Investigation Yield and Energy Balances for Biogas Production from Cow and Poultry Manure

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Abstract- Today the energy dilemma is one of the most serious problems of the world, particularly in the developing countries. The idea of using renewable and local energy sources is a new solution suggested to get rid of the dilemma. Therefore, this study aims to examine the effect of loading rate, temperature, stirrer, both single and co-digestion of feedstock on biogas function and energy efficiency ratio. In this study we used an industrial scale anaerobic digester (capacity: 925 lit.) with the retention time of 12 days. Tests were performed in 24 various treatments. Results gained from feeding the digester with the cow dung in 35°C through different loading rates with and without stirrer showed that the highest rate of biogas was developed in loading rate of 1/4 along with a stirrer. Likewise, results gained from various feeding processes with the loading rate of 1/4 showed that the highest biogas amount produced by treatment I2 (36-40°C, with the stirrer), with about 950 lit/day, and the most efficient energy rate was developed through treatment J2 (36-40°C, with the stirrer), with about 3.9 MJ. Feeding the digester with both cow dungs and poultry droppings (ratio: 1:2) in the mesophyll temperature using a stirrer with the loading rate of 1/4 is the best mode for producing biogas in terms of both energy efficiency ratio and a sustainable biogas production record.

Keywords- Anaerobic digester, Biogas, Energy efficiency, loading rates

1. Introduction

Today the energy dilemma is one of the most serious problems of the world, particularly in the developing countries. The idea of using renewable and local energy sources is a new solution suggested to get rid of the dilemma. As a biological method for treating the biodegradable wastes, anaerobic digestion is able to produce eco-friendly materials and recover energy which makes the technique to play an important role in refinement and the use of wet and very biodegradable wastes [1]. Function of anaerobic microorganisms in excreta of dairy and beef cattle, pigs, laying hens in the southern United States region in 1980 produced 582 x 10^6 m^3 methane valued at 141-446 million USD; it was increased to about 0.34 to 1.08 billion USD by 1990 [2]. The potential of methane production in Iran through anaerobic technology has been estimated to about 9300 million m^3 in 1996, where 1000 million m^3 is garbage with a large portion including livestock excreta and plant waste produced by animal husbandry and agricultural activities. Iranian broiler and breeder poultry farms produced 852000 tons poultry litter in 2000 [3]. The direct use of them in farmlands and orchards of the country may cause certain diseases; or depositing them for decay purposes may produce and emit methane and CO_2 gases across the atmosphere which may in turn damage the Ozone layer. While relying on the anaerobic technology not only protects the planet against the mentioned hazards, but also, it can produce about 54 million m^3 biogas as a source of energy [4]. Effective use of energy in agricultural activities will scale the environmental problems down, will protect natural resources and will develop the sustainable agriculture as an economical producing system [5]. Increasing energy efficiency and taking advantage of the renewable energy resources are effective in improving the air quality and reducing emission of the greenhouse gases. Another outcome of the increased energy efficiency is the decrease in operational costs and any cost that may be caused through producing agricultural crops [6]. Improving the efficiency of the agricultural systems using lower energy resources for producing crops will be helpful in decreasing the emission rate of the greenhouse gases [7]. Therefore, using of the energy resources is a very important issue, the importance of which has been doubled because of the increased energy demand caused by the improving technological condition and the increasing demands of human beings. This study analyzes the function and energy efficiency in producing biogas from cow and poultry manure.

2. Material and Method

A. Designing Digester

The digester designed in this study was a baffled two-stage plug-flow digester, the dimensions of which were as follows: Capacity: 925 lit, diameter: 58 cm and length: 3.5 m; the length to diameter ratio of digester was about 6:1 which is observed usually in the plug-flow systems. Two thermometers were prepared for measuring the temperature, one was placed at the beginning just after the feed entrance valve and another was placed at the end just after the second baffle of the digester. A manometer was placed just after the second baffle for measuring the system's pressure. What makes the plug-flow digester excellent is the aggregation of more sludge masses across the horizontal layer. A cross-sectional retrograde pump was used to compensate the reduced contact between the sludge and the effluent. Making the least turbulence in the system was the key advantage for choosing the pump. To do so, an open vane pump (1500 rpm) designed for circulating liquids with high viscosity was used. Initially the feed is entered the first chamber and after being digested by the anaerobic microorganisms, the produced biogas is left the gas outlet connected to the contour and then the fixed materials leave the reactor outlet. A filter was used to prevent the entering of the aerosols along with gas, water and foam to the contour. Figure 1 shows our manufactured digester.

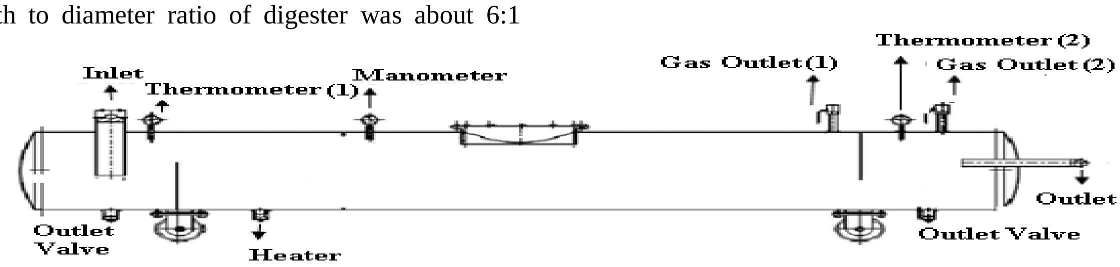

Fig. 1. Schematic of the digester

B. Experiments

The experiments were conducted in Tehran University Agriculture and Natural Resources Complex of Iran with the aim of producing biogas in various conditions and comparing the consumed energy and function. The experiments were as follows:

1. Producing biogas from cow dung in different loading rates in mesophyll temperature condition with/without stirrer.
2. Producing biogas from cow dung, poultry droppings and a combination of them in different conditions.

C. Conditions of the First Examination

At the beginning of each loading, the required fertilizer packs were prepared from a farmland within 5 km of the digester location using a car with fuel consumption of 0.09 L/day. Someone was tasked with the feeding the digester daily with a combination of water and caw dung with different ratios. The retention time and temperature were put at 12 days and 35°C, respectively. The quantities of total solids, volatile solids and pH were measured every day. To measure total solids (TS) a certain amount of the sample was taken and then poured into a weighted empty (W_1) and dried crucible. Then in order to desiccate the sample completely, the crucible containing the sample was put in the furnace set in 105°C. The crucible containing the dried sediment was weighted (W_2). The following equation was used to measure the TS value (L^{-1}).

$$\text{TS (mg L}^{-1}\text{)} = \frac{w_2 - w_1}{v} \quad (1)$$

For measuring the volatile suspended solids (VS), the crucible containing the sample (W_1) used for measuring the TS value was kept in the furnace set at 505°C for 3 hours in order to create ash. Crucible containing the weighted ash (W_2) was prepared and the following equation was used to measure the volatile suspended solids concentration:

$$\text{VS (mg L}^{-1}\text{)} = \frac{w_2 - w_1}{v} \quad (2)$$

D. Conditions of the Second Examination

Regarding the results gained from the first set of tests, the total solid amounts were considered 20% in the second set of examinations. To prepare this amount of the total solids, a certain amount of water was mixed with the excreta according to the following equations [8]. Since most parts of Iran have temperate climate, the examination was conducted at the range of 25-40°C. According to a daily manner the digester was fed with 50 liters feed, of which 35 liters were fresh and the remaining 15 liters were returned back from the digester outlet to the inlet for stirring the material in the digester and 35 liters were directed to outside.

Fresh discharge (kg day^{-1}) = Cow dung (m^3 day^{-1}) × Cow dung density (kg m^{-3}) (3)

Total solids (TS) of fresh discharge (kg day^{-1}) = Fresh discharge (kg day^{-1}) × Total solids (% fresh discharge) (4)

Assuming 20% concentration of TS in influent manure;

Total influent (kg day^{-1}) = Total solids of fresh discharge (kg day^{-1}) × $\frac{100}{20}$ (5)

Required water (kg day^{-1}) = Total influent (kg day^{-1}) - Total solids of fresh discharge (kg day^{-1}) (6)

F. Designing and Manufacturing a Circuit

Using Edison, version 4, a circuit was designed and manufactured to measure the heater's required energy. The circuit was equipped with a timer that showed how long the heater has been worked during the past 24 hours. The daily consumed energy amount was measured regarding the heater's consumed power. Figure 2 shows the circuit's features.

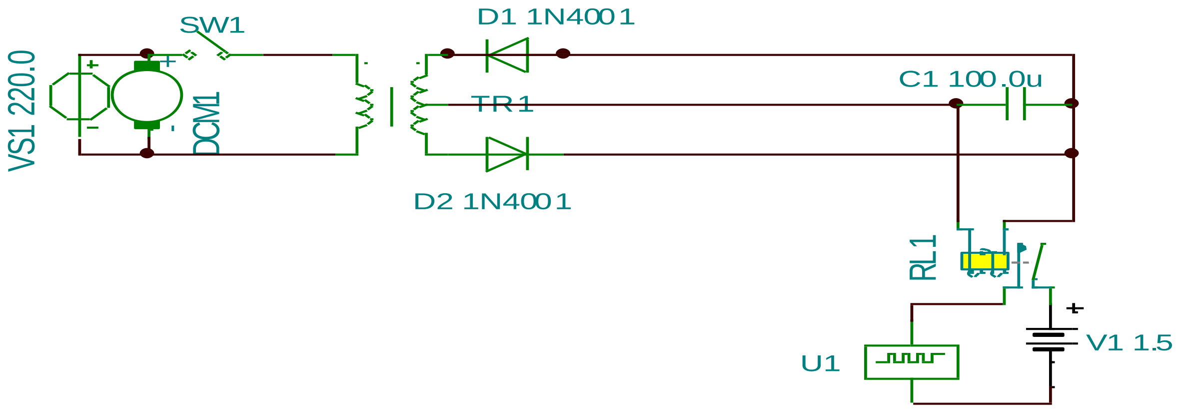

Fig. 2. Being on heaters hours a day

G. Energy Flow in the Biogas Production Machine

The inputs used in producing biogas through a digester are manpower, fuel, electricity and animal manure. Outputs of the studied system were the produced biogas and manure. If the input consumption rate and the required energy amount of each unit are known, the values for manpower, fossil fuels, electricity and animal manure can be measured through multiplying each input by the energy amount. Generally, it can be said [9, 10].

$$E_{input} = I_{consumption} \times ec_{input} \quad (7)$$

Where, E_{input} is the amount of consumed energy (MJ), $I_{consumption}$ is the amount of the consumed input (including manpower, fossil fuel, electricity and animal manure) (unit) and ec_{input} is the input content energy (MJ/unit). The required energy for the used inputs was considered using table 1 the required energy for the digester was considered equal to the energy required for pump and heater and the consumed energy in different parts of the digester was underestimated because of its very low amount.

Table 1. Energy coefficients of inputs and output.

type	Unit	Energy coefficients(MJ unit^{-1})	Reference
Inputs			
human labor	h	1.96	9, 10, 25,26,27
Cow manure	kg	0.3	25
Fossil Fuels			
Gasoline	L	46.3	25
Electricity	kWh	11.93	9, 10,25
Outputs			
biogas	m^3	22	25
Cow manure	kg	0.3	25

I. Energy Indices

In this part of the study we studied the energy indices used in the producing system which is treated as one of the most important measurements in energy analysis process. Some of the indices including energy ratio, energy productivity, special energy and net energy gain enable us to get a pervasive understanding on the energy status in agriculture section [11].

$$EnergyRatio = \frac{\text{Energy Output}}{\text{Energy Input}} \quad (8)$$

$$Energy\,\mathrm{Pr}oductivity = \frac{\text{Biogas Output}}{\text{Energy Input}} \quad (9)$$

$$SpecialEnergy = \frac{\text{Energy Input}}{\text{Biogas Output}} \quad (10)$$

Net Energy Gain = Energy Output - Energy Input (11)

J. Data Analysis

Data was analyzed using R2010bMatlab. Treatments (A_1, A_2), (B_1, B_2) and (C_1, C_2) specify feeding the digester with cow dung without and with stirrer in (26-30°C), (31-35°C) and (36-40°C) respectively; and treatments (D_1, D_2), (E_1, E_2) and (F_1, F_2) specify feeding the digester with a mix of cow and poultry manure (ratio: 1:1) without and with stirrer in (26-30°C), (31-35°C) and (36-40°C) respectively; and treatments (G_1, G_2), (H_1, H_2) and (I_1, I_2) specify feeding the digester with a mix of cow and poultry manure (ratio: 1:2) without and with stirrer in (26-30°C), (31-35°C) and (36-40°C) respectively; and Treatments (J_1, J_2), (K_1, K_2) and (L_1, L_2) specify feeding the digester with poultry manure without and with stirrer in (26-30°C), (31-35°C) and (36-40°C) respectively.

3. Results and Discussion

A. Results of the First Examination

pH always plays a significant role in the growth of microorganisms and in determining the sustainability length of digesters. pH of an anaerobic reactor varies with the microorganisms' metabolic activity which will result in the production of CO_2, volatile fatty acids and ammoniac [12]. PHs below 6 and above 8 have inhibitory effects on methanogen bacteria [13, 14]. Keeping pH in 6.8-7.0 range shows the stable function of the digester during the whole process and also shows that it has functioned in the optimum growth condition of methanogen bacteria. Moisture content of solid wastes is a necessary and effective factor in their bio-degradation. Biodegradability of the very biodegradable wastes including food waste is due to their high moisture content [14]. Hence, the idea of adding water or returning the digested sludge to the reactor was suggested to increase the biodegradability of the waste [15]. Diluting the waste with water not only increases the waste moisture, but also enables bacteria to move freely inside the digester which in turn improves the anaerobic digestion process [16]. As mentioned in table 2, the results showed that the digester decreased the loading rates of 1/2, 1/3, 1/4 and 1.5 as large as 80%, 66%, 45%, 37% and 83%, 79%, 67%, 47% respectively in total solids and volatile suspended solids. Comparing figures 3 and 4 suggests that using stirrer enhances the biogas production rate. The results of the study were consistent with the results reported by Stroot et al [17]. and Vavilin et al [15]. They indicated that the fully stirred digesters with a high loading rate suffer from an unstable function, while stirrers with the minimum stirring rate show acceptable functions in all loading rates. Therefore, we stirred the digester for only 1 minute in all daily loading rates; hence more biogas was produced in all loading rates. Decreasing the loading rate down to 1/4 enhanced biogas production and down to 1/5 reduced biogas production; the results were consistent with the other studies in this regard [17, 18, 19, 20]. The reason for the mentioned changes was that in the high loading rates acideogene and methanogen elements cannot function because of absorption of the main products and transmission of the poisonous materials by the solid phase, while in the low loading rates microorganisms are faced with the lack of feed which in turn the biogas production rate is reduced. In this experiment, digester was used for 12 days at 35°C in different loading rates, and finally the highest possible amount of biogas (350 lit/day) was produced in the loading rate of 1/4 using a stirrer.

Table 2. The amount of pH, TS and VS at different loading rates.

Treatment	pH	TS_{in} (%)	TS_{out} (%)	VS_{in} (%)	VS_{out} (%)
loading rate 1/2	6.8	75.5	15.5	54	9
loading rate 1/3	6.9	50	17	38	8
loading rate 1/4	6.9	20	11	15	5
loading rate 1/5	7	8	5	6	3.2

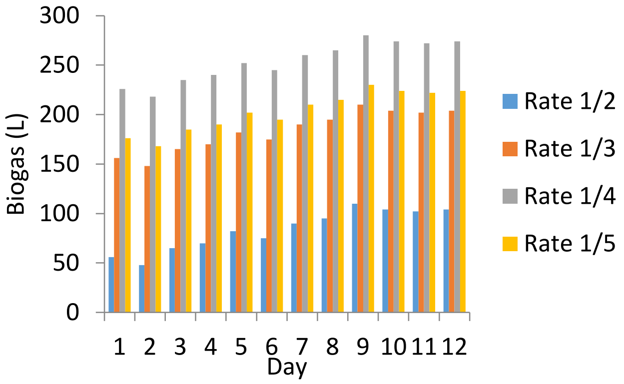

Fig. 3. Biogas yield without stirrer

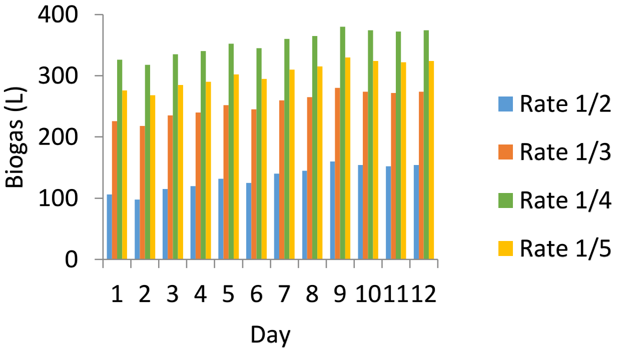

Fig. 4. Biogas yield with stirrer

B. Function Comparison

As figures 5, 6, 7 and 8 show, measurement of biogas production function in feeding the digester with the caw dung indicated that treatment C_2 (36-40°C with stirrer) has the best function among others and it can produce 560 lit/day biogas when the digester achieves a proper stability for producing biogas. The worst biogas production function was associated with the treatment A1 (26-30°C without stirrer), i.e. 80 lit/day. Measuring the biogas production function in the co-digestion of cow and poultry manure with the mixing ratio of 1:1 indicated that treatment F_2, among others, has the best function through producing about 630 lit/day biogas, while the worst function is associated with the treatment D_1 with about 168 lit/day. Measuring the biogas production function in the co-digestion of cow and poultry manure with the mixing ratio of 1:2 indicated that treatment I_2, among others, has the best function through producing about 950 lit/day biogas, while the worst function belonged to treatment G_1 with about 658 lit/day. Measuring the biogas production function in the co-digestion of cow and poultry manure with the mixing ratio of 1:2 indicated that treatment L_2, among others, has the best function through producing about 835 lit/day biogas, while the worst function is associated with the treatment J_1 with about 670 lit/day. The output gas of the digester in all tests could make a flame. As Figure (9, 10) indicates, adding bird droppings to the cow manure made the flame bluer which was due to the increased amount of methane in the biogas produced through feeding the digester with both cow and poultry manure in comparison to the biogas produced through feeding the digester only by cow manure.

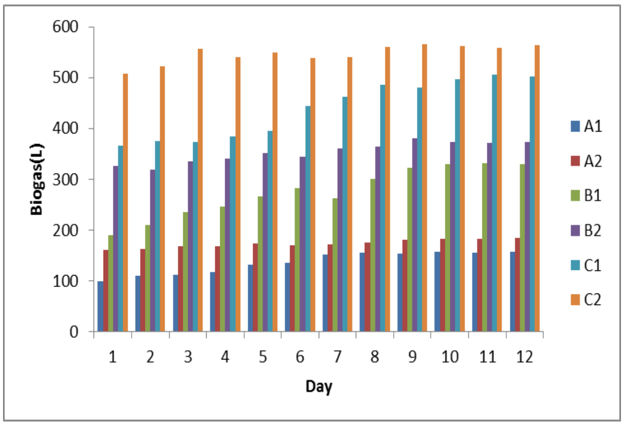

Fig. 5. Biogas yield from cow manure

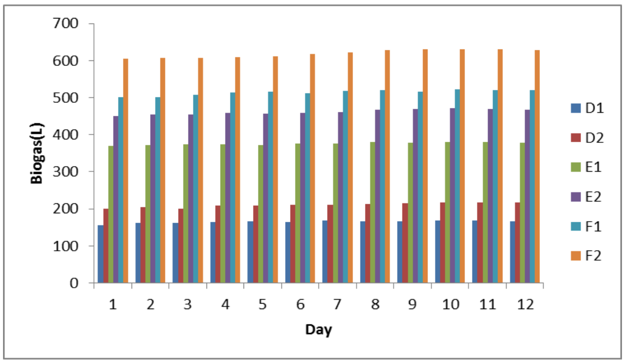

Fig. 6. Biogas yield from cow and poultry manure with the mixing ratio of 1:1

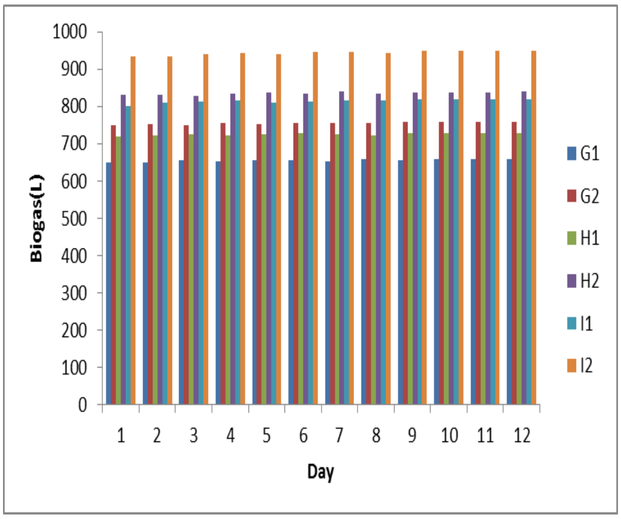

Fig. 7. Biogas yield from cow and poultry manure with the mixing ratio of 1:2

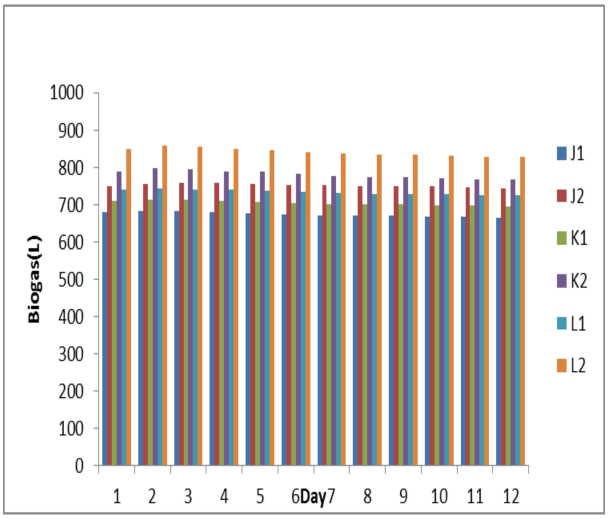

Fig. 8. Biogas yield from poultry manure

Fig. 9. The flame from cow manure

Fig. 10. The flame from cow and poultry manure

C. Comparing Energy Indices

Energy ratio, energy efficiency, special energy and the net added energy were measured through calculating the input and output energy values. According to the results, the use of stirrer increased considerably the produced energy. For instance, as table 3 shows, feeding the digester with the cow manure B_2 is the sole treatment which had more than 1 energy ratio while its energy ratio was decreased to less than 1 when no stirrer was used. According to the results, producing biogas from feeding the digester with only caw dung is not cost effective in terms of energy production. Although increased temperature in all treatments resulted in the increased biogas function, most of the treatments in temperatures above 35°C were not cost effective in terms of producing energy because they were consuming excessive energy for producing a certain amount of biogas. For example, in co-digestion of cow and poultry manure with ratio 1:1, treatments with more than 35°C temperature produced the highest amount of biogas, but since they consumed excessive amount of electrical energy, their energy ratio fell to less than 1. A study showed that the increased temperature enhances the biogas function [21]. In co-digestion of cow and poultry manure with ratio of 1:2, all treatments showed proper energy ratios. According to the results, co-digestion of caw and bird excreta with the ratio of 1:2 was the best mode for producing biogas. Although treatments involved with only the poultry manure showed highest energy ratio compared with other treatments, poultry manure were not sustainable for producing biogas because of their high nitrogen contents. In another similar study, energy efficiency in terms of the life cycle for the biogas systems was analyzed based upon 8 different raw materials. The results suggested that the output pure energy which leaves the biogas system is relatively low regarding the raw materials containing considerable amount of water (e.g. manure) which it was consistent with our results. Likewise, different transportations of the raw materials can alter significantly the input energy of the biogas systems [22]. A study examined the energy efficiency of the industrial hemp used for producing biogas and solid bio-fuel through four various sections, of which combustion had the highest pure energy efficiency and energy ratio. Biogas production section was poor in terms of either the input energy or energy efficiency, but was able to produce products with better quality such as electricity and automobile fuel [23]. Another study examined the energy efficiency of various biogas systems including single and co-digestion of the raw materials. Energy efficiency was significantly influenced by raw materials and transportation modes [24]. As mentioned above, transportation of the raw materials affects considerably the energy ratio. If our digester was in a place where there was no need to transport the manure for the daily consumption anymore, then, the energy ratio would be more than 1 in some other treatments because the fuel energy would be deleted from the consumed energy.

Table 3. Energy indicators

Treatment	Energy Input (MJ Day^{-1})	Energy Output (L MJ^{-1})	Energy Ration	Energy Productivity (MJ Day^{-1})	Specific Energy (MJ L^{-1})	Net Energy Gain (MJ)
A1	5.70	4.68	0.83	24.22	0.04	-1.01
A2	5.71	5.49	0.97	30.60	0.03	-0.21
B1	8.33	7.74	0.96	34.21	0.03	-0.59
B2	8.34	9.46	1.16	43.44	0.02	1.12
C1	17.11	11.35	0.68	26.25	0.04	-5.76
C2	17.06	13.71	0.82	32.59	0.03	-3.35
D1	5.25	4.93	0.95	31.67	0.03	-1.32
D2	5.29	5.93	1.13	40.08	0.02	0.64
E1	7.41	9.58	1.32	51.91	0.02	2.17
E2	7.36	11.46	1.59	64.26	0.03	4.10
F1	15.63	12.61	0.82	33.46	0.03	-3.02
F2	15.64	14.92	0.97	40.30	0.01	-0.72
G1	5.49	15.40	2.81	119.56	0.01	9.91
G2	5.50	17.60	3.21	137.74	0.01	12.11
H1	7.47	16.95	2.30	98.52	0.01	9.48
H2	7.48	19.37	2.63	113.41	0.02	11.89
I1	15.27	18.91	1.26	54.12	0.02	3.64
I2	15.28	21.76	1.45	62.69	0.02	6.48
J1	4.60	16.03	3.50	147.38	0.01	11.43
J2	4.61	17.75	3.88	164.26	0.01	13.14
K1	6.38	16.69	2.67	112.54	0.01	10.31
K2	6.33	17.47	2.81	118.95	0.01	11.14
L1	13.51	17.35	1.30	55.13	0.02	3.84
L2	13.52	18.79	1.41	59.90	0.02	5.27

4. Conclusion

Ranchers and birders in the developing countries encounter a serious problem in disposing the dung of their cow and poultry. A number of ranchers use directly the dung in the farmlands and orchards of the country which may result in transmission of certain diseases across the country; others deposit the dung for decaying in the environment which is led to formation and emission of methane and CO_2 in the atmosphere. It will in turn damage the Ozone layer. While, taking advantage of the anaerobic technology, not only we can eschew the mentioned risks but also we can use the dug for producing biogas as new source of energy. Similarly, the fertilizer produces from biogas can be used as a safe fertilizer in farmlands and orchards. The results of analysis of producing biogas from cow, poultry manure and a mixture of them showed that producing biogas from the cow manure is only cost effective when the energy is produced in 31-35°C with stirrer. By placing the digester in a place where there was no need to transport the manure some more treatments became proper for producing energy. The highest amount of the produced biogas belonged to I_2 with about 950 lit/day while the lowest amount belonged to A_2 with about 80 lit/day. The highest amount of energy was consumed through C_1 treatment, about 17 MJ/day, one reason among other was the high amount of energy consumed by the heater to warm the digester's contents in this treatment. The lowest amount of energy was consumed by J_1, about 4.6 MJ/day. The results showed that poultry manure require less energy for being heated compared with the cow manure because of the heat they emit from themselves. Treatment J_2 showed highest energy ratio (3.9 MJ), while treatment C_1 had the lowest energy ratio (about 0.6 MJ). Therefore, it can be concluded that co-digestion of cow and poultry manure with ratio of 1:2 is the best mode for producing biogas. Although treatments feed by the poultry manure showed highest energy ratio compared with other treatments, but poultry manures were unstable to produce biogas because of their high nitrogen contents.

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