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Biogas Production Enhancement from Mixed Animal Wastes at Mesophilic Anaerobic Digestion

Falah F. BaniHani*, Ahmad Qasaimeh**, Mohammad R. Abdallah/ Qasaimeh***
*(Department of Chemical Engineering, Al-Huson University College/Albalqa' Applied University, Jordan)
** (Department of Civil Engineering, Jadara University, Jordan)
***(Departments of Civil and Environmental Engineering, College of Engineering at Al Lith, Umm Al-Qura University, Saudi Arabia)

ABSTRACT
In this work, the effect of mixing ratio of cattle dung (CD) and poultry droppings (PD) on biogas generation was determined. Mixtures of various CD: PD ratios (100% : 0%; 50% : 50%; 60% : 40%; 80% : 20% and 0% : 100%) were prepared, analyzed and then aerobically digested for a period of 40 days. For each mixture, fermentation was carried out in a 20 L capacity digester. Results showed that biogas was obtained from the digestion of CD and PD alone, showing the biogas from CD was several times larger than that from PD. Furthermore, the resulted biogas yields from mixtures were found a function of the CD : PD ratio, the yield from the ratio 80 : 20 was the maximum. Biogas yields from the prepared mixtures were found and arranged from larger to lower in the form of (CD : PD) ratios as follow: 80% : 20%; 100% : 0.0%; 60% : 40%; 0.0% : 100%;50% : 50%. Addition of CD to PD enhances the PD production of biogas, while addition of a small portion of PD to CD gave the maximum yield, a result not determined in literature. In other hand, larger additions of PD to CD reduced the biogas yield. The effect of pH was also determined and found better around 7.0. These results are in agreement with research work in literature.
Keywords- biogas generation; mixing ratio; anaerobic digestion; cattle dung; poultry droppings.

I. Introduction

Energy has always been a driving force for a successful farming system. At present, government policy is to minimize fossil fuel use and shift to clean renewable energy. Research work in this line needs attention. Biogas is a renewable energy derived from organic matter, primarily cattle dung or any other agro-residue. It is used in cooking, lighting, running irrigation pump sets and in electricity generation. The need for alternative renewable energy sources from locally available resources cannot be over emphasized. Appropriate and economically feasible technologies that combine solid waste and wastewater treatment and energy production can simultaneously protect the surrounding water resources and enhance energy availability[1,2,3]. Biogas technology in which biogas is derived through anaerobic digestion of biomass, such as agricultural wastes, municipal and industrial waste, is one of such appropriate technology that can be adopted to ease environmental problems and enhance energy production. Biogas, which is a bio-energy produced from a biomass, has several advantages over other forms of renewable energies [4]. The anaerobic fermentation of wastes for biogas production does not reduce its value as a fertilizer supplement, since available nitrogen and other substances remain in the treated sludge [5,6], and most of the pathogens are destroyed in the process of anaerobic digestion [7]. Several researches undertaken in anaerobic digestion of wastes in developed countries have shown technical feasibility of digestion of these wastes. However, their studies in most often involve regulation of temperature [8,9], pH adjustment [10], pretreatment of waste [11] , and use of sophisticated digesters. Of all the forms of solid organic waste, the most abundant one is animal dung primarily from small farms, and mainly ones that have pollution problems originating from more tense waste disposal. Research continues to focus on the treatment of cattle dung for biogas production with possible optimization methods, which can be used to enhance the production for practical applications in technology. Omar et al.[12] observed an improvement in biogas yield up to 0.207 m3/ kg VS added with average methane content of 65% in the anaerobic treatment of cattle manure by addition of palm oil mill effluent in a laboratory scale bioreactor. In another study, Ounaar [13] obtained biogas production of 26.9 m3 with an average methane content of 61% during the anaerobic digestion of 440 kg of cow dung with an energy equivalent to 164.5 kWh. These results are encouraging for the use of animal waste available to produce renewable energy and clean environment. According to [14], decomposition of 1 MT of grass waste can possibly release 50 - 110 m3 of carbon dioxide and 90 -140 m3 of methane into the atmosphere. Methane is an important greenhouse gas with the ability of global warming around 25 times greater than that of carbon dioxide, and its atmospheric concentration has been increasing in to a range of 1 - 2% per year [15]. Conventional municipal solid waste (MSW) management has been mainly disposal by land filling[16]. However, waste from landfills has been identified as the major source of anthropogenic methane emission and an essential contributor to global warming [15]. Therefore, the increased production of MSW accompanied with environmental and economic difficulties facing the conventional methods of disposal have resulted in great efforts to find alternative methods of disposal [16]. The most promising alternative to incinerating and composting of these solid wastes is to digest its organic matter employing the anaerobic digestion [17]. Anaerobic digestion for biogas production has become a worldwide focus of research, because it produces energy that is renewable and environmentally friendly. Special emphasis was initially focused on anaerobic digestion of MSW for bioenargy production about a decade ago [18,19]. Anaerobic biological treatment can be an acceptable solution because it reduces and stabilizes solid wastes volume, produces biogas comprising mainly methane, carbon dioxide and traces amount of other gases [20]. In addition to biogas, a nutrient-rich digestat is also produced which provide either fertilizer or soil conditioner properties. Biological treatment of MSW to biogas by anaerobic digestion processes including source and mechanically sorted MSW has been previously discussed [21]. Biogas generation from biomass has been researched by various scientists such as that focused on the quantity and quality of biogas generated from several plant and animal wastes. A number of researchers [2, 4, 22, 23] focus on the generation of biogas from a particular waste type presupposing adequate availability of such waste type for sustainable biogas generation to satisfy the energy demand. More often, most people in need of this type of technology do not have enough particular type of waste to sustain and satisfy their energy needs. Thus, for such people, a need arises for a combination of whatever waste types available at any particular time to produce a biogas for their daily energy requirement. To fulfill this need, some scientists have carried out various researches on the effect of combining various types of wastes on biogas generation. Some researchers such as Kalia and Singh [19] could generate biogas from a combination of cattle and horse dung, while others studied biogas generation from piggery manure and POME (palm oil mill effluent) combination. In other hand, Iortyer [24] experimented on partially substitution of cattle dung with poultry droppings. They found the generation of biogas to be satisfactory and in the following order: biogas from cattle dung is larger than that from mixture, and biogas from mixture is larger than that from poultry droppings [25, 26]. Based on what experimented by Iortyer [24] using only one mixing ratio, therefore, the objectives of this research are to optimize the production of biogas from a mixture of cattle dung and poultry droppings at different mixing ratios, and to determine the effect of mixing ratio of poultry droppings and cattle dung on biogas generation.

II. Materials and Methods

Poultry droppings PDs and cattle dungs CDs used in this research work were randomly collected from commercial farms in north Jordan. The PDs were taken a farm few kilometers far from Irbid city in north Jordan, while CDs were taken from A-dulel cattle ranch in A-dulel town. The fresh substrates were taken immediately to Laboratories in Al-Huson University College for analysis. The main determined parameters were moisture content (MC), total solid (TS), volatile solid (VS), total Kjeldahl nitrogen (TKN), carbon content (CC) and pH. Weights of 5kg of mixed CD with PD were prepared in the following ratios: 100% CD : 00% PD; 60% CD : 40% PD; 50% CD : 50% PD; 20% CD : 80% PD; and 00% CD : 100% PD. These 5 kg prepared weights were then mixed with equal weights of water giving total samples, each having 10 kg with a ratio of 50:50 (w/w). These samples were then fed into five identical cylindrical metallic anaerobic digesters (reactors). Each digester has a height of 55 cm and a diameter of 27.5 cm of an effective capacity of 25 L. Each reactor had an appropriate port for feeding at top and an effluent port for discharge at bottom worked with the 10 kg samples for a period of 40 days to determine the effect of mixture ratio. The body of the digester contains a stirrer for the mixing of the substrate to enhance gas production. An exit pipe is provided at the top of the smaller cylindrical portion of the digester for biogas collection and measurement. Other materials used for the experiment include graduated transparent bucket and measuring cylinder for measuring the volume of gas production, hosepipe, thermometer, digital pH meter. The 100% CD : 00% PD and 00 % CD : 100 % PD are single substrate digestions used as data baseline as recommended by [4,27]. The prevailing temperature range was 24 to 34°C during the period of study. The experiment was conducted at uboptimum condition (ambient temperature without any form of temperature regulation, pH adjustment, pretreatment of substrates etc.). Volume measurements of biogas produced were done by water displacements. The method used was adopted from [4, 26]. Biogas production was monitored and measured for 40 days. Each experiment was repeated twice and the average values obtained were taken in the research work. Digital pH meters were used to measure the pH of the digesting slurries every seven days intervals. The ambient temperature was measured using respectively a maximum and minimum readings at 12.00 p.m and 12 a.m. The initial MC was determined using the oven-dry method at a temperature of 103 ± 2 oC for 24 h using equation (1), while TS was computed using equation (2) as shown below,

$$MC(\%)=\frac{(W_i - W_f)\times 100\%}{W_i} \quad (1)$$

$$TS(\%)=100-MC(\%) \quad (2)$$

where, W_i is initial weight and W_i is final weight. Initial pH, carbon (%) and nitrogen were determined before digestion. The percentage carbon was determined using the Walkley-Black method and percentage nitrogen by the micro-Kjiedhal method [4,28]. The prevailing temperature range was 28ºC - 35ºC during the period of the study. More details on the experimental setup can be found elsewhere [4]. The results of the analysis are shown in tables.1, 2 and 3.

III. Results and Discussion:

In this work, experimentation was started on finding out the composition of the substrates. Analysis for PD and CD were performed to find out the MC, TS, VS, TKN, CC and pH values. Result of this analysis is shown in (Table.1). For the important pH effect on digestion process and biogas rate, the pH values of the substrates were also determined at seventh day during digestion and are shown in (Table.2). In literature, many research work on anaerobic digestion of waste showed that pH of substrates has a strong influence on the production rate and yield of biogas from substrate. The methanogenic bacteria are known to be very sensitive to pH. The pH of the substrates was measured on the seventh day of digestion in accordance to [26], pH is an indicator of system process stability of anaerobic process. The values of the pH of the substrates determined in this research (Table.2) fall within the range of 6.5 to 7.2, which is the optimum pH for anaerobic digestion. In the absence of some other indicator, the pH value alone has been used to check the digester environment and gas production is often the highest when the pH is between 7.0 and 7.2 [26, 27]. Beyond these limits, digestion proceeds with less efficiency. When the pH falls to 6 and below, the efficiency drops rapidly during the acidic conditions, which become inhibitory to methanogenic (methane producing) bacteria. While at pH(= 7.0) there is a balance in the population of the acidogenic (acid producing) and methanogenic bacteria, which help to convert the acids generated during anaerobic Digestion into biogas . The digestion of these wastes was carried out progressively without any noticeable inhibition.

Table 1. The composition of the substrates

Composition	**Poultry dropping**	**Cattle dung**
Moisture Content MC (%)	57	68
Total Solid TS (%)	38	21
Volatile Solid VS (%)	12.2	14.8
Total Kjeldahl Nitrogen TKN (mg/g)	9.5	3.1
Carbon Content CC (%)	5	11.4
pH	7.2	6.8

Table 2. Mean pH values of the cattle dung CD and poultry droppings PD mixtures on 7th day of digestion.

Digester CD : PD	100% : 0%	50% : 50%	60% : 40%	80% : 20%	0% : 100%
PH	6.8	6.6	7.0	6.5	7.2

Table 3**.** The C:N ratio of CD and PD.

Waste type	**Replicates**			
	1	2	3	Mean
100:0 mixture of cattle and poultry droppings	11:1	14.6:1	10.6:1	12.2:1
0:100 mixture of cattle and poultry droppings	8.6:1	9.3:1	10.6:1	9.5:1

Table 4. Summary of biogas yield (in L/kg TS) from the mixtures of the cattle and poultry dropping

Waste Type	**Min/Max. Temp. Tc**	**1 (L/kg TS)**	**Replicates 2 (L/kg TS)**	**3 (L/kg TS)**	**Mean (L/kg TS)**
100:0 mixture of CD : PD (cattle dung only)	24-28	2.340	2. 318	2.231	2.251
0:100 mixture of CD : PD (poultry droppings only)	25-30	1.726	1.853	1.935	1.837
50:50 mixture of CD : PD	24-27	1.612	1.509	1.883	1.668
60:40 mixture of CD : PD	24-29	2.173	2.030	2.271	2.158
80:20 mixture of CD : PD	25-28	2.712	2.894	2.849	2.823

Analysis of nitrogen N in CD and PD were performed and shown in (Table.3) in a form of Carbon to Nitrogen ratios (C:N). The mean C:N ratios for CD and PD were 11.4 and 9.5 respectively. The C:N ratio for CD (11.4) was between 10:1 and 30:1, which is the favorable range for microbial action [26] while that for PD (9.5) was slightly below this range. This may have contributed to the lower gas yield from the poultry droppings. The microbial population involved in bioconversion process requires sufficient nutrients in the form of nitrogen and carbon to grow. If the nitrogen is not enough, the bacteria will not be able to produce the enzymes needed to utilize the carbon. While when there is too much nitrogen, especially in the form of ammonia, it can inhibit their growth [4, 24, 27]. The optimum ratio of C:N given by Hawkes [29] is between 20:1 and 30:1. From the summary of the average values of the measured day minimum and maximum temperatures during the 40 detention days (Table 4), the temperatures were ranged from 28 0C to 35 0C with temperature fluctuations in the range of 3 0C to 5 0C. All these temperatures were within the mesophyllic range and their fluctuations were within a range not not to cause an adverse effect on biogas production[4,30].

The total mean biogas yield for the mixture ratios of the CD and PD are shown in (Table. 4). It can be seen that the total mean biogas yield of mixture ratio was in the following order: 80% CD : 20% PD > 100% CD : 0% PD > 60% CD : 40% PD > 50% CD : 50% PD > 0% CD : 100% PD. Generally, as the proportion of poultry droppings increased in the mixture, the biogas yield decreased. This is because the mixture ratio of 0% CD : 100% PD (poultry droppings only) gave a biogas yield lower than that of the mixture ratio 100% CD : 0% PD (cattle dung only). Therefore, the more it was contained in the mixture the less total mean biogas yield produced. This differs from the results obtained by [4], who reported a higher yield of biogas from the anaerobic digestion of cattle dung. However, the mixture ratio of 80% CD : 20% PD which gave the highest total biogas yield appeared to be the optimum ratio at which cattle manure can be mixed with poultry droppings to produce biogas that could surpass even the amount produced by the cattle dung alone.

As shown in (Fig.1), the first gas production values were recorded on the 5th day for the cattle dung only, while for the mixtures 50% CD : 50% PD, 60% CD : 40% PD, 80% CD : 20% PD and poultry droppings only were recorded on the 3rd, 4th, 1st and 2nd days respectively. The highest daily mean biogas yield value on any day of the 40-day detention obtained from 80% CD : 20% PD mixture (0.198 L/Kg TS), while the next highest value (1.88 L/Kg TS) was obtained from the cattle dung. The lowest value (1.32 L/Kg TS) was given by the mixture 50% CD : 50% PD.

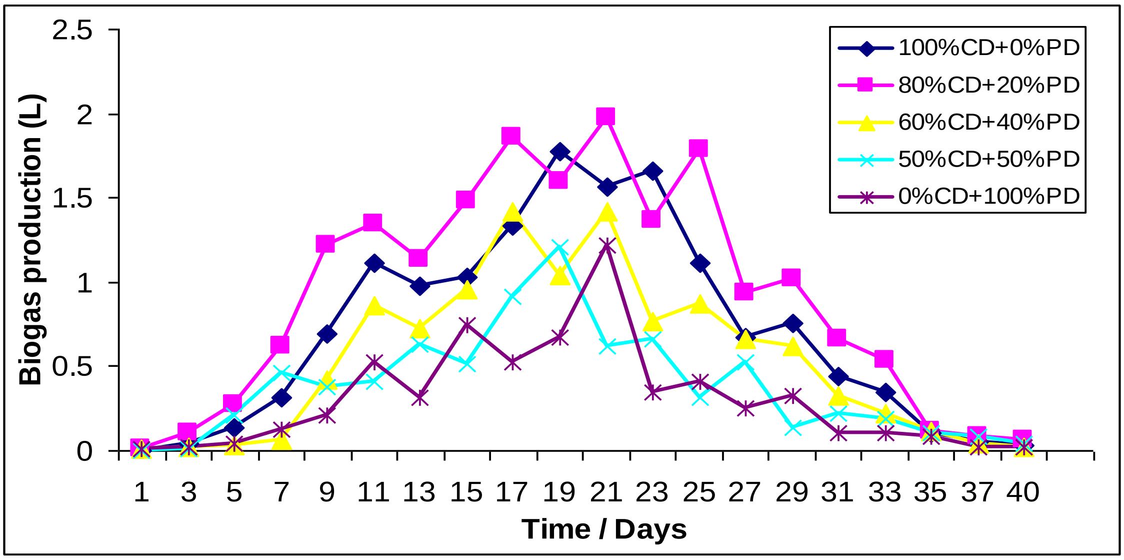

Figure 1. Effect of the mixture ratios of cattle dung CD and poultry droppings PD on mean daily biogas yield

During the first 5 days of (CD : PD) digestion (Fig.2), gas production of the different mixing ratios are seen and the 0% CD : 100% PD (poultry droppings alone) digestion showed the highest biogas yield. This agrees well with [31], who reported that poultry dropping waste degrades faster than cattle dung waste. However on 10th day, the 100% CD : 00% PD digester (cattle dung alone) took the lead by producing a total biogas yield in comparison to 0% CD P : 100% PD digester. This lead is seen continued during the 40 days period. This confirms in this work the ability of the cattle dung CD to produce more biogas than poultry dropping PD with time. Among all Digesters, the one having the 80% CD : 20% PD showed the highest total volume of biogas production. This is slightly higher than the biogas produced by the digester having the 100% CD : 00% PD. In other hand, the digester having the 60% CD : 40% PD produced lower total volume of biogas but is still higher than the biogas produced from the digesters having the 0% CD : 100% PD and 50% CD : 50% PD respectively.

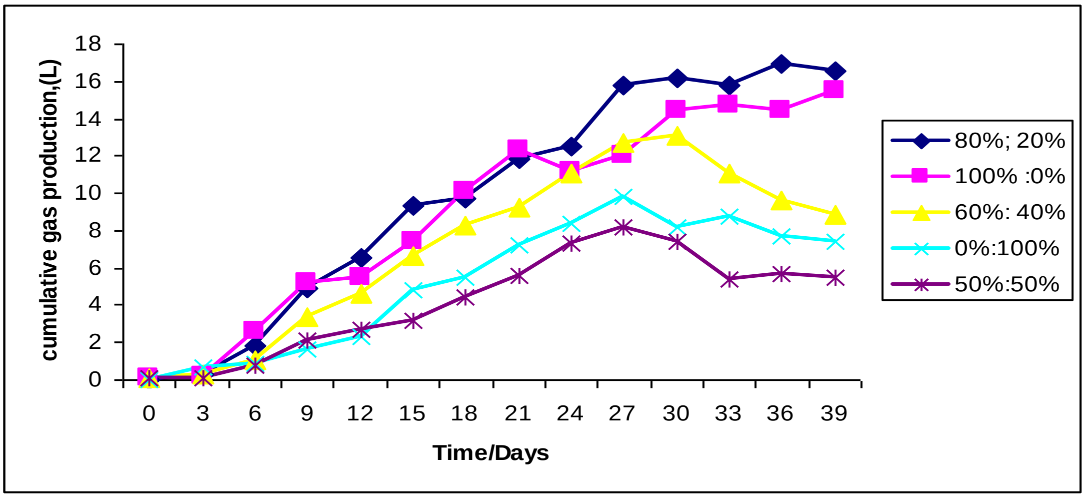

Figure 2. Cumulative biogas yield of cattle dung with poultry dropping with their mixing ratio

From the beginning and to the end of the 40 days during the experiment (Fig.1), the digester having the 100% CD : 00% PD after maintaining maximum experienced a great decline in gas production in the end part of the experiment. This shows the tendency of the 80% CD : 20% PD digester to produce more gas than the single substrate digestion of cow dung CD with time; here addition of 20% PD enhanced the CD production of biogas. While more addition of PD with CD reduces the biogas production, an example is the 50% CD : 50% PD digester, showing the least gas yield but still better than the 0% CD : 100% PD yield. For all used ratios of (CD : PD) in digesters (Fig.1), production of biogas is shown maximum in the period between 15 to 27 days with time. The order of gas production for the CD : PD ratios is resulted as follow: 80% CD : 20% PD > 100% CD : 0% PD > 60% CD : 40% PD > 00% CD : 100% PD > 50% CD : 50% PD.

IV. Conclusion

Mixing of cattle dung and poultry droppings have generally increased the biogas yield compared with the biogas yields from pure cattle dung and poultry droppings. The potentials of the maximum biogas production from the cattle dung and poultry dropping mixtures are found in the following order: 80% CD : 20% PD > 100% CD : 00% PD > 60% CD : 40% PD > 50% CD : 50% PYD > 00% CD : 100% PD. The maximum biogas yield is attained with mixtures with a ratio of 80% CD : 20% PD, while the second is pure CD (100% CD : 00% PD). Such result indicates that addition of small portions of PD to CD enhances the CD production of biogas. In other hand increases in CD addition to PD enhances the PD production of biogas until reaching the 80% CD : 20% PD ratio. Pure PD gives the minimum biogas production, while pure CD needs a small portion addition of PD. This in a long way not only solves the problem of adequate energy lack for poor rural, but also helps in maintaining the safe and clean disposal of such waste. However, longer digestion detention periods may be required at other conditions, because gas production has not ceased for the digesters, especially for the 20% CD : 80% PD digester. This can be left to further research work.

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