Co-digestion of Cattle Manure and Tea Waste for Biogas Production

Mehmet Volkan Aksay*‡, Mehmet Ozkaymak*, Rahman Calhan**

*Department of Energy System Engineering, Faculty of Technology, Karabuk University, Turkey

**Department of Environmental Engineering, Faculty of Engineering, Karabuk University, Turkey

(volkanaksay@karabuk.edu.tr, mozkaymak@karabuk.edu.tr, rahmancalhan@karabuk.edu.tr)

‡ Department of Energy System Engineering, Faculty of Technology, Karabuk University, Turkey, Tel: +90 370 418 71 00, Fax: +90 370 418 71 01, volkanaksay@karabuk.edu.tr

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Abstract- The increase of world population brings energy and food requirements. Increasing energy demand drives humanity towards new energy sources and work towards energy efficiency developments. Concordantly, due to population growth, the amount of waste is also increasing and causing environmental -issues. Biogas production by co-digestion of wastes -could be a common solution to both issues. Animal manures are typically used as a main substrate in co-digestion applications. Tea waste is used as a co-substrate in this -work due to having large production and consumption volume in Turkey. The aim of this study is to emerge new methods for disposal and reuse of household tea waste. For this purpose, co-digestion method was carried out to determine the biogas potential of household tea waste. Laboratory scale batch type co-digestion is carried out for 80 days under mesophilic (37±2 ºC) conditions. All reactors fed with different mixing ratio of wastes and operated with different stirring speeds. The results showed that co-digestion of the wastes have positive impact on biogas and methane yield. Optimum biogas yield is 296.89 mL/gVS and 77.10% methane content are obtained from A2 which consist of 75% cattle manure and 25% tea waste with 100 rpm stirring speed. According to the results, co-digestion of cattle manure and household tea waste both have a positive effect on biogas production and methane content of biogas.

Keywords Biogas, Co-digestion, cattle manure, tea waste.

1. Introduction

Rapid population growth and industrialization throughout the world are leading to an increase in food demand. Simultaneously, in agriculture and livestock industry has been growing up._The growing industry brings animal and agricultural wastes to the scene. If the wastes are not controlled, environmental pollution could not be overcome and threatens human health [1].

One of the most important animal waste is the cattle manure that causes global warming due to the formation of methane gas which leads to eutrophication of surface water resources, pathogenic problems and bad odor. According to the data of 2017 from the Turkey Statistical Institute (TSI), 16,105,025 total cattle is available in Turkey [2]. According to the data obtained from the literature, average of 10 kg/day, 3.65 tons/year manure is obtained from one cattle [3-5]. According to the data, 58,783,341 tons/year could be obtained from cattle manure in Turkey, which is equivalent to 1,939,850,261 m^3/year biogas and 9,117,296 MWh of electricity [5,6]. Current number of biogas plants based on agricultural and animal wastes is 24 in Turkey and total installed power is 78.5 MWe, total electricity production is 699,166 MWh per year. These plants are provided by the government for a 10-year 13.3 $/kWh tariff guarantee which is the highest feed-in tariff guarantee among renewable energy sources [7]. Turkey had 540 MW installed biomass capacity in 2017 and Turkey Energy and Natural Resources Ministry targets to reach 700 MW in 2019 and 1000 MW in 2023 [8]. In line with the target, the number of existing facilities are now limited and thus, energy efficiency are insufficient, as well. The number of facilities should be increased and studies are to be raised on the efficiency of biogas later on.

There have been many studies carried out about cattle manure so far and production of biogas and organic fertilizer by anaerobic digestion are the most widely used methods. Anaerobic digestion is the process of obtaining biogas that mainly consists of methane and carbon dioxide (CO_2) from organic matter in an anaerobic environment. Animal manures are typically used for anaerobic digestion process to produce organic fertilizer and biogas which provides electricity income in cogeneration system. However, because of the characteristics of some substrates, unfavourable conditions can arise due to anaerobic digestion of single substrate (mono digestion). Animal manure may cause inhibition of methanogens due to high nitrogen (N) content and has low organic load, in contrast plants and agricultural wastes are seasonal and have low N content. Such problems can be solved by adding co-substrate called co-digestion process, therefore the methane yield can be increased [9,10].

Conventionally, anaerobic digestion involves a single substrate, but Co-digestion is the digestion of a homogeneous mixture of two or more substrates. Co-digestion enhances nutrient balance, allows homogenization of particulate, floating, settling wastes by mixing with animal manure or waste water sludge, optimizes rheological properties, increases regular biogas production and provides additional fertilizer [11].

Co-fermentation of cattle manure with high methane potential wastes such as oily residues, alcohol residues, agricultural wastes and food industry or food waste produces more biogas than mono-digestion of cattle manure. Therefore, co-fermentation can increase the profitability of biogas plants. In addition, the organic wastes of the food industry, which are produced annually in large quantities and in many places, and convenient for co-fermentation with animal manure, has been used instead of throwing away [12,13]. Vegetable and agricultural wastes should be assessed for co-digestion except straws, corn stalk, sugar beet leaves, corn silage, beet pulp, which are –particularly used as animal feed, or a new product such as straw mat [4].

According to the Food and Agriculture Organization (FAO) report on the current and future development of world tea production and trade in 2015, Turkey is in the 1st position in Europe on annual tea production and 5th position in the World after China, India, Kenya and Sri Lanka respectively [14]. According to TSI tea production data, total tea production is 1300 thousand tons in 2017 in Turkey [15].

Dried and ground tea leaves are used by steeping with hot water and then the outcomes could be assessed as a waste. The waste, which is produced and consumed in large quantities, is discarded as a mixture with other domestic wastes besides it has a high moisture content. So, it easily deteriorates when discarded and causing problems such as leaking water and odor occurs [15].

The amount of tea leaves waste is also increasing, depending on the overconsumption. New methods for the disposal and reuse of tea leaves waste need to be developed. Tea leaves are steeped in water and does not mix with –any other substances, and that is very convenient in principle of waste separation at source. Tea leaves have a useful content of amino acids, proteins, vitamins, tannins and polyphenols. After steeping of the tea leaves, some of the nutrients still remain in the tea leaves [15]. Therefore, this waste could be used for biogas production unless assessing as feed or other product.

Wastes such as cattle, sheep, poultry, wastewater treatment sludge, silage, barley, wheat straw, paddy straw grass waste etc. have been studied in literature and there is adequate information about biogas potential and methane content but such data about household tea waste was not reached [17- 19].

Studies which have been carried out about tea wastes have been using industrial tea waste as mineral support to soil [20], biogas production from industrial instant tea leachate [21], reduction of bacterial contamination in fresh black tea by gamma radiation and determination of important minerals [22], volatile compounds and sensor characteristics of various instant teas [23], activated carbon production from tea plant wastes [24] etc., but no study has been done on biogas production by co-fermentation of cattle manure and household tea wastes. In this study, anaerobic co-digestion of cattle manure with household tea waste was studied with the aim of determination maximum biogas yield for the first time.

2. Material and Methods

2.1. Waste Characteristics

In this study, cattle manure, spent tea waste and inoculum were used. Cattle manure was obtained from a farm having 50 cattle. Spent tea wastes are received from Karabuk University Faculty of Technology student canteen. The tea brand is The State Economic Entity of General Directorate of Tea Operations (ÇAYKUR) organic tea produced in the Hemsin organic basin, which is certified in every step of the way from production to consumption, with no chemicals used at any stage. Tea is only steeped with water, collected by method of separation in a source without mixing with another waste.

Table 1. The characteristics of wastes and inoculum

Parameter	Cattle Manure	Tea Waste	Inoculum
Carbon, C (%)	38,57±0.5	53,78±0.9	35,81±0.4
Nitrogen, N (%)	5,86±0.6	3,81±0.4	4,43±0.8
C: N	6,582	14,12	8,08
Total Solids, TS (%)	23,61±0.8	30,5±0.2	10±0.1
Volatile Solids, VS (%)	90,42±4.3	97,21±0.8	91,13±2.7
Chemical Oxygen Demand, COD (mg/L)	29600±248	na	na
pH	6,98±0.05	5,37±0.08	7,04±0.07

The inoculum used in the study was obtained from the pilot scale biogas plant of Karabuk University with 6m^3 reactors and 6m^3 final storage tank operating on the continuous feed system in the mesophilic conditions with the cattle manure. The wastes were kept in the refrigerator at +5 °C until used after being characterized. The waste characteristics are summarized in Table 1.

2.2. Analytical Methods

Biogas measurements were performed daily with a gasometer operating according to water displacement principle and the content of methane, carbon dioxide, hydrogen sulphide in biogas was made with GEOTECH 5000 model biogas analyser. pH measurements were performed with WTW Inolab 720 pH meter. C, N, TS, VS and COD analyses were performed according to standard methods [23].

2.3. Experimental Setup

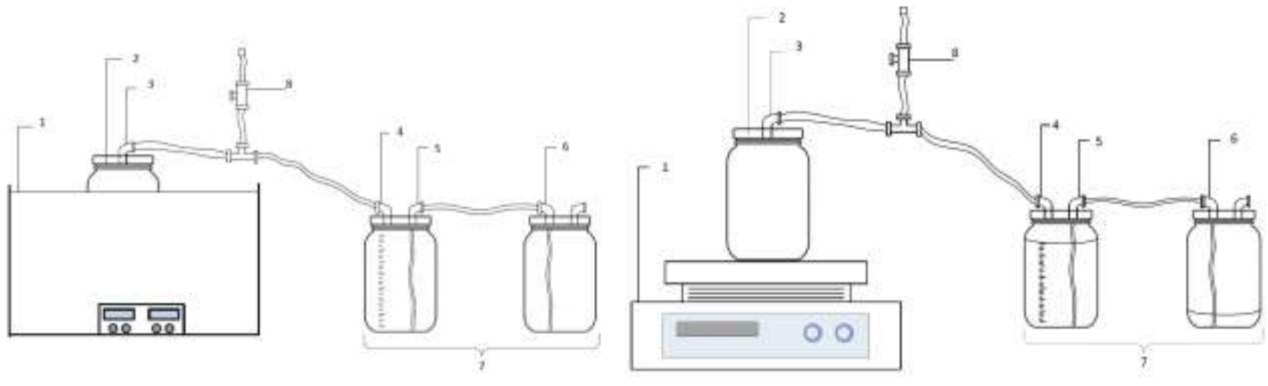
1 litter glass bottles were used as the reactor and air tightness was provided by screw cap, gasket and pneumatic hose and fittings to determine the effect on biogas production by co-digestion of cattle manure with tea leaves waste. Two experimental setups were installed with the aim of determining the effect of stirring speed on biogas production. At the first setup (Fig 1a) temperature-controlled water bath was used to keep the temperature stationary and reactors were shaked manually once a day. At the second setup (Fig 1b) hot plate magnetic stirrers were used to keep the temperature stationary so as to carry out the stirring process. Daily biogas productions were measured by water replacement principle.

In this study, two important factors were investigated: tea waste mixing ratio of cattle manure and the effect of reactor stirring speed on biogas production. All reactors were fed with substrates to provide 50 g TS/L at different mixing ratios (Table 3). In all reactors, 100 ml of inoculum was added, and the dry matter content was adjusted to 10% by diluting with pure water at a working volume of 0.6 litres. The experiments were carried out with 3 repetitions with batch type feeding systems under mesophilic conditions (37±2 ºC). Anaerobic digestion process was conducted during 80 days until the end of biogas production in the reactors. Reactor waste mixing ratios and stirring speed are shown in Table 2.

Table 2. Waste mixing ratios and stirring speed.

Reactors	Cattle manure	Tea Waste	Stirring Speed(rpm)
A1	100%	0%	100
A2	75%	25%	100
A3	50%	50%	100
A4	25%	75%	100
A5	0%	100%	100
N1	100%	0%	0
N2	75%	25%	0
N3	50%	50%	0
N4	25%	75%	0
N5	0%	100%	0

Initial characteristics of all reactors are given in Table 3. Anaerobic fermentation is a biological process that organic materials are converted into biogas, consisting of hydrolysis, acidogenesis, acetogenesis and methanogenesis steps. Parameters such as temperature, organic loading rate, hydraulic retention time and pH were generally used to monitor anaerobic fermentation process performance. Among these, the most commonly used parameter is pH. pH directly affects acidogenic and methanogenic microbial community during anaerobic fermentation [26]. The optimum pH for hydrolysis and acidogenesis is between 5.5-6.5 and for methanogenesis is between 6.8-7.2 [27]. Therefore, pH of reactors was adjusted between 6.5-7.5 by adding 1N Sodium Hydroxide (NaOH) [28]. Anaerobic digestion process generally carried out at mesophilic and thermophilic temperature ranges. Methanogenic microorganisms can survive in a wide temperature range, but optimum operational conditions can be ensured at mesophilic temperatures for methanogens [29]. Therefore, this study was carried out under only mesophilic temperature (37±2 ºC) conditions.



(a) (b)

Fig 1. Experimental setup a) Water bath setup b) Hot plate magnetic stirrer setup (1-water bath/hot plate magnetic stirrer, 2- reactor, 3- biogas output, 4- biogas input, 5- water output, 6- water input, 7- gasometer, 8- gas sampling point)

Table 3. Initial characteristics of reactors

Reactors	TS (g/L)	VS (%)	Average COD (mg/L)	pH
A1	50	76.64±3.2	29600±153	7.04±0.08
A2	50	80.87±2.8	28200±242	7.40±0.05
A3	50	81.64±1.9	34200±306	6.81±0.06
A4	50	83.85±3.1	40000±313	6.79±0.03
A5	50	86.15±2.4	43400±297	7.67±0.04
N1	50	77.23±2.3	29800±162	7.29±0.06
N2	50	80.94±1.8	28300±254	7.26±0.05
N3	50	82.78±2.7	34100±330	6.91±0.05
N4	50	83.22±1.4	38900±190	7.07±0.04
N5	50	84.03±1.5	41300±145	7.50±0.07

3. Results and Discussion

Total biogas production and methane content are shown in Fig. 2. A1 and N1 are fed only with cattle manure and the only difference between them is the stirring speeds. After 80 days, 9540 ml and 7810 ml biogas were obtained from these reactors, respectively. As a result, 22% more biogas was obtained from A1. Moreover, as shown in table 4, maximum methane content was found 70.3% in A1 and 66.7% in N1. Considering this data, the stirring speed of 100 rpm has a positive effect on biogas yield and methane content. In addition, the biogas yields of A1 and N1 were 248.95 mL/gVS, 203.81 mL/gVS, and methane yields were 175.01 mL/gVS, 135.94 mL/gVS, respectively. The obtained biogas yield is between 200-300 mL/gVS in Brachtl (2000) and Thome-Kozmiensky (1995) studies [30-32].

A2 and N2 are composed of 75% cattle manure and 25% tea wastes. Total 12005 ml biogas from A2 and 9630 ml biogas from N2 were obtained in 80 days. A2 has 24.67% more biogas yield than N2 which has the same substrate ratio with different stirring speed, and 25.83% more than A1 which has the same stirring speed but different substrate ratio. In addition, methane contents A2, A1, N2 obtained from Table 4 were 77.1%, 70.3% and 57.2%, respectively. Within the context of this data, co-fermentation of 75% cattle manure and 25% tea waste were found to provide more methane content than anaerobic fermentation of only cattle manure as described in literature.

Total biogas production of A3-A4-A5 are 1320ml, 1290ml, and 1170 ml, respectively as shown in Figure 2. Besides, the production for N3-N4-N5 are 1395ml, 1090ml and 720 ml, respectively.

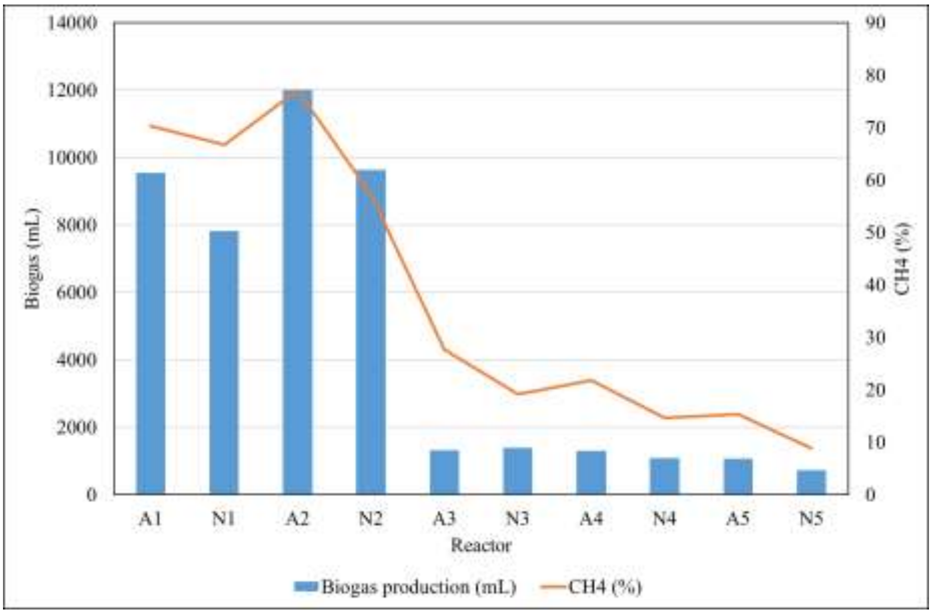


Fig 2. Total biogas production and methane content

Table 4. Final Characteristics of reactors

Reactor	pH Initial	pH Final	Biogas Yield (mL/gVS)	CH_4 (%)	CH_4 Yield (mL/gVS)	COD Removal (%)
A1	7.04±0.08	6.97±0.02	248.95±17.2	70.30±2.8	175.01±4.9	75.9
A2	7.40±0.05	7.28±0.04	296.89±18.4	77.10±3.1	228.90±9.1	68.3
A3	6.81±0.06	5.09±0.05	32.33±6.4	27.70±2.2	8.73±4.3	65.1
A4	6.79±0.03	5.39±0.08	30.76±4.2	21.80±1.8	6.70±2.1	67.6
A5	7.67±0.04	5.60±0.09	27.16±3.8	15.30±2.4	4.15±3.2	64.2
N1	7.29±0.06	7.06±0.04	203.81±15.8	66.70±2.8	135.94±6.1	84.1
N2	7.26±0.05	6.98±0.06	238.16±19.6	57.20±3.1	135.75±8.0	77.3
N3	6.91±0.05	5.44±0.07	34.17±5.8	19.20±1.7	6.50±3.3	62.1
N4	7.07±0.04	5.44±0.05	25.99±5.6	14.70±1.3	3.82±1.2	68
N5	7.50±0.07	5.56±0.08	16.71±4.4	8.90±2.3	1.48±0.7	65.1

In addition, the biogas methane content was 27.7%, 21.8%, and 15.3% for A3-A4-A5, 19.2%, 14.7%, and 8.9% for N3-N4-N5, respectively. Comparing the biogas and methane yields of A3 and N3, the stirring speed (100 rpm) was found to be a positive input for methane content but it has some drawbacks- for biogas production. Depending on the comparison between A4 and N4, 100 rpm stirring speed plays an important role on biogas production and methane content. Moreover, the same results were obtained in A5 and N5. According to the results, in the A3-A4-A5 and N3-N4-N5 where the mixture of tea wastes in the reactor were more than 25%, biogas production reduced an excessive amount. Kondo et. al [16] was specified that polyphenol and tannin in the tea have antimicrobial properties. Therefore, it is considered that microorganism was inhibited by high tea waste content. COD removal efficiencies were also investigated as a result of the experiment. COD removal ratios are between 84.1% and 62.1%. The highest COD removal was obtained at N1 and A1, in contrast the lowest was at N3 and A5.

The A1-2, N1-2 provided biogas production up to the end of 80 days, while the A3-4-5 and N3-4-5 produced very small quantities after 25th day, as seen in Fig.3 and Fig.4. The A1 and A2 reached the highest daily biogas production values between the 30-40th days. In the following days, the A2 typically produced more daily biogas than the A1 and produced more total biogas than A1. The similar results have been observed with N1 and N2. N1 reached the highest daily biogas production values between 25-30th days and N2 reached between 10-15th days. After 25th day, N2 produced more daily biogas than the N1 and produced more total biogas than N1.

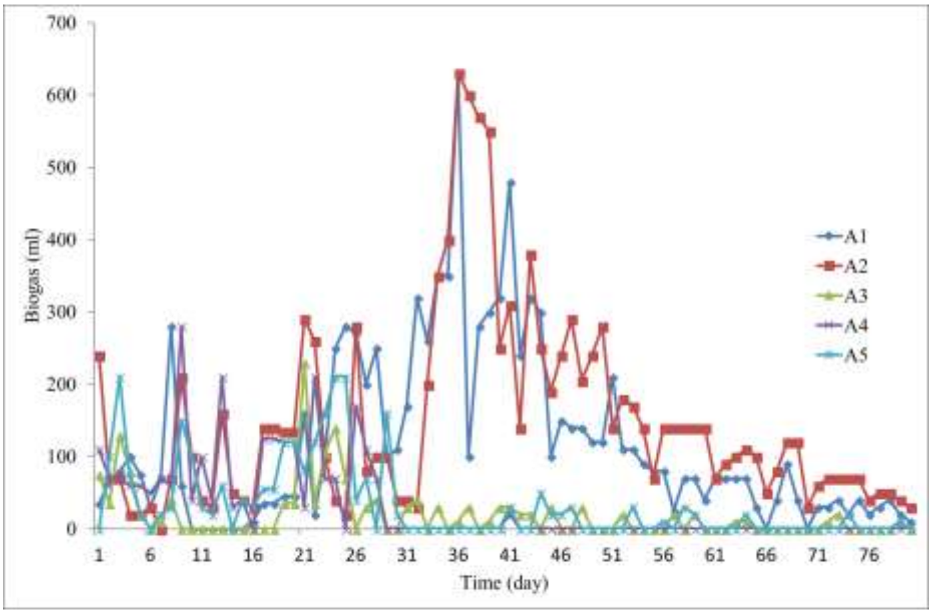


Fig 3. Daily production of A reactors

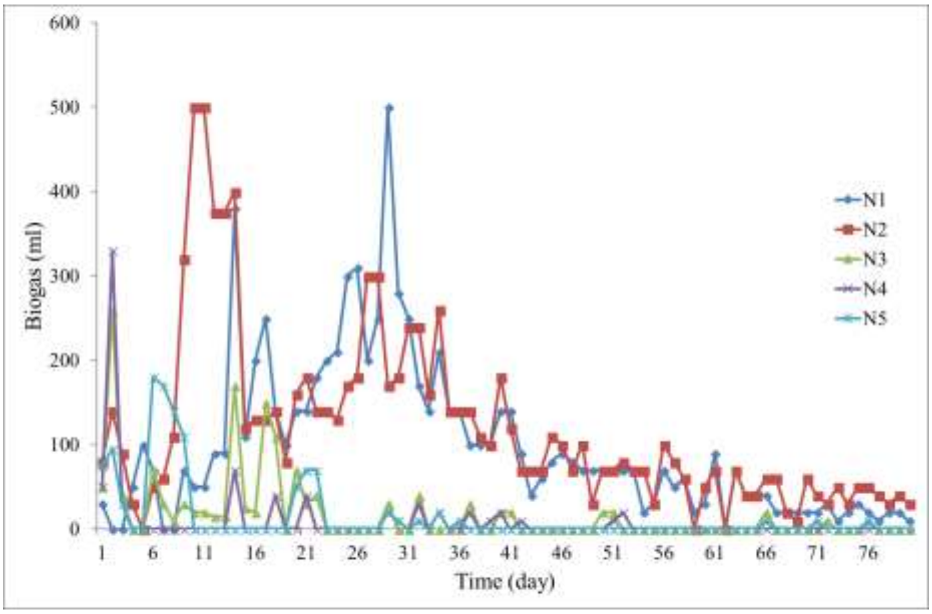


Fig 4. Daily production of N reactors

Although initially the reactor pH was regulated by adding NaOH, the pH reduced in the following days when the amount of tea was increased in the mixture, then the methanogenic microbial community disappeared. Keeping the pH value at the desired value by continuous chemical addition brings extra cost and therefore the applicability is to be reduced. The results show that the anaerobic mono-fermentation of the tea waste and the biogas yield are inefficient. Better biogas yield and methane ratio can be obtained by co-fermentation with cattle manure. For this reason, the optimum mixing ratio obtained for 25% tea waste, %75 cattle manure. In addition, economic and environmental benefits are provided from a household organic waste produced and consumed in large quantities.

4. Conclusion

The use of biogas as a renewable energy source has gained serious importance in recent years. Developed and developing countries are investing in biogas and are doing research to increase the amount of biogas that could be produced from the unit mass. There are many different ways to increase the amount of biogas. One of them is the co-fermentation method. In this study, co-fermentation of tea wastes with cattle manure was studied As a result of the experiments, 25.83% more biogas yield and more methane content were obtained from the A2 reactor (25% tea waste - 75% cattle manure) compared to the A1 reactor (100% cattle manure) under the same working conditions. The effect of stirring speed on the biogas production was also investigated and it was observed that 24.67% more biogas yield was obtained when the A2 and N2 reactors were compared. Beside this, economic and environmental benefits are provided from the waste disposal.

Acknowledgements

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