of treatment plants.

Figure 3 shows that over 29% of electrical energy consumption of the WWTP has been allocated to aeration and about 50% of electrical energy was used in sludge treatment equipments and up to 21% of electrical energy consumption of treatment plant was consumed in primary treatment pumps, disinfection and other parts. However, the results of a study conducted in Switzerland by Descoins (2012) on energy index of a treatment plant which was employed activated sludge method with anaerobic digester indicate that 25% of the total energy amount was consumed by pumps and 70% by air compressor. In 2013, Chae and Kang (2013) studied the treatment plants in Spain using activated sludge and the results showed that 22% of energy was consumed in pumping sector and 42% of the total energy was consumed by aeration sector. The results obtained from Amol treatment plant seems reasonable compared to the above-mentioned studies.

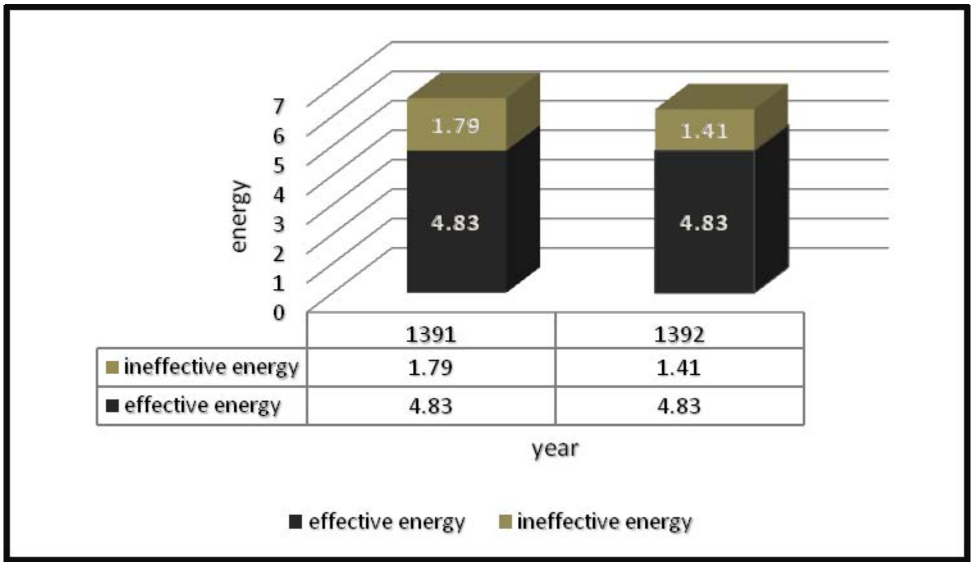

Fig. 4. The amount of energy consumed by WWTP of industrial zone of Amol.

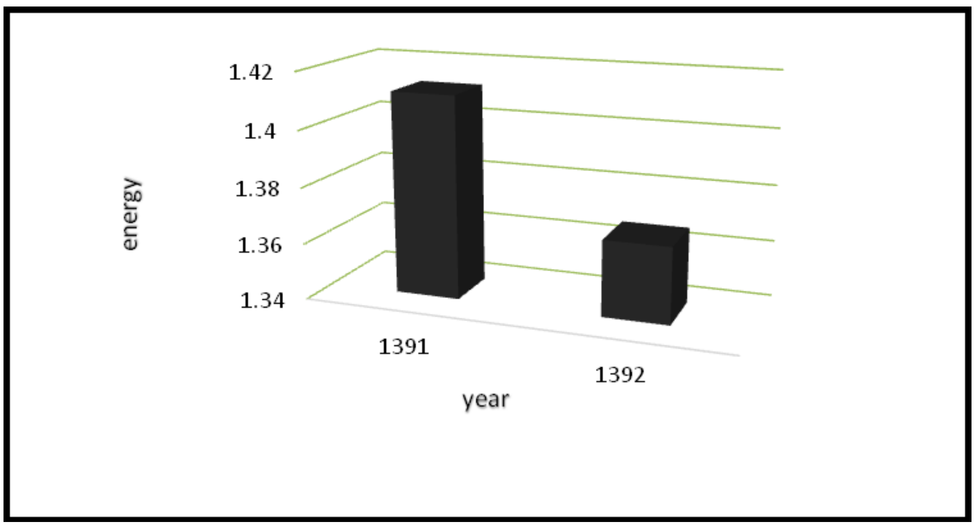

Fig. 5. The electrical energy consumption of the WWTP per 1 kilogram removed COD.

Estimating the Ineffective Electrical Energy Consumed in the WWTP

Table 1 indicates that the daily average electrical energy consumption per 1 cubic meter of effluent in 2012 and 2013 was 6.62 and 6.24 kWh respectively according to the electrical bills. Figure 2 shows that the electrical energy consumed by the WWTP of Amol which was obtained from equation 2 and based on the energy consumption of electrical equipments existed in different units of the plant was 4.83 kWh which is considered as effective electrical energy. Regarding the obtained results, the electrical energy consumed in other units such as laboratory and control room is the calculable ineffective energy which is presented in figure 4.

As it was shown in figure 4, the amount of ineffective energy per 1 cubic meter of daily effluent was 1.41 and 1.79 in 2012 and 2013, respectively. In 2012, about 27% and in 2013, about 23% of the total electrical energy consumption in WWTP was wasted on matters other than treatment process which has been called ineffective electrical energy. These figures are more appropriate compared to the study simultaneously conducted on Nasirabad WWTP. In this plant, the ineffective energy was approximately 40% and 42% of total energy respectively for 2012 and 2013. This means that energy efficiency index (EEI) of Amol WWTP is higher than Nasirabad plant, that is, electrical energy is used more efficient which is considered to be a remarkable

Table 1. The amount of energy consumed in 2012.

The amount of energy consumed (kwh)	Number of days in every period	Date
9988680	30	2012/6
13281216	34	2012/7
7941564	27	2012/8
9587680	31	2012/9
10374840	30	2013/10
9619456	28	2013/11
11375040	30	2013/12
11455	The average of daily energy consumed	
6.62	average daily consumption of electric energy per 1 cubic meter of effluent	

Table 2. The amount of energy consumed in 2013.

The amount of energy consumed (kwh)	Number of days in every period	Date
12591960	30	2013/1
8290776	26	2013/2
11156520	30	2013/3
12662136	31	2013/4
13153280	35	2013/5
8163788	31	2013/6
5535108	27	2013/7
7008372	29	2013/8
7963320	30	2013/9
10156672	32	2013/10
9168208	28	2013/11
10787880	30	2013/12
10799	The average of daily energy consumed	
6.24	average daily consumption of electric energy per 1 cubic meter of effluent	

achievement since the costs of ineffective electrical energy is also conducted by industrial tariff. Thus, by efficiently using electrical energy in control room and laboratory or applying a separate electricity meter for these units with non-industrial tariff, the costs of energy consumption can be significantly reduced.

Determining the amount of effective energy in terms of removed COD

The monthly average amount of amount of COD entered into and exited from the WWTP in 2012 was 3485 and 5 mg/lit, respectively. The effective electrical energy consumption of the plant was 4.83 kWh and average inflow discharge was 1100 m^3/day. In 2013, the average amount of COD entered and exited was 3593 and 61 mg/lit, respectively. Considering the effective electrical energy and the average inflow discharge, the amount of electrical energy consumption per 1 kilogram removed COD is calculable which is indicated in figure 5.

Figure 5 shows that the amount of electrical energy consumption per 1 kilogram removed COD in 2012 and 2013 was 1.367 and 1.412 kWh respectively. According to the study conducted in Iranian industrial town company in 2007, the energy consumption in terms of one kilogram COD removal in a number of industrial towns' treatment plants is indicated in table 3 (Mardan and Tofighi, 2007).

CONCLUSION

The obtained figures from the treatment plant of the industrial zone of Amol which is shown in figure 5 is higher than the figures shown in table 3. However, the figures in table 3 indicate the amount of energy consumed in system design procedure and certainly more energy is consumed in operating these WWTPs.

Concerning the obtained results, it can be concluded that energy consumption is not effectively managed in the

Table 3. The existing electrical equipment in the WWTP of Amol.

Hours (h/day)	Power (kw)	Number of equipment	Equipment	Number of unit	Unit
24	0.55	1	Pump	1	1- Bar screen
12	3.6	3	Pump	1	2-Equalization tank
14	0.8	1	Mixer		
12	22	4	Blower	4	3-Aeration tank
12	0.031	1	Dosing pump	1	4-Disinfectant system
8	0.18	3	Mixer		
16	2.2	2	Pump	1	5-Sludge thickening
16	2.2	1	Pump	1	6-Sludge digestion
12	0.4	1	Mixer	1	7-Sludge storage
12	8	2	Compressor	1	8-filter press

Table 4. The comparison of energy values in s number of industrial zones' treatment plants.

The energy consumption in terms of one kilogram COD removal (W)	Process	w.w treatment plant
40	Extended aeration A.S	Industrial zone of AGHGHALA
15	UAFB+IFAS	Industrial zone of ABASABAD
10	UABR+UAFB+SBR[1]	Industrial zone of MASHHAD
40	Aeration lagoon	Industrial zone of SEMNAN
42	Absorption-Bio-Oxidation	Industrial zone of SARI

WWTP of Amol, while by efficiently using electrical energy; it can be possible to preserve electrical energy sources as a national asset and also considerably economize on them. Moreover, the effective aeration optimization of the pumps and blowers performance in the aeration basin, the sludge management and reduction should be considered more seriously. The electrical energy consumed in pumps and blowers has a direct relationship with the rate of aeration in the basins and the level of pressure drop. By more appropriately optimizing aeration units, effectively managing them and using the methods such as employing ultrasonic waves and send them to the sewage system which can change the chemical structure and the size of the particulate organic matters, the rate of biological treatment process and consequently the sewage treatment will be increased (Mehrdadi *et al*., 2012a); furthermore, the rate of aeration and electrical energy consumption will be reduced. Additionally, by using these waves, a huge amount of excess sludge will be reduced and therefore less electrical energy will be consumed for sludge equipments (Mehrdadi *et al*., 2012b; Mardan, Tofighi, 2007). Moreover, if treatment plants designed in a way that the produced electrical energy and sludge treatment in anaerobic sector can be utilized to generate electrical energy, the treatment plants remarkably gain sufficient independence from energy sources (Chae and Kang, 2013). Thus, it can be possible to save more electrical energy. With regard to the importance of energy and its related issues, rising prices and reduction of energy supplies, the effective managerial approaches should be adopted to reduce energy consumption in wastewater treatment plants. Furthermore, experts and designers of WWTPs should more seriously consider the amount of energy wasted in the processes as well as enhance energy efficiency.

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