SILA SCIENCE

Future Energy Sources 1 (4) (2009) 133-150

Future Energy Sources

www.silscience.com

# Effect of the geometry of the digester mixer on biogas production

Abdulcelil Bugutekin[1,*], Mustafa Yilmaz[2], Ahmet Korhan Binark[3]

[1]*Adıyaman University, Vocational School, Adiyaman*
[2]*Marmara University, Engineering Faculty, Istanbul*
[3]*Marmara University, Faculty of Technical Education, Istanbul*

Received: 12 April 2009; accepted 17 June 2009

**Abstract**

Power need, increased with improved technology and population, made renewable resources much more important. One of these renewable energy resources is produced by processing waste product. There are many parameters (type of waste product, temperature, mixing, pH, waiting time, etc.) affecting the performance of biogas production. One of the important parameters is the waste product mixing. In this work, biogas production to become conditioned, providing boundary conditions of biogas production was built in the laboratories of the Technical Education Faculty of Marmara University. Effect of mixing on biogas production was investigated. As a mixing system, a magnetic mechanic mixing system having the properties of 2 min/h and 30 rev/min was selected. Three different type mixers, without mixing ($F_1$), T profile blade type mixer ($F_2$), 6 blade Rushton mixer ($F_3$) also modeled by Star-CCM+ software were used for CFD analysis. Some amount of cattle waste was put into digesters and those digesters were stored in biogas to become conditioned at same conditions for 45 days and 309 K at each 24 hour period, amount of biogas production, methane percentage and pH values were measured and graphs of these data were evaluated. Results of experiments show that digester ($F_3$) having Rushton mixer more efficient (about 30 %) than digester ($F_1$) without mixing and was more efficient (about 15.4%) than digester ($F_2$) having T profile blade type mixer. Also, it was observed that T profile blade type mixer was more efficient (about 16.6 %) than digester ($F_1$).

*Keywords*: Biogas; Production; Effect of Geometry; Rushton mixer
© Sila Science. All rights reserved.

* Corresponding author. Tel.: +90-416-223-2125; fax: +9- 416-223-2129.
*E-mail address*: abugutekin@adiyaman.edu.tr (A. Bugutekin).

## 1. Introduction

Power need, increased with improved technology and population, made renewable resources much more important. One of these renewable energy resources is produced by processing waste product. There are many parameters (type of waste product, temperature, mixing, pH, waiting time, etc.) affecting the performance of biogas production (Kan, 2009). One of the important parameters is the waste product mixing. It can be run into studies below when investigating literature with respect to waste mixing: Chan et.al. has investigated the impact of leachate recirculation on the co-disposal of three major wastes (municipal solid waste, sewage sludge and sediment dredgings) and monitored chemical parameters (pH, $CO_2$, ammoniacal-N, total-P) and gas production (total gas volume, production rates and concentrations of $CH_4$ and $CO_2$) for 11 weeks. They found that leachate recirculation reduced waste stabilization time and was effective in enhancing gas production and improving leachate quality, especially in terms of COD and leachate recirculation could maximize the efficiency and waste volume reduction rate of landfill sites (Chan et al., 2002). Lastela et al. (2002) have operated an experimental anaerobic digestion arrangement includes anaerobic inclined reactor, grinding system, mixer, loading unit, biogas discharging system, gas analyzer, gas purifying unit to improve $CH_4$ production by inoculating different bacteria into the semi-solid organic waste (Lastela et al., 2002).

Karim et al. (2005a) have operated six laboratory scale biogas mixed anaerobic digesters to study the effect of biogas recycling rates and draft tube height on their performance. The digesters produced methane at 0.40–0.45 L per liter of digester volume per day. A higher methane production rate was observed

in unmixed digesters, while increased biogas circulation rate reduced methane production. However, different draft tube heights caused no difference in the methane production rate. As a result, they observed that slight air permeability of tubing or leakage on the vacuum side of the air pump may have caused air infiltration (up to 15% oxygen in the biogas) in the digesters mixed by biogas recirculation (Karim, et al 2005a). Onat et al. (2004) have developed a biogas production system with anaerobic digestion process of organic waste under condition of 10 rev/min mixing speed and mesophilic environment temperature about 308-311 K.

Karim et al. (2005b) have studied the effect of mode of mixing (biogas recirculation, impeller mixing, and slurry recirculation) and waste strength on the performance of laboratory scale digesters. They fed the digesters with 5% and 10% manure slurry, at a constant energy supply per unit volume (8 W/m3). The experiments were conducted in eight laboratory scale digesters, each having a working volume of 3.73 L, at a controlled temperature of 308 ± 2 K. They kept hydraulic retention time (HRT) constant at 16.2 days (Karim et al., 2005b). Andara and Esteban (1999) presented studies on the determination of a kinetic model in an anaerobic digestion process. They applied to the organic stabilization of the solid fraction of piggery slurry. The substratum results after filtering the farm wastewaters through a 1 mm mesh hydraulic sieve. They used two pilot scale reactors, one digester was working in layered way Ð without agitation Ð and other was mixed with a stirrer. The experiments were carried out in a discontinuous process, 60 days hydraulic retention time, in the mesophilic interval (308 K) (Andara and Esteban, 1999). Ong et al. (2000) have investigated cattle-manure slurry in the quiescent state by measuring the amount of biogas production in three discernible layers; a floating (top) “scum” layer, a bottom sludge layer and a watery middle layer. Karim et al. (2005c) have

studied an investigation about anaerobic digestion of animal waste in according to waste strength versus impact of mixing using laboratory scale digesters having a working volume of 3.73 L were operated at a controlled temperature of 308 K. Borole et al. (2005) have reported the production of methane in a 100-L digester and the results of an investigation into the effect of partial mixing induced by gas upflow/recirculation in the digester by operating with and without the mixing induced by gas recirculation through an internal draft tube. Kestkar et al. (2003) have developed a mathematical model for anaerobic digestion of cattle manure to describe the dynamic behavior of non-ideal mixing continuous flow reactors. Vavilin et al. (2004) have investigated batch anaerobic co-digestion of municipal household solid waste (MHSW) and digested manure in mesophilic conditions. They studied the different waste-to-biomass ratios and intensity of mixing theoretically and experimentally. They found that when organic loading was high, intensive mixing resulted in acidification and failure of the process, while low mixing intensity was crucial for successful digestion (Vavilin et al., 2004). Janzekovic et al. (2005) have found that when the dry matter content in the liquid manure amounted to 5.05–5.74%, the pit with incorporated aerator after 20 min of mixing became to contain the greatest quantity of the dry matter. Also, when the aerated liquid manure was spread on the surface more uniformly; it flowed off the plants and penetrated faster into the ground up to the roots. When the aerated liquid manure was sprinkled, the bad smell in the environment was considerately lower (Janzekovic et al., 2005). Chen et al. (1979) have found that the degree of mixing and the power consumption are greatly affected by the slurry's rheological properties in agitation. Although the rheological properties of livestock manure slurry have been shown to be non-Newtonian pseudoplastic, they studied the correlations

between the impeller power consumption in mixing manure slurry and the slurry's physical properties.

They found that the slurry power numbers were much higher than the Newtonian power numbers in the transition range (Chen et al., 1979). Sadaka et al. (2000) have developed a batch anaerobic composting system to study the effects of mixing on anaerobic composting of higher solids beef manure with biogas recovery. They used two 4-L reactors with one reactor being mixed by inverting it 10 times twice daily. Volatile solids decreased by 7.3 and 9.6% for unmixed and mixed manure, respectively. Chemical oxygen demand, total Kjeldahl nitrogen and ammonia nitrogen decreased by 37.9%. Biogas production increased by 33.3% with mixed manure compared to unmixed manure (Sadaka et al., 2000). Patni et al. (1991) have studied on concentrations of hydrogen sulfide ($H_2S$), ammonia ($NH_3$), carbon dioxide $CO_2$), and methane ($CH_4$) during mixing of slurry in subfloor manure storage pits in dairy-cattle, swine, and caged-layer barns. Sievers et al. (1989) has applied tests to determine the rapid-mixing, velocity gradient (G) and detention time (t), for optimum coagulation of suspended solids from dilute beef cattle, poultry and swine manure slurries being treated with ferric iron salts or chitosan. They found that rapid or slow mixing effects negatively (Sievers et al., 1989). Kalia et al. (2001) have batch fermented forty kilograms of pure cattle dung and cattle dung mixed with 10% digested slurry obtained from a weld biogas plant in horizontal biogas digesters for 15 weeks under weld conditions with mean ambient temperature 293 - 296 K. They found that mixing of slurry speed up the gas production (Kalia et al., 2001). Amon et al. (2007) have researched crops and animal manures for biogas production in a project aimed at optimizing anaerobic digestion of maize and dairy cattle manures. They measured methane production for 60 days in 11 eudiometer batch digesters at 311 K by mixing for 10 second

at each 10 minute (Amon et al., 2007).

Kesthkar et al. (2003) have developed a mathematical model for anaerobic digestion of cattle manure to describe the dynamic behavior of non-ideal mixing continuous flow reactors. They showed that deviations from ideal mixing regime result in decreased performance of anaerobic reactors. They were also shown that methane yield is strongly dependent on pH of the reactor. In addition, methane yield was shown to increase with greater retention times and increased degree of mixing in the reactor. Completely mixed reactors required a shorter retention time than incompletely mixed reactors to achieve the same methane yield (Keshtkar et al., 2003).

In our study, three different type mixers also modeled by Star-CCM+ software were used in the experiments of biogas production realized in the laboratories of Technical Education Faculty of Marmara University (Bugutekin, 2007)

## 2. **Digester mixing systems in biogas production**

The material of fermentation should have properties of fluidity in all parts forming the producer. Also the homogenous distribution of material in the producer should be necessary. The size of parts being fairly small is an important factor of increasing the activity of fermentation. In the position of non-mixing materials in producer, the materials existed in the base and the top have more dry material contents than the middle section because of swimming and precipitation. This decreases the activity of bacteria and also the top section have dryer material content prevents the produced gaseous emerging outside (Bugutekin, 2007). In our study; first of all non-mixing system ($F_1$) shown in Fig. 1 (Bugutekin, 2007) It was selected for the reason of comparison and than T

profile blade type mixer ($F_2$) and 6 blade Rushton mixer ($F_3$). Fig. 2 were used at the same time and the conditions (Axaopoulos et al., 2001; Kongoli et al., 2002; Yapici, 2003; Davidson et al., 2003; Campolo et al., 2003; Schafer et al., 2005; Hitomi et al., 2006).

T profile blade type mixer is used in mixers needed little mixing and there is no baffle inner part of the fermenter. Rushton mixers are generally used in bio-reactors containing materials having the properties of pH, oxygen and the chemical features. Also, Star-CCM+ software is applied these mixers as the experiments go on and the surface temperature distributions and the surface vectorial speed distributions while mixing are got.

## 3. **Test equipment and experiments**

The experimental set in biogas production was built in the energy Laboratory of Technical Education Faculty of Marmara University as seen Fig. 3 (Bugutekin, 2007). Also the chemical and physical properties of waste used in experiments are given in Table 1.

As a mixing system, magnetic mechanic mixing system having the properties of 2 min/h operating time period and 30 rev./min. was selected. Three different type mixers; without mixing ($F_1$), T profile blade type mixer ($F_2$), 6 blade Rushton mixer ($F_3$) were used in experiments. Some amount of cattle waste was put into digesters and those digesters were stored in biogas to become conditioned at same conditions for 45 days and 309 K. At each 24 hour period, amount of biogas production, methane percentage and pH values were measured and graphs of these data were evaluated (Bugutekin, 2007). Total solids (TS), volatile solid (VS), pH, chemical oxygen demand (COD), were determined according to standard methods (Clesceri et al., 2000) .

All measurement devices (pH-meter, thermometer, manometer) are calibrated. Methane in the biogas was determined with a gas chromatograph. The pressure in the digester and the gas collecting gas bag was set by the difference in water level between the water displacement bottle and the gas collecting gas bag. The samples were packed into 500 g polyethylene bags and stored at 272 K in a freezer until used.

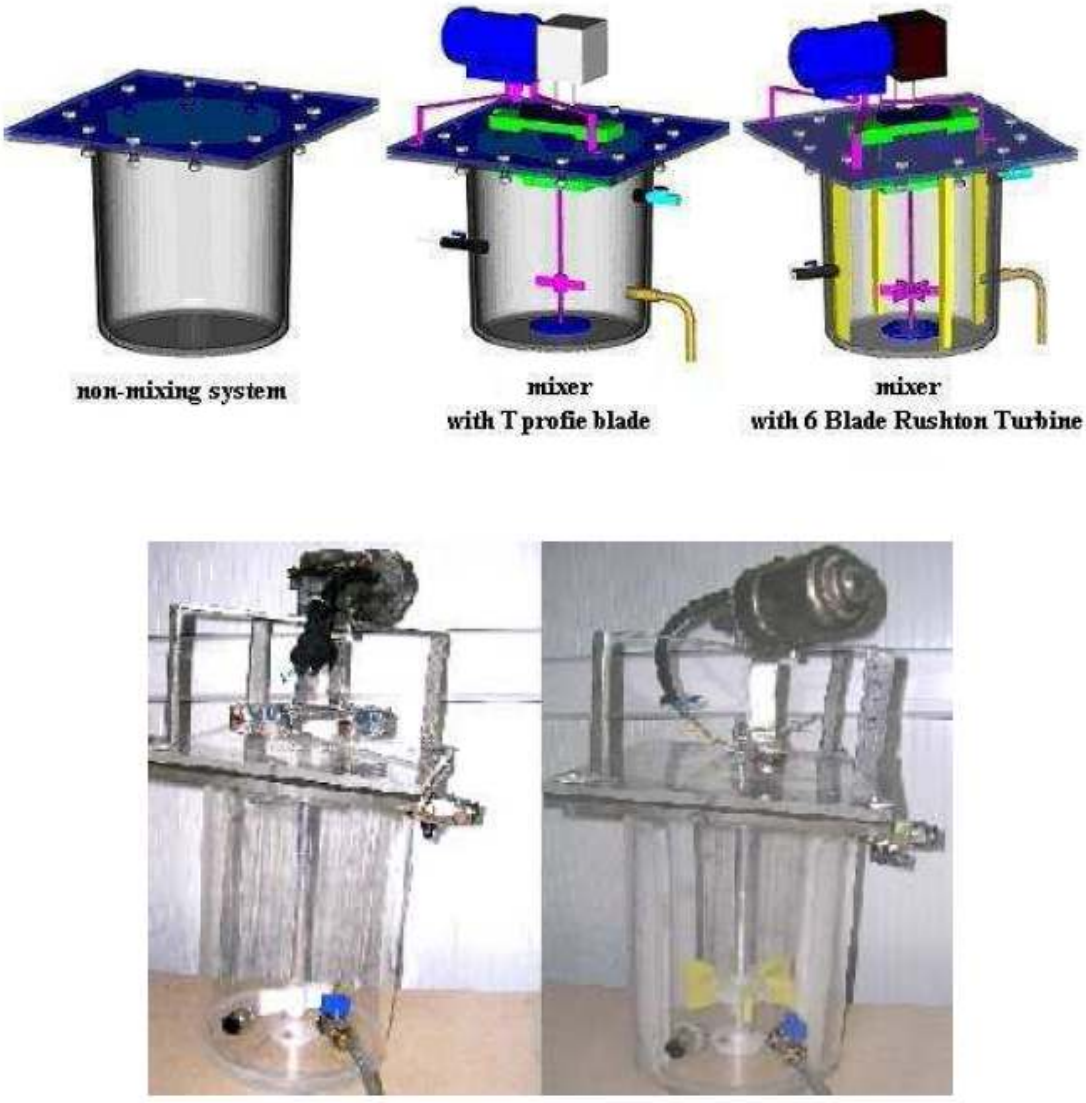



Fig. 1. Without mixing, T profile blade type mixer, 6 blade Rushton mixer are used in the experiments.

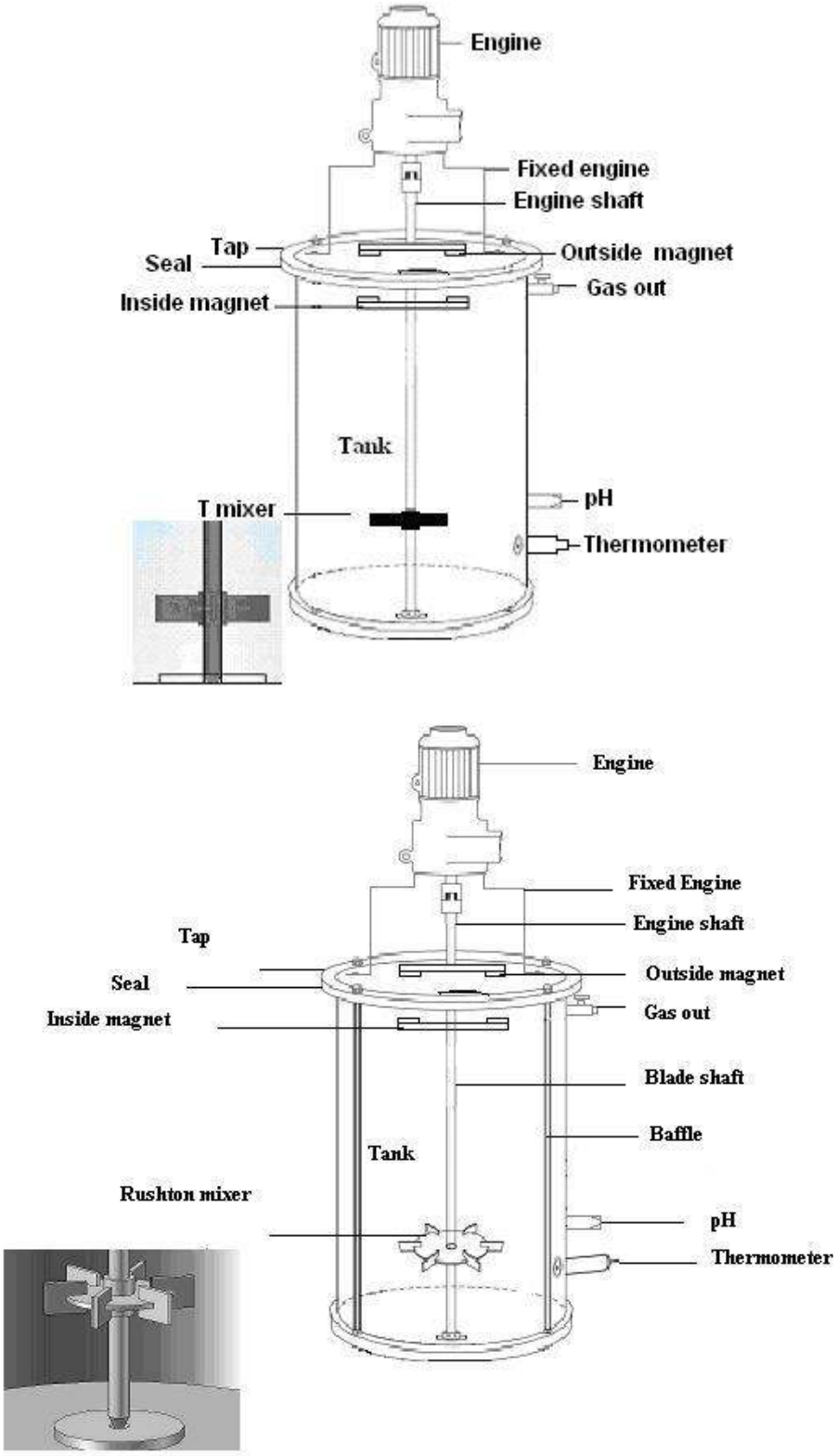
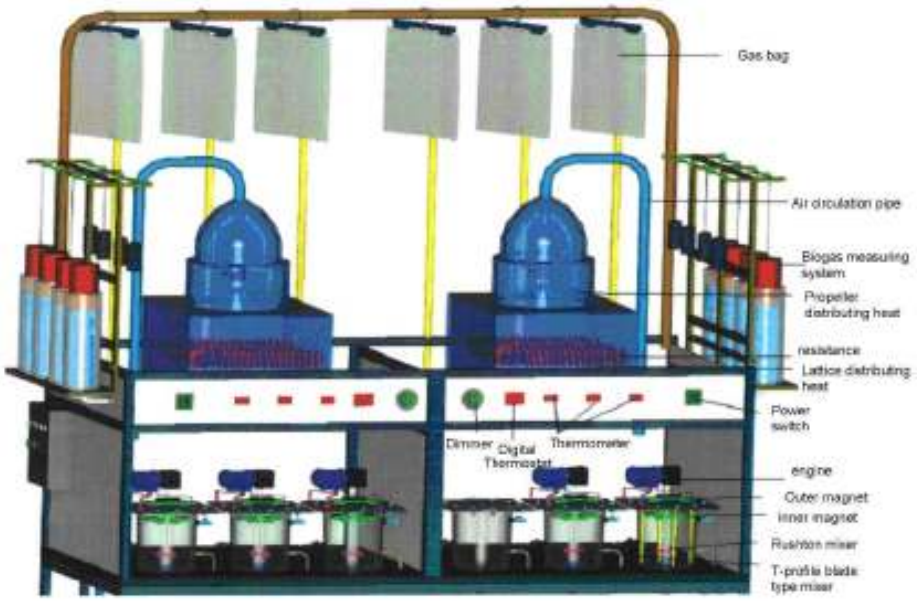



Fig. 2. T profile blade type mixer and 6 blade Rushton mixer 6-blade Rushton mixers are used in an experiment and fermenter.



A




B

Fig. 3. A and B The experimental set in biogas production.

Table 1

The chemical and physical properties of waste used in experiments

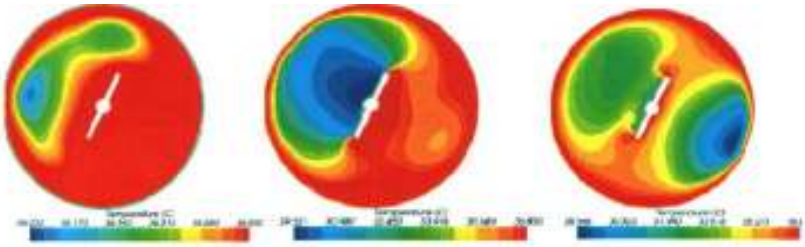
| Physical and Chemical Properties | Numerical values |
|---|---|
| Total solids (%) | 12 |
| Total solids (g/L) | 141.4 |
| Ratio of the volatile solid matter (g/L) | 90.1 |
| Necessity of the chemical oxygen (g/L) | 38.5 |
| pH | 6.5/7.5 |
| Waiting time (day) | 45 |
| Mixing model | Rushton mixer (6-blades with baffle)<br>T-profile type mixer without mixing |
| Thermal conductivity of waste (W/m K) | 0.12-0.19 |
| Specific heat of waste (kJ/kg $^{o}$C) | 4.2 (Ebadian, 1998) |
| Mixing period (min/h) | 2 |
| Temperature (K) | 308±1 |
| Type of mixing | Continuous mixing |
| Revolution of the mixing engine (rev/min) | 30 |
| Density (kg/m$^3$) | 1090 |
| Viscosity at 308 K (kg/m s) | 0.084 |

## 4. Results and discussion

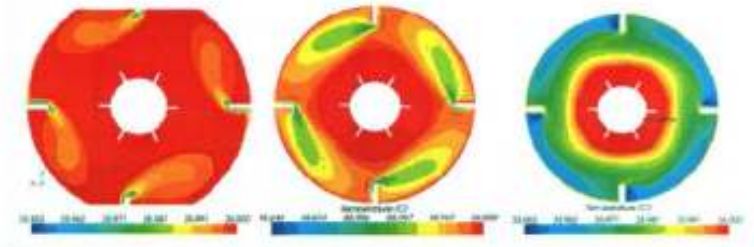
The surface temperature distributions and the surface vectorial speed distributions at different time step of the solution applied by Star-CCM+ in Figs. 4 and 5.

It is shown that; because of the better mixing then the T profile's the surface temperature distributions and the surface vectorial speed distributions of the Rushton mixer are more homogenous than the T profile mixer's. Also, the variations of biogas production amount, pH in biogas and Methane percentage versus time for three different mixing systems are given in Figs. 6-8.

Especially after 13$^{th}$ day, the amount of biogas production in liter and the methane percentage belonging to the Rushton mixer ($F_3$) are greater than the T profile mixer ($F_2$) and without mixing's ($F_1$).

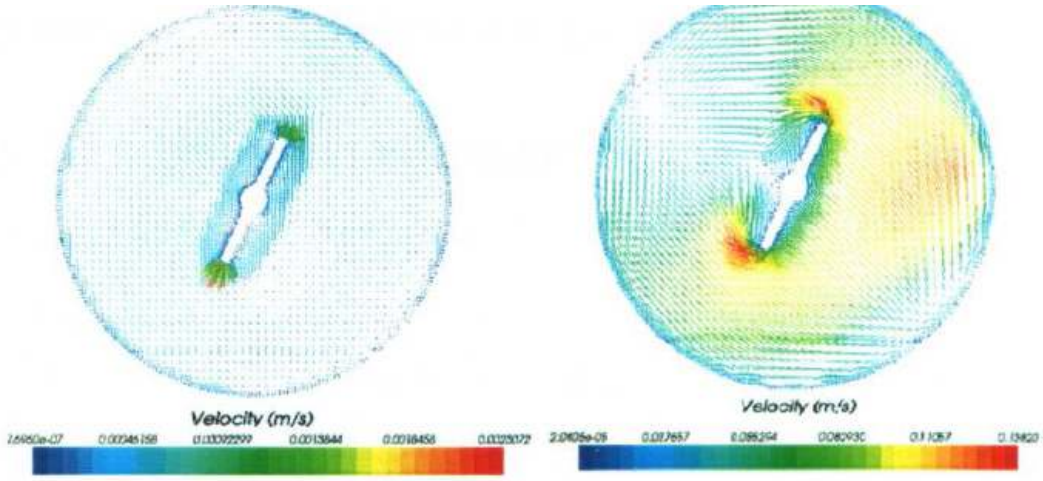


(a)

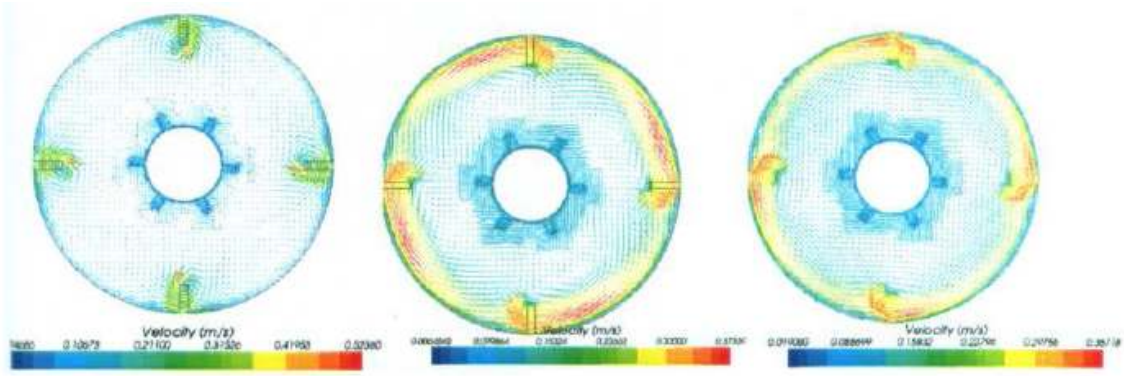


(b)

Fig. 4. The surface temperature distributions while mixing for a) T profile blade type mixer b) 6 blade Rushton mixer.




(a)




(b)

Fig. 5. The surface vectorial speed distributions while mixing for a) T profile blade type mixer b) 6 blade Rushton mixer.

Results of the experiments showed that digester ($F_3$) having Rushton mixer was more efficient (about 30 %) than digester ($F_1$) without mixing and as more efficient (about 15.4 %) than digester ($F_2$) having T profile blade type mixer.

Also, it was observed that T profile blade type mixer was more efficient (about 16.6 %) than digester ($F_1$) without mixing.

For the reasons of the boundary conditions in biogas productions being so variable and the type of the waste being so different, we can say that these propositions should be considered:

- The effect of mixing speed on biogas production.
- Effect of the type of mixing like a discontinuous one and/or continuous one of the efficiency of biogas production.
- Effect of the geometrical size of the biogas digesters in the laboratory sized or large foundations on biogas production.
- The storing of biogas in liquid form.

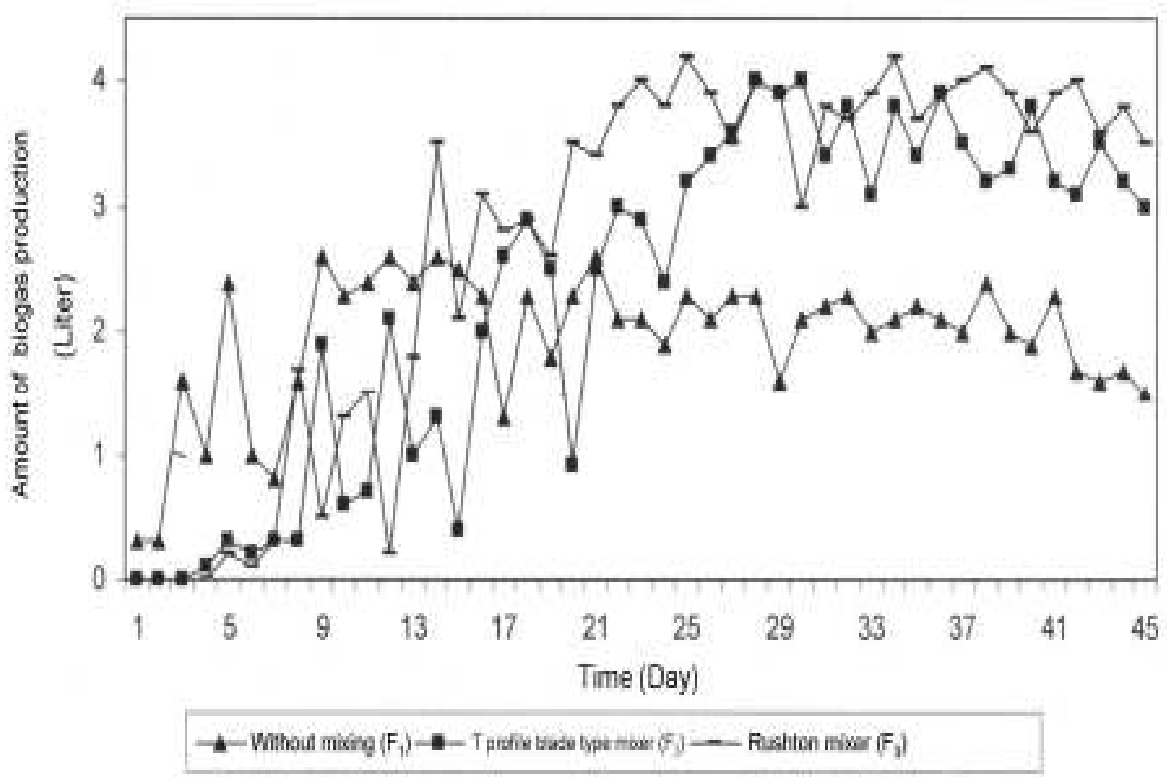



Fig. 6. The variations of biogas production amount versus time for three different mixing systems.

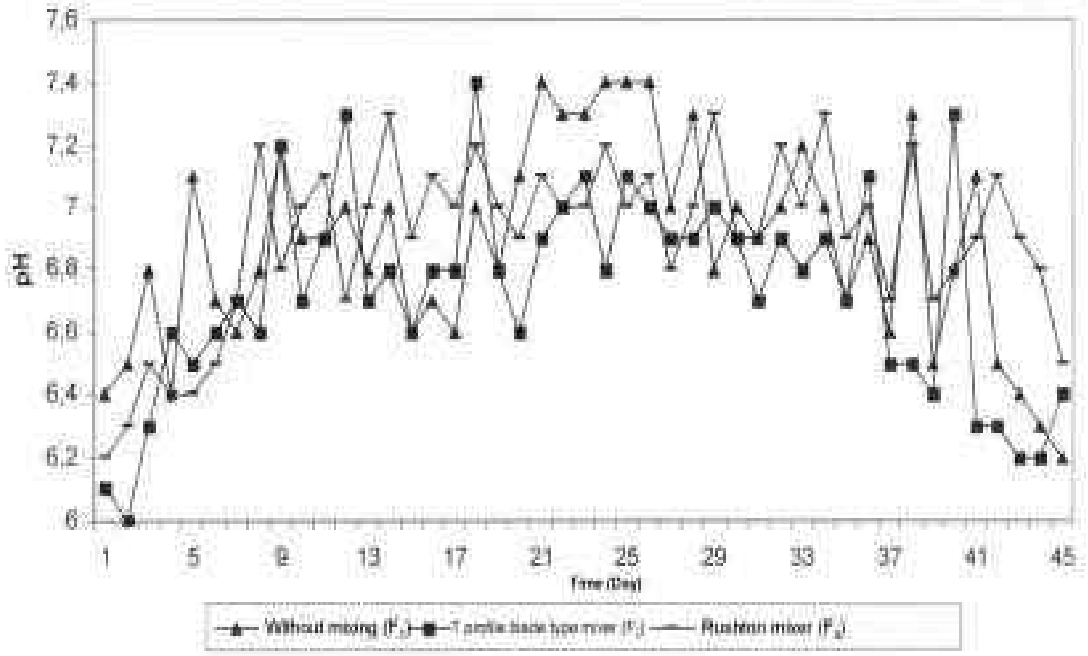



Fig. 7. The variations of pH in biogas versus time for three different mixing systems.

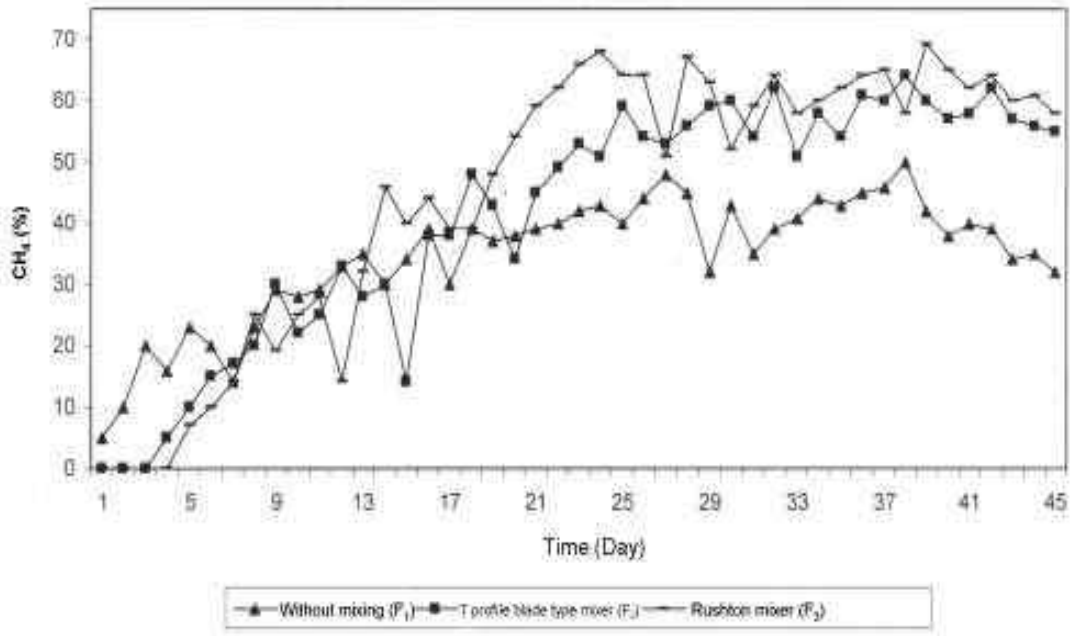



Fig. 8. The variations of methane percentage versus time for three different mixing systems.

## 5. Conclusion

Effect of mixing on biogas production was investigated. As a mixing system, a magnetic mechanic mixing system having the properties of 2 min/h and 30rev/min was selected. Three different type mixers, without mixing, T profile blade type mixer, 6 blade Rushton mixer also modeled by Star-CCM+ software were used for CFD analysis.

The most important parameters for biogas production are. (a) temperature, (b) pH, (c) digestion time, (d) mixing speed, (e) the type of mixing, and (f) the geometrical size of the biogas digesters.

## Acknowledgements

This work was sponsored by the scientific search projects commissions (BAPKO) of Marmara University in Istanbul in Turkey (Contract no. BSE-072/131102). We would like to thank the BAPKO for the financial support.

### References

Amon, T., Amon, B., Kryvoruchko, V., Zollitsch, W., Mayer, M., Gruber, L. 2007. Biogas production from maize and dairy cattle manure-Influence of biomass composition on the methane yield. Agric Ecosyst Environ 118:173-182.

Andara, A. R., Esteban, J. M. I. 1999. Kinetic study of anaerobic digestion of the solid fraction of piggery slurries. Biomass Bioenergy 17:435-443.

Axaopoulos, P., Panagakis, P., Tsavdaris, A., Georgakakis, D. 2001. Agricultural University of Athens, Agricultural Engineering Department, Laboratory of Farm Structures, Athens, Greece.

Borole, A. P., Klason, K. T., Ridenour, W., Holland, J., Karim, K., Al-Dahhan, M. H., 2006. Methane production in a 100-L upflow bioreactor by anaerobic digestion of farm waste. Appl Biochem Biotechnol 5:129-132.

Bugutekin, A. 2007. Investigation of biogas production from waste product. Doctorate Thesis. Marmara University, Faculty of Technical Education, Istanbul.

Campolo, M., Sbrizzai, F., Soldati, A. 2003. Time-dependent low structures and Lagrangian mixing in Rushton-impeller baffled-tank reactor. Chem Eng Sci 58:1615-1629.

Chan, G. Y. S., Chu, L. B., Wong, M. H. 2002. Effects of leachate recirculation on biogas production from andfill co-disposal of municipal solid waste, sewage sludge and marine sediment. Environ Pollut 118:393-399.

Chen, Y. R., Hashimoto, A. G. 1979. Impeller mixing of livestock manure slurries. Am Soc Agric Eng 22:34-36.

Clesceri, L. S., Greeberg, A. E., Eaton, A. D. 2000. Standard methods for the examination of water and wastewater. 20th ed. Washington, DC, USA: American Public Health Association (APHA).

Davidson, M. K., Sushil, S., Eggleton, C. D., Marrten, M. R. 2003. Using computational fluid dynamics software to estimate circulation time distributions in bioreactors. Biotechnol Prog l9:1480-1486.

Ebadian, M. A. 1998. Improved mixing and sampling systems for vitrification melter feeds. U.S. Department of Energy Office of Fossil Energy Federal Energy Technology Center.

Hitomi, D., Kato, Y., Kubo, T., Okuzaki, S., Sugihama H. 2006. Finite element analysis of a flow induced by a rushton in an baffled stirred vessel. J Chem Eng Japan 39:275-283.

Janzekovic, M., Mursec, B., Cusb, F., Ploj, T., Janzekovic, I., Zuperl, U. 2005. Use of machines for liquid manure aerating and mixing. J Mat Proc Technol 162-163:744-750.

Kalia, Anjan K., Singh, S. P. 2001. Effect of mixing digested slurry on the rate of biogas production from dairy manure in batch fermenter. Energy Sources 23:711-715.

Kan, A. 2009. General characteristics of waste management: A review. Energy Educ Sci Technol Part A 23:55-69

Karim, K., Thomas, K. K., Hoffinann, R., Drescher, S. R., Depaoli, W. D., Al-Dahhan, M. H. 2005a. Anaerobic digestion of animal waste: Effect of mixing. Biores Technol 96:1607-1612.

Karim, K., Hoffman, R., Klasson, K. T., Al-Dahhan, M. H. 2005b. Anaerobic digestion of animal waste: Effect of modde of mixing. Water Res 36:3597-3606.

Karim, K., Hoffinan, R., Klasson, K. T., Al-Dahhan, M. H. 2005c. Anaerobic digestion of animal waste: Waste strength versus impact of mixing. Biores Technol 96:1771-1781.

Keshtkar, A., Meyssami, B., Abolhamd, G., Ghaforian, H., Khalagi, A. M. 2003. Mathematical modeling of non-ideal mixing continuous flow reactors for anaerobic digestion of cattle manure. Biores Technol 87:113-124.

Kongoli, C. E., Bland, W. L. 2002. Influence of manure application on surface energy and snow cover. J Environ Quality 31:1166-1173.

Lastela, G., Testa, C., Cornacchia, G., Notornicola, M., Voltasio, F., Sharma, V. K. 2002. Anaerobic digestion of semi-solid organic waste: biogas production and its purification. Energy Convers Manage 43:63-75.

Onat S., Topaloğlu, B. 2004. A model for biogas production system. Proceeding of the 5th National Clean Energy Symposium, pp. 601-608, May 26-28, Istanbul.

Ong, H. K., Greenfeld, P. F., Pullammanappallil, P. C. 2000. An operational strategy for improved biomethanation of cattle-manure slurry in an unmixed, single-stage, digester. Biores Technol 73:87-89.

Patni, N. K., Clarke, S. P. 1991. Transient hazardous conditions in animal building due to manure gas released during slurry mixing. Appl Eng Agric 7:478-484.

Sadaka, S., Engler, C. R. 2000. Effects of mixing on anaerobic composting of beef manure" Am Soc Agric Eng 43:4993-5001.

Schafer, M., Karasozen, B., Uludag, Y., Yapici, K., Ugur, O. 2005. Numerical method for optimizing stirrer configurations. Comput Chem Eng 30:183-190.

Sievers, D. M. 1989. Rapid mixing influences on chemical coagulation of manures. Biol Wastes 28:103-114.

Vavilin, V. A., Angelidaki, L. 2004. Anaerobic degradation of solid material: importance of initiation centers for methanogenesis, mixing intensity, and 2d distributed model. Published online November 11, 2004 in Wiley InterScience.

Yapici, K. 2003. Numerical investigation of stirred tank hydrodynamic. In partial fulfillment of the requirements for the degree of master of science in the Department of Chemical Engineering, Middle East Technical University, Ankara.