INVESTIGATION OF GREENHOUSE GAS EMISSIONS FROM DISSOLVED AIR FLOTATION PROCESS

Pelin Yapıcıoğlu
Harran University, Department Of Environmental Engineering, Turkey.
pyapicioglu@harran.edu.tr

ABSTRACT

Industrial wastewater treatment facilities have been regarded as one of the greenhouse gas (GHG) emission sources. Dissolved air flotation (DAF) process which is carried out to remove fats, oil and grease and carbonaceous materials in a dairy wastewater treatment plant is considered as one of the major GHG generator sources. This paper investigated the GHG emissions of a DAF unit operated in an industrial wastewater treatment facility. The direct emission was estimated from FOG and organic materials removal from wastewater. A new estimation tool was developed, in this study. The indirect emission was figured out from electricity and chemical depletion for DAF process. This study aimed to estimate the greenhouse gas emissions from a dissolved air flotation tank using a new developed model based on IPCC approach. Total direct emission from DAF unit was 3616.2 kg CO_2e/d. CH_4 emission was higher than CO_2 emissions. The results showed that electricity depletion was the main resource of the GHG emissions in DAF unit with the value of 3752.35 kg CO_2e/d related to indirect emissions. For the reduction of greenhouse gas emission, electricity consumption should be taken under control.

Keywords: greenhouse gas, wastewater treatment plant, dissolved air flotation, direct emission, indirect emission.

1. INTRODUCTION

Greenhouse gas (GHG) emissions have tended to increase because of the industrial, municipal and agricultural activities in recent years [1,2]. Wastewater treatment plants (WWTPs) have been regarded as one of the GHG emissions emitters in the last decades [1,2,3,4]. Carbon dioxide (CO_2) and methane (CH_4) are regarded as the major greenhouse gases releasing from WWTPs due to biochemical or biological treatment processes, sludge handling and disposal processes, chemical addition for the treatment process and sludge stabilization processes, electricity consumption and planning maintenance and repair routines in the plant [2,4,5]. CO_2 could be resulted in decomposition of the carbonaceous materials and respiration of the microorganisms which are responsible from the wastewater treatment. The other major gas is CH_4 releasing from wastewater treatment process. CH_4 could be formed under the anaerobic conditions in the wastewater treatment units. It could be considered that anaerobic layers and inadequate aerated zones have emitted CH_4 emissions in the treatment units [5].

GHG emissions could be categorized as the direct emissions and the indirect emissions [4,6]. The direct emissions in the WWTPs contains releasing emissions at the storage system which are GHG emissions resulting from the wastewater treatment technologies and forming GHG emissions at discharging area of the effluent. The indirect greenhouse gas emissions have been resulted from energy consumption, chemical use and sludge handling and disposal processes [4,6]. The industrial wastewater plants have released the large quantities of direct and indirect GHG emissions due to highly organic wastewater composition and existing treatment processes. The dairy industry is regarded as one of these facilities. Especially, some treatment processes which require air and chemical substances have emitted indirect and direct emissions from dairy industry WWTPs.

The dairy industry has been regarded as one of the polluting plants because of wastewater generation and highly organic wastewater discharging. Chemical oxygen demand (COD) and fats, oil and grease (FOG) are the major contamination indexes of the dairy wastewaters [7]. The dairy wastewater possesses highly organic structure and fats, oil and grease content. DAF has been commonly applied for organic substances removal from wastewater [8,9]. DAF process is carried out as before the anaerobic treatment configurations [10]. This technology is considered as a kind of flotation process which degrades FOG and other organic materials from wastewater [11]. The most important parameters for ensuring the maximum removal efficiencies are (1) deciding the size of microbubbles and the coagulation and flocculation processes which based on the pH of the media, (2) the concentrations and the kinds of coagulants and (3) flocculants added [9,12]. It is obvious that air is a need for the formation of microbubbles in the tank. Also, chemical use for the coagulation and flocculation process lead to indirect emission. Also, CH_4 emission and CO_2 emission were released due to FOG and organic materials removal (COD) from wastewater, respectively [5]. Unaerated and inadequate aerated zone lead to anaerobic conditions so CH_4 emissions have been emitted. Aeration is carried out for FOG removal. So, indirectly FOG removal cause to CH_4 emissions. Also, COD removal indirectly leads to CO_2 emission because CO_2 is formed in the result of carbonaceous materials decomposition [5].

In this study, the direct and indirect GHG emissions from dissolved air floatation process were investigated. The indirect emission was determined using IPCC approach based on electricity and chemical use. The direct emission was estimated using a new developed model in this study. This study aimed to examine the direct and indirect GHG emissions for DAF process in a dairy WWTP and to propose the minimization methods the GHG emissions. The originality of this paper is that the direct and indirect GHG emissions were investigated using a new developed model for a DAF Tank.

2. MATERIALS AND METHOD

2.1. Definition of the Study Area and DAF Process

The industrial WWTP is in the south eastern of Turkey. The wastewater characteristics of the plant have been shown in Table 1. The wastewater analyses have been carried out using Standard Methods [13].

Table 1. Inlet Wastewater Characteristics

Parameter	Influent Value
FOG	360 mg/L
TSS	425 mg/L
COD	12500 mg/L
pH	6
Wastewater Flow	2100 m^3/d

Figure 1 shows the wastewater treatment flow diagram in the WWTP. FOG and carbonaceous matters disposal are ensured with DAF process. The DAF tanks are designed and operated to dispose the suspended solid materials, carbonaceous matters, and FOG from a water body. Contaminant matters have been removed with the use of dissolved air supplied by a blower in a wastewater flow under high pressure supporting with a recycle flow of DAF outlet [5]. The bubbles and organic substances have been rising to the tank surface and have been forming a floating media of matters that they are removed by a skimmer. DAF process is based on the size and formation of bubbles, contact of bubble-particles, amount of pumped air, and modelling of the treatment and treatment areas of the flotation unit [12]. In general, a coagulant such as ferric chloride or aluminum sulfate has been added to the inlet of the DAF tank to agglomerate the colloidal matters and a flocculant (polyelectrolyte etc.) to conglomerate the particulates into bigger flocks.

The DAF system was operated continually under different conditions to obtain the highest removal efficiencies, in this paper. The DAF tank is a kind of crossflow plate pack tanks. At DAF unit, ferric chloride has been added as the coagulant.

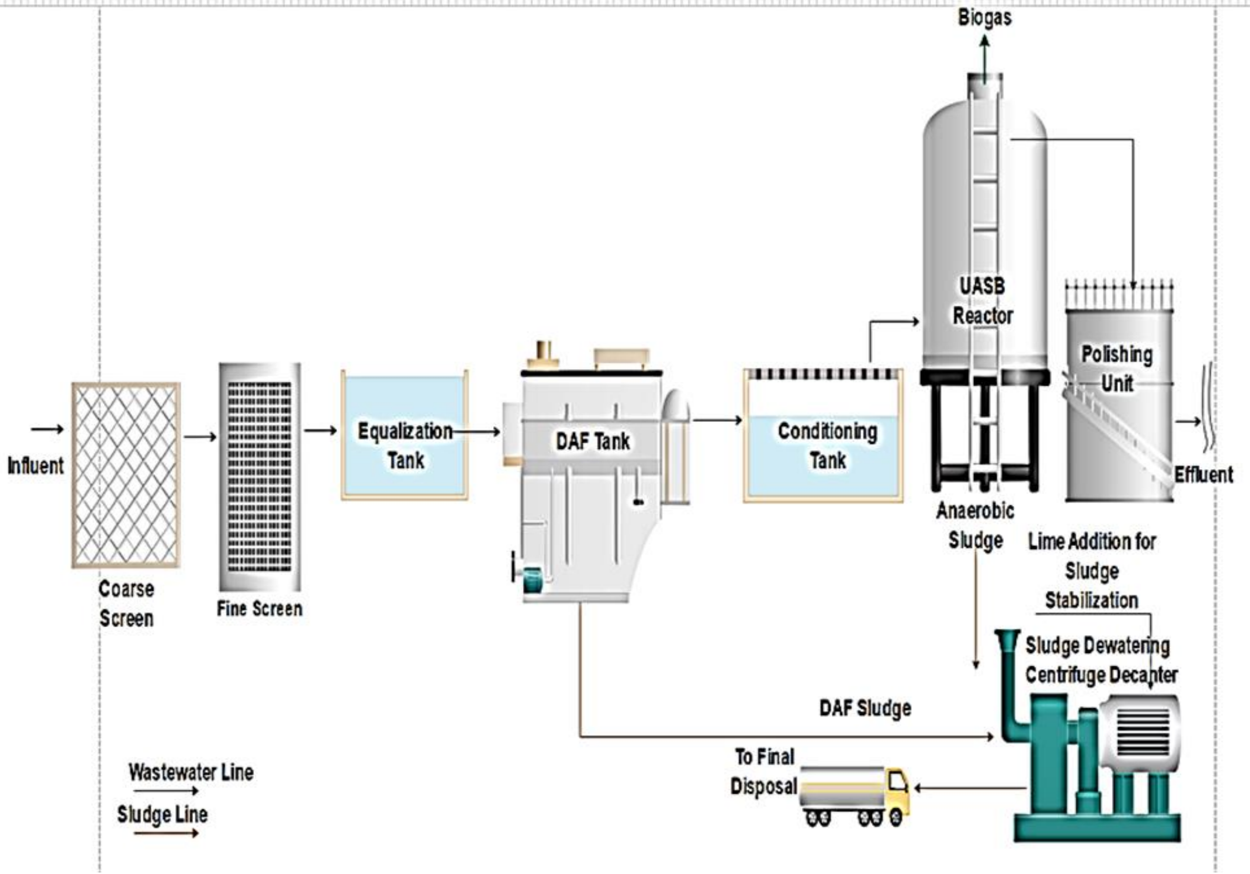

Figure 1. Wastewater treatment flow diagram of the dairy WWTP

2.2. Determination of Direct GHG Emissions

The direct GHG emission has been considered as the greenhouse gas emissions resulting from physicochemical reactions which are coagulation and flocculation, in DAF system. It was considered that CO_2 is the GHG resulting from COD removal in the wastewater due to organic materials decomposition. It is assumed that CH_4 is occurred when FOG is removed from wastewater. Unaerated zone has led to anaerobic conditions so CH_4 emissions have been released. Aeration is applied for FOG removal. So, FOG removal leads to CH_4 emissions, indirectly. CO_2 is formed in the result of carbonaceous materials decomposition. So, COD removal indirectly causes to CO_2 emission. Also, DAF sludge was considered in this study. It was assumed that sludge generation was 90% of COD and FOG removal considering the DAF sludge amounts. It was assumed that 10% of COD and FOG removal was returned to GHG emissions.

From this point of view, an estimation tool was developed based on IPCC approach [1]. Similarly, Kyung et al. (2015) [2] developed a greenhouse gas estimation model based on organic materials removal from wastewater in their study. Biological oxygen demand (BOD) removal was used as a contaminant source for CO_2 and CH_4, as nitrogen (TKN) removal was the resource of N_2O in the study by Kyung et al. (2015) [2]. They similarly used global warming potential (GWP) of each gases and organic materials removal in order to figure out the GHG emissions. In this study, it was considered that FOG and COD removal led to CH_4 and CO_2 emissions, respectively [1,5]. Based on this consideration, a model was developed in this study. Direct CO_2 emission ($GHGEdirect,CO_2$) is figured out multiplying COD removal ($COD_{removed}$) (kg/m^3) and wastewater flow (Q) (m^3/d) and global warming potential (GWP) of Carbon Dioxide ($GWPCO_2$) whose value is "1" in this study. Similarly, direct CH_4 emission ($GHGEdirect,CH_4$) is estimated multiplying FOG removal ($F_{removed}$) and wastewater flow (Q) and global warming potential of CH_4 ($GWPCH_4$). GWP of methane is 28 [1]. The calculation terms of direct emissions developed in this study were given in Eq.1. and Eq.2. The data used for estimation of the direct GHG emission was given in Table 2. The direct GHG emission is the sum of CO_2 and CH_4 emissions (Eq.3.). Also, the gases apart from CO_2 and CH_4 were ignored in the result of the treatment process from COD and FOG removal. Also, CH_4 is formed in the anaerobic micro zones of DAF unit as a result of COD decomposition. But in this study, this CH_4 was ignored due to COD decomposition from micro zones. According to the principle of anaerobic treatment, mostly volatile fatty acids are used by methanogens in order to generate CH_4 [5]. Considering this principle, it could be said that CH_4 was largely released from FOG removal.

$$GHGEdirect,CO_2 = (COD_{removed} \times Q \times GWPCO_2) \quad (1)$$
$$GHGEdirect,CH_4 = (F_{removed} \times Q \times GWPCH_4) \quad (2)$$
$$GHGE_{direct} = GHGEdirect,CO_2 + GHGEdirect,CH_4 \quad (3)$$

Table 2. Data set for the estimation of direct GHG emission

Parameter	Value
Q (m^3/d)	2100
COD removed ($COD_{removed}$) (kg/m^3)	0.84
FOG removed ($F_{removed}$) (kg/m^3)	0.315

2.3. Estimation of Indirect GHG Emissions

Two constituents of indirect GHG emissions were under consideration, in this paper. Electricity depletion in order to operate of the DAF unit was considered to determine the indirect GHG emissions. The indirect emission due to chemical consumption is the other constituent to carry out the process. Sludge handling process was ignored in this study due to disposal of sludge by the municipality.

The indirect GHG emission related to the energy depletion was estimated with the help of multiplying electricity consumption (EC) (kWh) of the DAF unit and the emission factor ($EF_{electricity}$) of the electricity depletion corresponded to Turkey (kg CO_2e/kWh). Energy consumption is corresponded to electricity consumption. Energy consumption of the process was obtained from the electricity counters. Emission factor of electricity consumption is 0.497 kg CO_2e/kWh [14]. Indirect emission was estimated using the model developed by Kyung et al (2015). The estimation tool has been shown in Eq.4 [2].

$$GHGE_{indirect,electricity} = EC \times EF_{electricity} \quad (4)$$

The other indirect emission was due to chemical consumption in DAF unit. It could be determined using daily chemical depletion ($L_{chemical}$) (kg/d) and the emission factor of the chemical substance ($EF_{chemical}$) (Kyung et al., 2015). The indirect emission could be estimated by multiplying chemical depletion and the emission factor. $EF_{chemical}$ related to ferric chloride is 2.71 kgCO_2e/kg ferric chloride [2,15,16]. The indirect emission from chemical consumption could be figured out with using Eq.5 and Eq.6. [2].

$$GHGE_{indirect,chemical} = L_{chemical} \times EF_{Chemical} \quad (5)$$
$$L_{chemical} = Q \times F \quad (6)$$

Total indirect GHG emission is considered as the total of the indirect emissions from energy and chemical depletion. Eq.7. demonstrates the estimation term. Table 2 shows the data used for the calculation of indirect emissions

$$GHGE_{indirect} = GHGE_{indirect,electricity} + GHGE_{indirect,chemical} \quad (7)$$

Table 2. Data set for the estimation of indirect GHG emission

Data	Value
Ferric chloride concentration (F, mg/L)	21
Electricity consumption (EC, kWh)	7550
Wastewater flow (Q, m^3/d)	2100
$EF_{electricity}$ (kg CO_2e/kWh)	0.497
$EF_{chemical}$ (kgCO_2e/kg ferric chloride)	2.71

3. RESULTS AND DISCUSSION

3.1. Direct GHG Emissions

The results revealed that direct CH_4 emission was higher than CO_2 emission for the DAF unit. The values of CH_4 and CO_2 emissions were 1852.2 and 1764 kg CO_2e/d, respectively. Total direct GHG emission is 3616.2 kg CO_2e/d. Figure 2 shows the benchmarking of the direct GHG emissions.

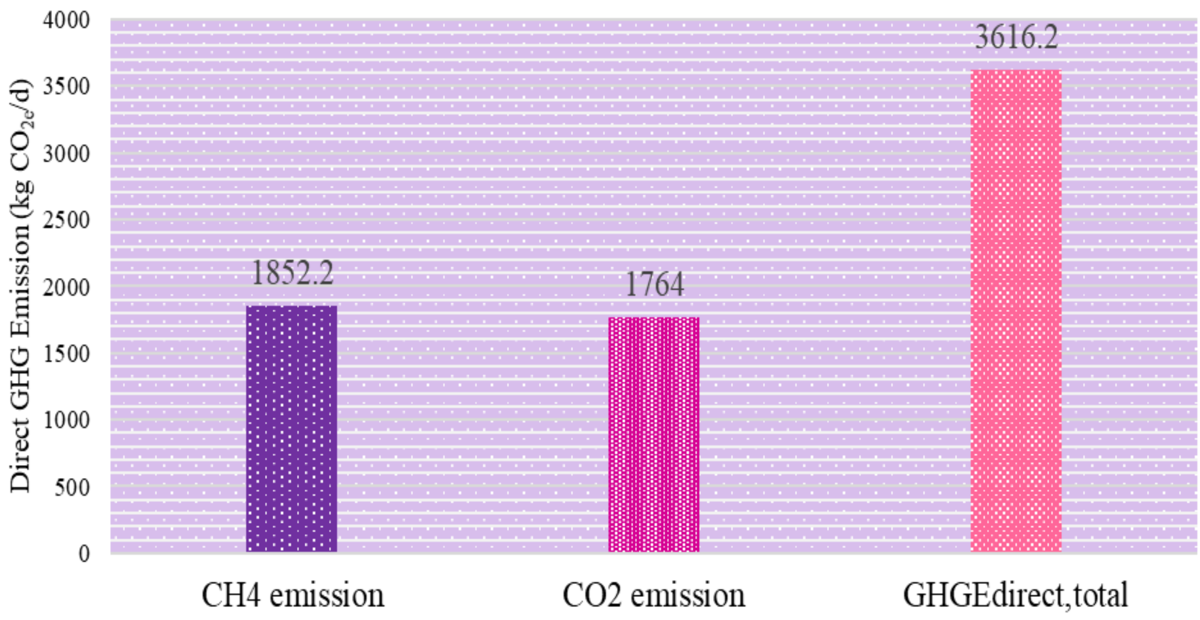

Figure 2. Direct GHG emissions

This study is the reference study for the DAF units in the literature. The study confirms that dissolved air flotation process emits not only CH_4 emissions but also CO_2 emissions. Especially the inadequate aerated zone could emit CH_4 emissions. In the literature, the tratment processes based on aeration process such as dissolved air flotation process release CH_4 emissions. Kyung et al. (2015) determined the direct GHG emission for a municipal wastewater treatment plant that 5-stage Bardenpho process was applied as 3701 ± 269 kg CO_2e/d [2]. They reported higher emissions than reported in this study. It can be said that Bardenpho process emit GHG emission higher than dissolved air flotation process. Masuda et al. (2015) [17] similarly reported that the aeration process released methane emissions similar with this study.

3.2. Indirect GHG Emissions

The indirect emission resulting from energy depletion was higher than chemical consumption. It could be resulted from operating the blower to ensure air for the treatment process. This technology depletes excessive quantities of energy. The indirect emission related to the electricity depletion was 96.9% of the total indirect emission. The indirect emission from chemical consumption was 119.51 kg CO_2e/d. Total indirect emission of the DAF unit was 3871.86 kg CO_2e/d. Figure 3 demonstrates the benchmarking of the emissions.

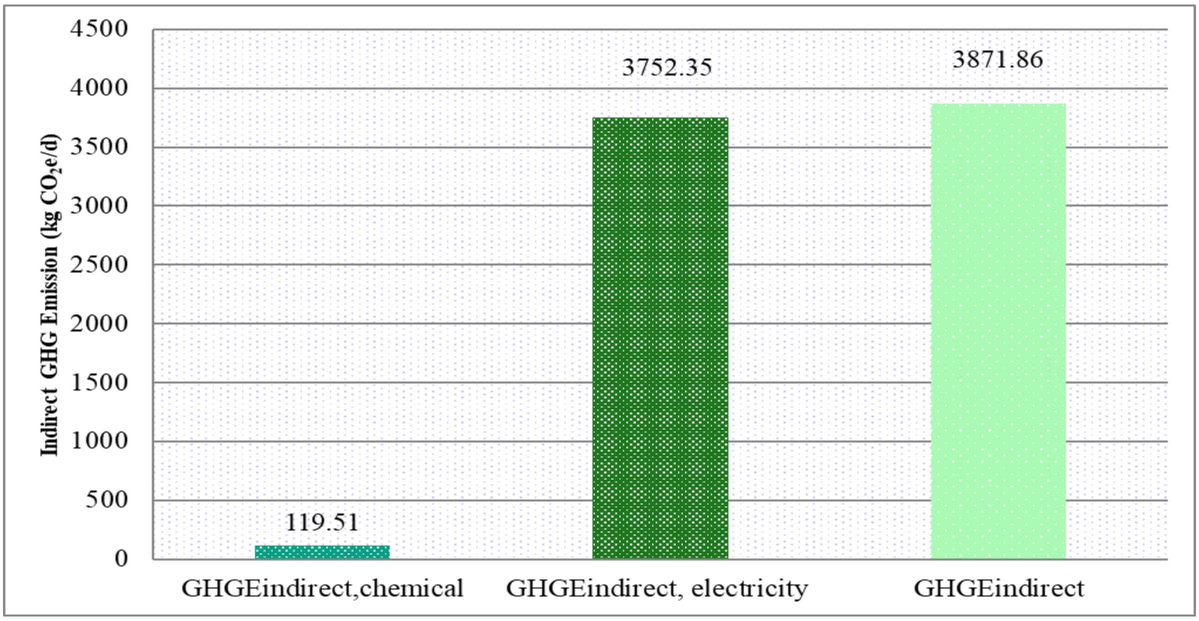

Figure 3. Indirect GHG emissions

Also, the indirect emission due to energy depletion was the major greenhouse gas emission resource at DAF unit in the value of 3752.35 kg CO_2e/d. It can be said that the electricity consumption of blower and air pumps led to the highest emission. Kyung et al. (2015) carried out a similar study for a domestic WWTP [2]. On the contrary, they found that chemical consumption was the main resource of indirect GHG emission (2.698 ± 336 kg CO_2e/d), and it corresponded to 58.8% of total indirect GHG emissions (4,591 ± 576 kg CO_2e/d). In this study, indirect GHG emission from chemical use was 2.9% of total indirect GHG emissions. It could be considered that dissolved air process emits less indirect emissions than biological aeration process. Another study about GHG emission was performed by Rodriguez-Caballero et al. (2014) [18]. They found that the highest GHG emission was monitored in the aeration tank. If the values of emissions are compared, indirect GHG emissions were higher than direct greenhouse gas emissions in this study similarly. In another study, Shahabadi et al. (2009) [19] reported similar results in the value for the aerobic system was 1313 kg CO_2e/d. Chemical use was the main source of their study contrast with this study.

3.3. Minimization of GHG Emissions

The results revealed that electricity consumption led to the highest emission for DAF process. It could be due to operating the blower to ensure air to carry out the treatment process. The DAF technology depletes large quantities of electricity. So, electricity consumption for DAF tank should take under control. Renewable energy resources could be considered. DAF sludge resulting from chemical treatment could be used as the biomass for energy use. Sludge management is an environmental challenge for the wastewater treatment plants. With this purpose, sludge reduction could be achieved.

Also, sludge could be used as an energy resource. Also, planned DAF maintenance should be carried out in the plant. Maintenance of air pumps and blower should be applied. Energy saving air pumps and low energy blower could be used in the plant to take under control the electricity consumption.

4. CONCLUSIONS

DAF is a treatment process that releases not only indirect emissions but also direct GHG emissions from a dairy industry wastewater treatment plant. Energy depletion led to the largest GHG emissions in the value of 3752.35 kg CO_2e/d from DAF process.

A new comprehensive developed model in this study could be applied for DAF processes for all types of industrial wastewater treatment plant.

Energy depletion was the main source of GHG emissions of DAF process. It could be due to operating blower for the treatment process. Electricity depletion should be checked to reduce the GHG emissions of DAF process. Planned maintenance of air pumps and blower should be carried out to take under control the electricity consumption. Energy saving air pumps and low energy blower should be used in the plant to decrease the electricity consumption of DAF process.

REFERENCES

[1] IPCC. Climate Change 2014 Mitigation of Climate Change, Cambridge University Press, Cambridge, England, 2014.

[2] Kyung, D., Kim, M., Chang, J. & Lee, W. (2015). Estimation of greenhouse gas emissions from a hybrid wastewater treatment plant. Journal of Cleaner Production, 95,117–123.

[3] Corominas, L., Flores-Alsına, X., Snip, L. & Vanrolleghem, P.A. (2012). Comparison of different modeling approaches to better evaluate greenhouse gas emissions from whole wastewater treatment plants. Biotechnology and Bioengineering, 109(11), 2854–2863.

[4] Yapıcıoğlu, P. (2018). Greenhouse Gases Emissions Minimization of Wastewater Treatment, MSc thesis, Harran University Graduate School of Natural and Applied Sciences Department of Environmental Engineering, 96pp.

[5] Metcalf & Eddy, (2014). Wastewater Engineering: Treatment and Resource Recovery 5th ed, Boston, USA, McGraw-Hill.

[6] Parravicini, V., Svardal, K. and Krampe, J. (2016). Greenhouse gas emissions from wastewater treatment plants. Energy Procedia, 97, 246–253.

[7] Yapıcıoğlu, P., & Filibeli, A. (2017). Proceedings from IATS '17: The 8th International Advanced Technologies Symposiu. Elazığ, Turkey.

[8] Falletti, L., Conte, L., Zaggia, A., Battistini, T. & Garosi, D. (2014). Food industry wastewater treatment plant based on flotation and MBBR. Modern Environment Science and Engineering, 1, 562-566.

[9] Pereira, M.S., Borges, A.C., Heleno, F.F., Squillace, L.F.A. & Faroni, L.R.D. (2018). Treatment of synthetic milk industry wastewater using batch dissolved air flotation. Journal of Cleaner Production, 189, 729-737.

[10] Castillo, A., Vall, P., Garrido-Baserba, M., Comas, J. & Poch, M. (2017). Selection of industrial (food, drink and milk sector) wastewater treatment technologies: a multi-criteria assessment. Journal of Cleaner Production, 143, 180-190.

[11] Behin, J. & Bahrami, S. (2012). Modeling an industrial dissolved air flotation tank used for separating oil from wastewater. Chemical Engineering and Processing, 59, 1–8.

[12] Edzwald, J.K. (2010). Dissolved air flotation and me. Water Research, 44, 2077-2106.

[13] American Public Health Association, American Water Works Association, (1999). Standard Methods for the Examination of Water and Wastewater, USA.

[14] IEA, 2016. World Energy Statistics 2016. Key world energy statistics http://www.iea.org/statistics/topics/energybalances/.

[15] Ashrafi, O., Yerushalmi, L. & Haghighat, F. (2013). Application of dynamic models to estimate greenhouse gas emission by wastewater treatment plants of the pulp and paper industry. Environmental Science and Pollution Research, 20(3), 1858–1869.

[16] Yerushalmi, L., Ashrafi, O. & Haghighat, F. (2013). Reductions in greenhouse gas (GHG) generation and energy consumption in wastewater treatment plants. Water Science and Technology, 67(5), 1159–1164.

[17] Masuda, S., Suzuki, S., Sano, I., Li, Y.Y., Nishimura, O. (2015). The seasonal variation of emission of greenhouse gases from a full-scale sewage treatment plant. Chemosphere, 140, 167-173.

[18] Rodriguez-Caballero, A., Aymerich, I,, Poch, M., Pijuan, M. (2014). Evaluation of process conditions triggering emissions of green-house gases from a biological wastewater treatment system. Science of The Total Environment, 493, 384-391.

[19] Shahabadi, M.B., Yerushalmi, L., Haghighat, F. (2009). Impact of process design on greenhouse gas (GHG) generation by wastewater treatment plants. Water Research, 43(10), 2679-2687.