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An experimental examination of energy production from domestic-based waste water treatment sludge

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Abstract

In Turkey, treatment sludge that obtained from domestic wastewater and water treatment plants causes storage and disposal problems. In the current situation, there are 69 domestic wastewater treatment plants in Turkey and this corresponds to approximately 13% of the population. Total 500 thousand tons of treatment sludge is released from these treatment plants, annually. In the case of all municipalities establish a wastewater treatment plant in Turkey, approximately, 4 million tons of treatment sludge is projected to release in a year. Additionally, 3.6 million tons of treatment sludge will be obtained from the manufacturing industry. In other words, approximately $7.6 \leftrightarrow 10^6$ tons of treatment sludge potential exists in Turkey and in the same amount of the storage area ($7.6 \leftrightarrow 10^6$ m^3) is needed for the storage of this treatment sludge, perennially.

In this study, energy production from wastewater treatment sludge through the anaerobic method has been investigated and compared to the aerobic treatment method. Also, advantages and disadvantages of both methods have been introduced. In order to determine biogas production capacity from treatment sludge, some amount of sample sludge has been taken from the final sedimentation tank before belt press in a wastewater treatment plant and it has been experimentally analyzed.

Key words: *Wastewater treatment sludge, Anaerobic treatment, Energy production from waste, Renewable energy*

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1. Introduction

Today's increasing urban population brings about domestic wastewater problems which can be overcome with the help of wastewater treatment plants (McCarthy, 1982; Turker, 2008). Leaving domestic wastewater to the nature causes contamination of the rivers, lakes and underground water and also, this affects plant, animal and human health indirectly and negatively (Erdogan *et al*., 2011).

Most European countries have been trying to keep under control of wastewater through wastewater disposal facilities for the last 30 years. With these established facilities, the pollutants that being in the wastewater are removed by applying physical, chemical, aerobic or anaerobic methods and therefore, desired discharge parameters can be achieved at the end of the processes. Nevertheless, after the removal of the pollutants from wastewater, there are still some pollutants remain in the wastewater. They cannot be removed completely and they are kept in treatment sludge, which is the final product of the treatment process. That means the problem of wastewater transforms into the problem of wastewater sludge.

Handling treatment sludge that coming out of the treatment processes in wastewater treatment plants is a major problem in all over the world. In a similar way, treatment sludge that coming from wastewater treatment plants can also cause storage and disposal problems in Turkey. There are 69 domestic wastewater treatment plants in the country, running by the municipalities, which correspond to approximately 13% of the population and 500 thousand tons of treatment sludge is released by these plants, annually (Topal and Toraman, 2003). In the case of every municipality establishes its own wastewater treatment facility, the projected amount of treatment sludge is to reach the number of 4 million tons. In addition, 3.6 million tons of treatment sludge is released by the manufacturing industry. In other words, approximately $7.6 \leftrightarrow 10^6$ tons of treatment sludge potential exists in Turkey and in the same amount of the storage area ($7.6 \leftrightarrow 10^6$ m^3) is needed for the storage of this treatment sludge, annually.

In this study, energy production from wastewater treatment sludge through the anaerobic method has been investigated, analyzed experimentally and compared to the aerobic treatment method. Also, advantages and disadvantages of both methods have been introduced.

2. Materials and methods

For the treatment of the wastewater, there are three methods are used which can be listed as physical, chemical and biological methods. Generally, the chemical treatment is not needed for the process of domestic wastewater treatment. The physical treatment methods that used for the process of treatment, are; screens, sand arresters, filtration basins, sedimentation tanks. Biological treatment methods can be examined as in two methods, aerobic and anaerobic treatment methods. In domestic wastewater treatment processes, while aerobic treatment is a fundamental and mandatory process, anaerobic treatment is a subsidiary treatment process which is used to support the aerobic treatment system.

In aerobic treatment systems, microorganisms that take place in the wastewater can purify the water by taking the pollutants into their bodies. With this, they reduce the value of Chemical Oxygen Demand (COD) in order to clean the wastewater. As for anaerobic treatment, the carbon source as carbohydrate, fat and protein structure that present in wastewater can be converted into methane and carbon dioxide by the microorganisms. In this process an oxygen-free environment should be provided completely (Gujer and Zehnder, 1983).

2.1. Comparison of Aerobic and Anaerobic Treatment

There are some superiorities of anaerobic treatment comparing to aerobic treatment which are given in table 1. With the application of anaerobic treatment, the waste disposal process can be carried out by consuming very little energy and furthermore biogas production can be attained as a subsidiary product. As for aerobic treatment, while more than half of the energy potentials that take place in waste remains in biomass, in anaerobic treatment, 90% of these potentials can be converted into biogas. The nutritional requirement of anaerobic treatment is lower than aerobic treatment. In anaerobic treatment, the large portion of the raw material is transformed into biogas; therefore, the amount of sludge reduces. Anaerobic ambient bacteria can remain passive for a long time by suspending themselves at + 15 °C temperature and when they reach at the proper ambient temperatures they can resume on their activities.

Glucose-based substrate fragmentation model for aerobic treatment:

$C_6H_{12}O_6 + 6O_2 \rightarrow 6\ CO_2 + 6\ H_2O\ G^0 = -2840$ kJ

Table 1. Comparison of aerobic and anaerobic treatments (Turker, 2008; Gijzen, 2001; Melegari de Souza, *et al*., 2012)

Comparison	Aerobic Treatment	Anaerobic Treatment
Carbon Balance	50–60% incorporated into CO_2; 40–50% incorporated into biomass	95% converted to biogas; 5% incorporated into microbial biomass.
Energy Balance	60% of available energy is used in the new biomass, 40% lost as process heat.	90% retained as methane (CH_4), 3–5% lost as heat, and 5–7% is used in new biomass formation.
Energy Requirements	High energy requirements for ventilation	Energy requirements are small for the operations such as mixing
Nutritional Needs	High nutrient requirements	Low nutrient requirements
Start-up	Short start-up period	Relatively long start-up period.
Technological State	Mature (established) technology	Developing technology especially for specific applications
Costs	-Low investment costs. -High operating costs for aeration, additional nutrient and sludge removal and maintenance	-Often moderate investment costs. -Low operating costs due to low power consumption and additional nutrients hardly required

Glucose-based substrate fragmentation model for anaerobic treatment:

$C_6H_{12}O_6 \rightarrow 3\ CO_2 + 3\ CH_4\ G^0 = -393$ kJ

1 mol of glucose, 6 moles of oxygen and 6 moles of carbon dioxide and water are formed in the process of aerobic treatment. As it can be seen from the model, 6 moles of oxygen must be given to the system, corresponding to one mole of glucose. This situation considerably increases the energy requirements of the system. As for anaerobic treatment, 1 mol of glucose can be decomposed 3 moles of carbon dioxide and methane through bacterial activities.

In addition to these advantages of anaerobic treatment there are some disadvantages should also be considered. The main disadvantage of anaerobic treatment is the duration of treatment process, which is very slow. This situation both increases the size of the digester and the cost of the initial investment. With the aerobic treatment, it is possible to purify wastewater much faster and larger quantities. The value of COD is has to be more than 5 g/l to purify the wastewater with anaerobic treatment (Stuckey, 1998). However, the studies that have been carried out in recent years show the COD values that below this value can also be applied to anaerobic treatment processes. The second disadvantage of the anaerobic treatment is to provide heat from outside because the formation of anaerobic process can be carried out at about 38 °C. As a solution to this problem, the biogas that obtained from the process can be used to meet the need for heat.

In addition to all these, biogas contains hydrogen sulfide (H_2S) which causes odor problems. This problem can be solved by removing hydrogen sulfide through purifier systems that have been developed in recent years.

2.2. Experimental Setup

In this study, anaerobic (oxygen-free) fermenters with the capacity of 15 l have been used for the processes. The configuration of the anaerobic fermenter is given in Figure 1. The anaerobic fermenter is designed according to both fed-batch and continuous system. The temperature in the fermenter has been measured with a thermometer and controlled by an automation system so that the

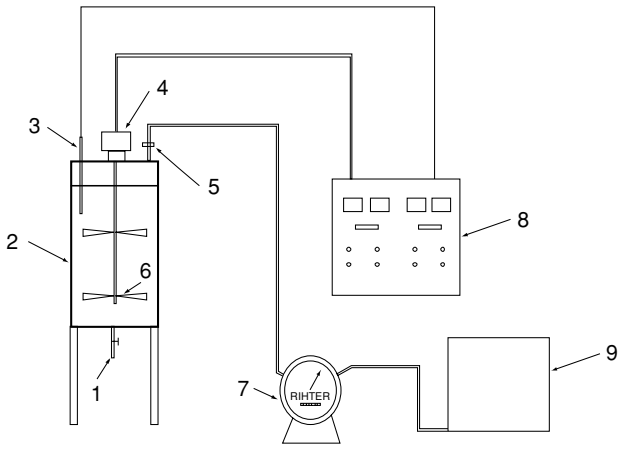


Fig. 1. Anaerobic Fermenter: 1. Discharge valve, 2. Fermenter, 3. Thermocouple, 4. Mixer engine, 5. Gas relief valve, 6. Mixer, 7. Gas flow meter, 8. Control cabinet, 9. Gas storage.

system can work at the desired temperatures. There is a mixer in the fermenter, the speed of which can be adjusted by frequency converters. The amount of gas that produced in the anaerobic fermenter is continuously measured with a gas meter. Biogas that being measured by the gas meter is stored in a gas storage tank through a collecting system.

The experiments have been realized in an anaerobic medium with the fed-batch method. Some amount of sample treatment sludge has been taken from the final sedimentation tank in a wastewater treatment plant and it has been analyzed in order to determine biogas potential. As inoculation material, the liquid has been taken from an active fermenter which is running on cattle manure. This inoculation material was added to the system as an amount which is around %10 of the mass. During the experiments, the amount of the gas and its quality was recorded on a daily basis. Samples have been analyzed according to dry matter (DM), Organic Dry Matter (ODM), pH, Total Kjedhal Nitrogen (TKN) both at the beginning and at the end of the experimental processes.

3. Experimental results

For the trial, 10 kg of the sludge which has been taken from the sludge that derived from before belt press, final sedimentation tank of the treatment plant and it was fed to the anaerobic fermenter. During the trials, mesophilic conditions were established at 38 °C. Physical properties of the sludge that used for the trials are given in table 2.

The experiments were ended when daily amount of biogas production rate was less than 90% of the total biogas production. In the systems that are being operated with fed-batch method, the realization period of 70% of the total biogas production is considered as detention period (Kishore *et al.*, 1987). At the end of the experiment, the detention period has been determined as 10 days. As a result of the heavy metals analysis, there were no heavy metal values detected to inhibit anaerobic treatment.

The daily and total amount of biogas production results are given in Figures 2 and 3, respectively. Maximum daily biogas production has been occurred on the 25th day of the experiment. Total amount of biogas production was fixed from the day on 45th, because there was no new biogas production. (Fig 2 and 3 are not clear enough for publish, pls improve them)

Throughout the experiments, 26.60 liters biogas was produced from 9 kg wastewater sludge. Methane content of the produced biogas is 73%.

The amount of biogas that has been produced from wastewater treatments sludge per organic dry matter was calculated as 85.94 l/kg ODM. The biogas production capacity of wastewater sludge was 2.96 liters/kg sludge. Total and daily biogas production quantities are presented in the following graphs.

4. Conclusions and recommendations

Principally, the type of treatment sludge has to be determined to evaluate biogas production correctly. It is also very important to determine whether domestic based treatment sludge mixed with industrial waste or not because it is necessary to define the characteristics of the sludge. The choice of the treatment method that would be used in the domestic-based treatment plant is another important factor for the composition of the sludge. The biogas potential of the anaerobic treatment may vary

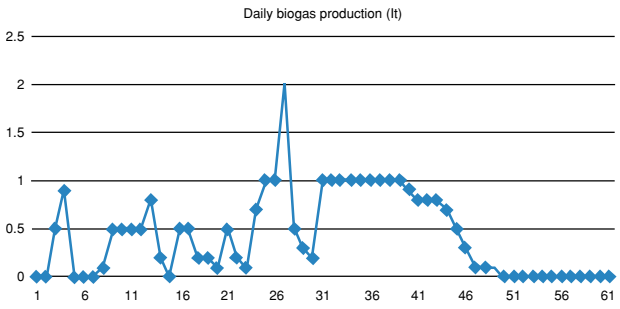


Fig. 2. The amount of biogas production on a daily basis.

Table 2.
The physical properties of the treatment sludge

Sample	Dry Matter (%)	Organic Dry Matter (%)
Sludge	3.9	88.18

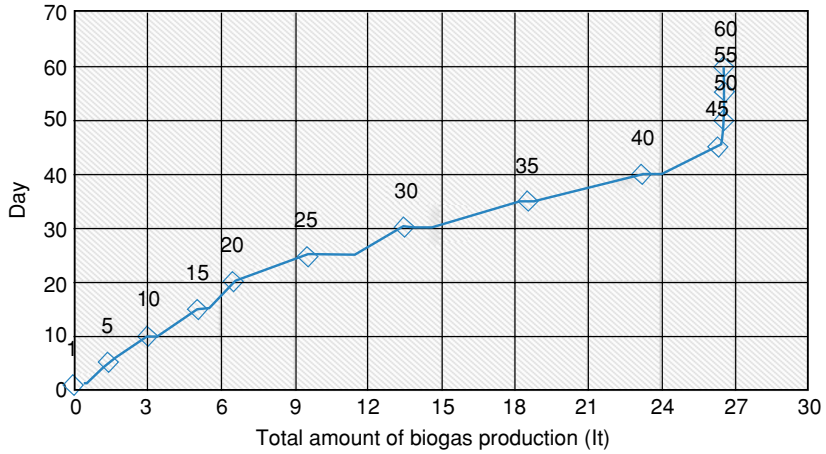


Fig. 3. Total amount of biogas production.

depending on the presence or absence of preliminary sedimentation tank of the system.

During the study, temperature was constant, at 38 °C and pH was observed around 7. The treatment sludge that used in the experiments was analyzed and its heavy metals limits values were found safe for the production of biogas.

Organic dry matter content of the sludge that used in the study was 88.18%. As a result of experimental studies, the efficiency of the biogas that obtained from the treatment sludge was 2.96 l/kg sludge. Considering this value it can be understood that this number is low. The biggest reason for this, the amount of Organic Dry Matter (ODM) in the treatment sludge is at the low level. In this study, the obtained biogas efficiency was 85.94 l/kg ODM per organic dry matter.

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