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Effect of Temperature on Anaerobic Co-digestion of Cattle dung with Lignocellulosic Biomass

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ABSTRACT

The objective of this paper is to investigate the effect of temperature on anaerobic digestion of different lignocellulosic biomass such as bamboo dust and saw dust and compare it with the results of fresh cattle dung. Bamboo dust and saw dust were mixed with cattle dung in 1:3 ratio in batch type anaerobic digesters of volume 1000 ml at 35°C, 45°C and 55°C temperatures. At five day interval, 10 ml of digested slurry was taken out from the digesters and tested for total solid and volatile solid contents. Effect of temperature on kinetic rate constant was also studied. It was observed that biogas production increases with temperature. The kinetic rate constant plays a significant role to indicate the digestion process.

Keywords – anaerobic digestion, biogas production, co-digestion, kinetic rate constant, lignocellulosic biomasses.

1. INTRODUCTION

As the cost of petrol and diesel is increasing day by day, development of alternate fuel source is getting emphasized. Currently biogas production from cattle dung is getting a very good response due to its economical and eco-friendly usage. Although cattle dung is used worldwide for biogas production due to its readily digestible nature, it is not abundant in south Asian countries like India. Whereas various bio-wastes with high cellulose content like bamboo dust, saw dust are obtainable in plenty in this region. These wastes are either uneconomically used or disposed of as they are, thereby causing serious pollution problems. These bio-wastes also contain lignin rendering its anaerobic digestion slow with conventional digestion methods. As a result these bio-wastes cannot be directly used for biogas production. To break the lignin content pre-treatment were done and were mixed with cattle dung to enhance the biogas production.

It is already established that the effectiveness of anaerobic digestion naturally depends upon the intensity of bacterial activity. Therefore it is very important to control the factors that affect the bacterial activity [1]. Bushwell and Hatfield, 1996 [2] identified the anaerobic bacteria and the conditions that promote methane production in the 1930s [Mahanta, 2004]. Lusk, 1998 [3] studied different types of digesters with internal heating and found that gas production was the maximum in mesophilic condition. Among the many factors, temperature is one important factor which affects the anaerobic digestion. Anaerobic digestion can take place under psychrophilic (<15°C) condition, mesophilic condition (15°C-45°C) and thermophilic condition (45°C-65°C) [4]. The anaerobic digestion under thermophilic condition provides the various advantages such as high metabolic rates, high specific growth rate of bacteria, at the same time high death rates of bacteria also as compared to mesophilic condition [5]. Mackie and Bryant, 1995 [6] found that thermophilic (60°C) anaerobic digestion of cattle waste is more stable as compared to mesophilic (40°C). Thermophilic digestion is 4 (Four) times more intense and can yield more biogas. Thermophilic stabilization of energy plants at 55°C is truly economical as it produces more biogas [7].

The objective of the present study is to investigate the effect of temperature on biogas production rate from co-digestion of bamboo dust and saw dust each mixed with cattle dung. The result of the biogas production rate from co-digestion of bamboo dust and saw dust each mixed with cattle dung was compared with that of the fresh cattle dung.

2. MATERAIALS AND METHODS

The biomasses bamboo dust and saw dust were collected locally, cleaned and dried under sun. Then they were dried in the hot air oven for 24 hours and separately ball milled and strained through IS sieve of size 44. The undersized particles of size 0.355 mm were used as feed material for the anaerobic digestion. Fresh cattle dung was collected from the local dairy farm.

Total solid and volatile matter of cattle dung as well as that of lignocellulosic biomasses were determined following standard test methods ASTM E1756-08, and E872-82 (Reapproved 2006) respectively. Carbon and Nitrogen content was determined by using Energy Dispersive X-ray Spectroscopy (EDX) analytical technique.

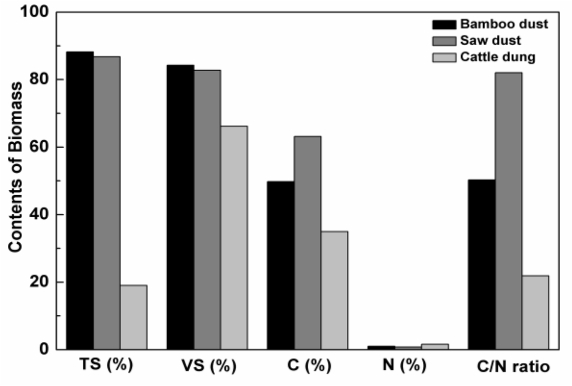

Fig. 1 Contents of biomass

Table 1 Characterization of Bamboo Dust, Saw Dust and Cattle Dung

Parameter	Bamboo Dust	Saw Dust	Cattle Dung
TS (%)	88.23	86.77	19.02
VS (%)	84.24	82.79	66.2
C (%)	49.79	63.17	35
N (%)	0.99	0.77	1.6
C:N ratio	50.29	82.03	21.87

Table 1 and Fig. 1 present the results of the characterization of bamboo dust, saw dust and cattle dung on dry weight basis. Total solid (TS) of bamboo dust and saw dust were 88.23 and 86.77% respectively and that of cattle dung was 19.02%. The C:N ratio of bamboo dust and saw dust was 50.29 and 82.03 whereas that of cattle dung was 21.87:1. Hills and Roberts, 1981 [8] reported that the performance of digesters containing dairy manure and field crop residues is the maximum when the C:N ratio of the feed mixtures was between 25 to 30:1 and total solid of the slurry was 8%. Budiyono et al., 2010 [9] stated that TSs content of 7.4 and 9.2% in cattle dung exhibit the best performance for digestibility. Mahanta et al., 2004 [10] reported that for cattle dung at 35°C temperature maximum gas production was obtained with 8% total solid. That is why to get the maximum biogas production from bamboo dust and saw dust, they were first mixed with fresh cattle dung in 1: 3 ratio, so that their overall C:N ratio comes in between 25 to 30:1. After that water was mixed with the mixtures in 1:3 ratios to bring down the total solid to 9%.

3. EXPERIMENTAL SET-UP AND PROCEDURE

The schematic diagram of the experimental set-up is shown in Fig. 2. It consists of a laboratory bio-digester made of borosilicate glass of capacity 1000 ml with air tight rubber cork fitted into its opening. Thermometer and copper tube were fitted through the rubber cork for measuring the slurry temperature and fitting the connecting tube. The other end of the connecting tube was passed through a 500 ml solution bottle containing brine solution. Thus, the biogas produced in the biodigester by the anaerobic digestion process was delivered through the connecting tube to the solution bottle containing brine. The pressure of the biogas produced caused displacement of the brine solution which is then collected in a 200 ml beaker placed on the other side of the solution bottle. The amount of solution collected in the beaker represented the amount of biogas produced in the biodigester. A sampling port was provided through the cork fitted with a valve to take out sample from time to time testing of sample for total solid, volatile solid and pH.

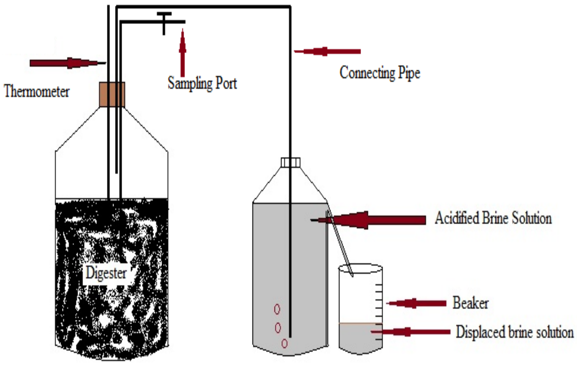

Fig. 2 Schematic diagram of experimental set-up

A weighing balance was used to measure the required mass of cattle dung and biomasses. The mercury-in-glass thermometer (range -10^{O}C to 110^{O}C) fitted to the bio-digester through the cork was used to measure the daily temperature of the slurry and a digital pH meter was used to determine the pH of the fermentation slurry. The constant temperatures of the digesters were maintained by putting the digesters in the water bath at fixed temperature. Three sets of digesters each set having bamboo dust co-digested with cattle dung, saw dust co-digested with cattle dung and fresh cattle dung each having three samples were prepared. Both bamboo dust and saw dust were mixed with fresh cattle dung in 1:3 ratio and water was added to the mixtures in 1:3 ratio. Water was mixed with the fresh cattle dung in 1:1.125 ratio thus making the total solid of the slurry 9.04%. The filled in digesters were kept in water bath at 35^{O}C, 45^{O}C, and 55^{O}C temperatures respectively to study the effect of temperature on gas production from fresh cattle dung, bamboo dust and cattle dung mixture and saw dust and cattle dung mixtures for 50 days HRT. The temperature of the feedstock was measured twice a day with the help of the thermometer fitted through the cork and pH was monitored on weekly basis. Gas production was measured by water displacement method.

Table 2 Properties of Biomass Cattle Dung Mixtures

Substrates	Total Solid (%)	C:N ratio
Bamboo dust and cattle dung mixture	9.4	26.73
Saw dust and cattle dung mixture	9.3	30.19
Fresh cattle dung	9.04	21.87

Table 2 shows the influent TS (%) and C:N ratios of bamboo dust and cattle dung mixture; saw dust and cattle dung mixture and fresh cattle dung. The influent total solid and C:N ratio of bamboo dust and cattle dung mixture were found to be 9.4% and 26.73 respectively, and for saw dust and cattle dung mixtures they were 9.3% and 30.19 respectively which is a favourable condition for good biogas production. Whereas in case of fresh cattle dung slurry the total solid and C:N ratio was found to be 9.04% and 21.87 respectively.

The biogas production was monitored daily and measured every five days. The biogas production was observed and recorded for 50 days until biogas production reduced significantly and it was found that the biogas production was very slow at the beginning and at the end of observation. This is because the biogas production in batch condition directly corresponds to specific growth rate of methanogenic bacteria in biodigester [9, 11].

4. KINETIC MODEL

A first order kinetic equation was derived for decaying of reactant (volatile solid of biomass) per day [12]. A simple method to fit constants using single linear regression is presented. Equation for substrate utilization rate is

$$\frac{d[A]}{dt} = -k[A] \tag{1}$$

where *[A]* = concentration of biodegradable volatile solid in gm, $[A]_0$ = initial concentration of biodegradable volatile solid in gm, *k* = kinetic rate constant, and *t* = HRT in days.

Integrating Eq. (1),

$$[A] = [A]_0 \exp(-kt) \tag{2}$$

Taking natural logarithm of Eq.(2), we have

$$\ln[A] = \ln[A]_o - kt \tag{3}$$

which is the form of a straight line curve of the form $Y=mX+c$. This provides an easy method to estimate constants of proposed model, using a simple and linear regression {ln*[A]* vs HRT}. The readings were taken every five days over a period of 50 days, so taking these readings a curve is fitted using least square method, which is eventually a straight line according to Eq. (3). Value of kinetic rate constant *k* is obtained using Eq. (3). Based on the measured values of volatile matters at regular interval the value of kinetic parameter is evaluated from the slope of Eq. (3).

5. RESULTS AND DISCUSSION

5.1 Effect of temperature on cumulative biogas production

The gas production rate for the fresh cattle dung as well as the biomass mixtures, bamboo dust and cattle dung mixture and saw dust and cattle dung mixture at 35^{O}C, $45\ ^{O}$C and 55^{O}C temperatures were recorded on daily basis for a period of 50 days. Khandelwal and Mahdi, 1986 [13] have reported that for the northeast India, 55 days retention time is recommended.

Comparison of gas production rate of fresh cattle dung, bamboo dust and cattle dung mixture and saw dust and cattle dung mixture at three different temperatures is shown in Table III as well as in Fig. 4. It is clear from the table and the graph that biogas yield improves with co-digestion. Secondly, bamboo dust and cattle dung mixture yields higher biogas in mesophilic condition (35^{O}C) as compared to saw dust and cattle dung mixture, whereas in thermophilic condition (55^{O}C), saw dust and cattle dung mixture yielded better than that of bamboo dust and cattle dung mixture.

Table 3 Comparison of Cumulative Biogas Production

Sample	**Gas production in ml/gm VS (50 days)**		
	35°C	**45°C**	**55°C**
Bamboo Dust and cattle dung mixture	20.54	15.36	25.61
Saw Dust and cattle dung mixture	19.35	16.56	29.21
Fresh Cattle Dung	18.13	10.62	22.21

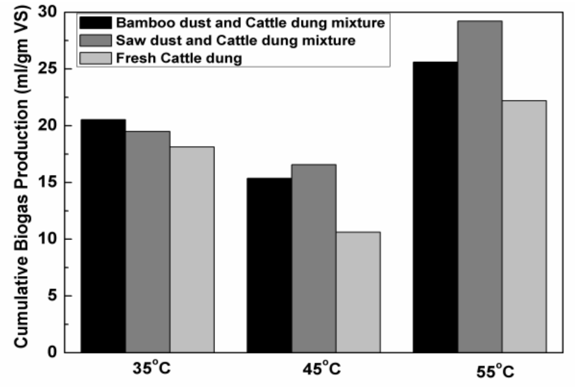

Fig. 4 Cumulative gas production at different temperatures

Fig. 5-7 show the comparison of cumulative biogas production rate of fresh cattle dung with bamboo dust mixture and saw dust mixture at temperatures 35°C, 45°C and 55°C respectively. It is seen that In case of fresh cattle dung the highest biogas production was obtained at 55°C, followed by 35°C and 45°C respectively. But at all the temperatures biogas production from bamboo dust and saw dust co-digested with cattle dung was higher than that of the fresh cattle dung. It is attributed to the fact that co-digestion of cattle dung with lignocellulosic biomass enhances the biogas production [8, 16, 17]. On the other hand saw dust mixed with cattle dung and bamboo dust and cattle dung mixture has the highest biogas production rate at 55°C, followed by 35°C and 45°C. In mesophilic condition biogas production of bamboo dust and cattle dung mixture is higher than that of saw dust and cattle dung mixture, but as temperature increases biogas production rate of saw dust and cattle dung mixture increases. The reason may be due to the breakage of the lignin content of saw dust. Also at thermophilic digestion, biogas production starts earlier as compared to 35°C and 45°C. So, comparing all the three figures it can be concluded that with increase in temperature biogas production rate can be made faster and better.

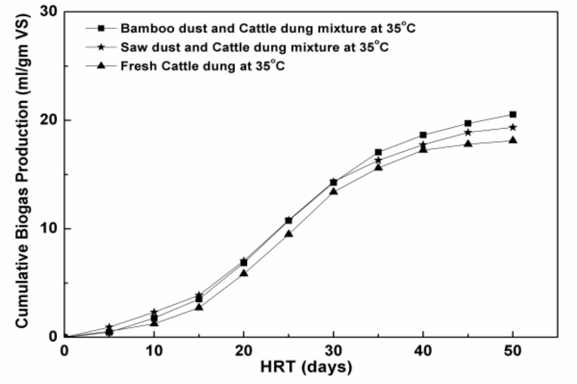

Fig. 5 cumulative biogas production at 35°C

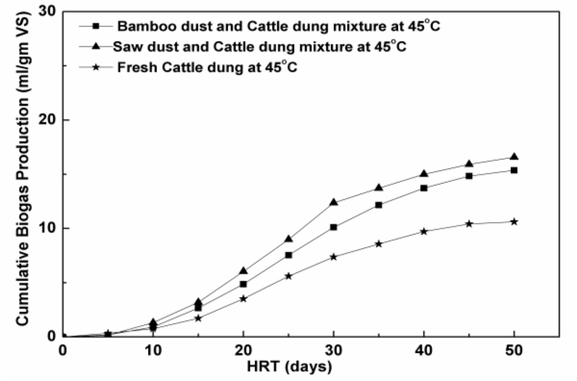

Fig. 6 cumulative biogas production at 45°C

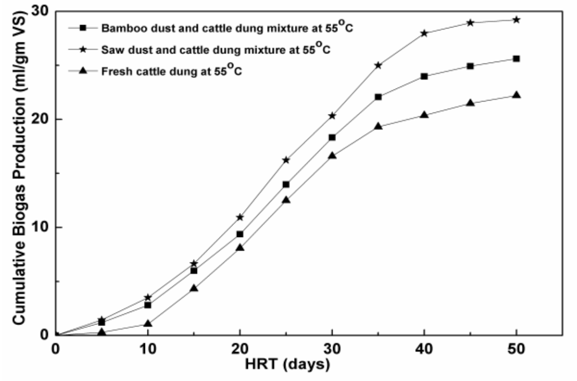

Fig. 7 cumulative biogas production at 55°C

The large amount of biogas production at 35°C in mesophilic condition and at 55°C in thermophilic condition is probably due to large microbial activity in mesophilic and thermophilic temperature range respectively [14].

5.2 Effect of temperature on kinetic rate constant

5.2.1 Bamboo dust and cattle dung mixture

Here the substrate consists of 56.25 gm of bamboo dust, 168.75 gm of cattle dung and 675 ml of water fed to the digester. Value of $[A]_0$ or the influent volatile solid mass of bamboo dust and cattle dung mixture is 65.2695 gm. At five day interval, 10 ml of digested slurry was taken out from the digesters and tested for total solid and volatile solid contents. After plotting the data of volatile solid content at temperature 55°C, 45°C and 35°C, against HRT and fitting the curve, kinetic rate constant, k at three different temperatures was obtained. The equations obtained at temperatures 55°C, 45°C and 35°C were,

$$ln[A] = -0.0456t + 4.1433 \quad (4)$$

$$ln[A] = -0.0331t + 4.1632 \quad (5)$$

$$ln[A] = -0.0368t + 4.2001 \quad (6)$$

respectively. From equations 4, 5 and 6, value of *k* at temperature 55°C, 45°C and 35°C are 0.0456, 0.0331 and 0.0368, respectively.

5.2.2 Saw dust and cattle dung mixture

Here the substrate consists of 56.25 gm of saw dust, 168.75 gm of cattle dung and 675 ml of water fed to the digester. Value of $[A]_0$ or the influent volatile solid mass of saw dust and cattle dung mixture is 63.867 gm. At five day interval, 10 ml of digested slurry was taken out from the digesters and tested for total solid and volatile solid contents. After plotting the data of volatile solid content at temperature 55°C, 45°C and 35°C, against HRT and fitting the curve, kinetic rate constant, k at three different temperatures were obtained. The equations obtained at temperatures 55°C, 45°C and 35°C were,

$$ln[A] = -0.0617t + 4.1881 \quad (7)$$

$$ln[A] = -0.0328t + 4.1715 \quad (8)$$

$$ln[A] = -0.0417t + 4.1966 \quad (9)$$

respectively. From equations 7, 8 and 9, value of *k* at temperature 55°C, 45°C and 35°C are 0.0617, 0.0328 and 0.0417 respectively.

5.2.3 Fresh cattle dung slurry

Here the substrate consists of 450 gm of fresh cattle dung and 506 ml of water is fed to the digester. The influent volatile solid of the cattle dung slurry is 55.608 gm. Digested slurry was taken out every five days interval for total sold and volatile solid content analysis.

After plotting the data of volatile solid content at temperature 55°C, 45°C and 35°C, against HRT and fitting the curve, kinetic rate constant, k at three different temperatures were obtained. The equations obtained at temperatures 55°C, 45°C and 35°C were,

$$ln[A] = -0.0327t + 4.0441 \quad (10)$$

$$ln[A] = -0.0181t + 2.9151 \quad (11)$$

$$ln[A] = -0.0174t + 3.3836 \quad (12)$$

Value of kinetic rate constant at temperatures 55°C, 45°C and 35°C are obtained from Eq.10, 11 and 12 and they are 0.0327, .0181 and 0.0174 respectively.

Table IV shows the substrate concentration and values of *k* at different temperatures for fresh cattle dung, bamboo dust and cattle dung mixture and saw dust and cattle dung mixture. Fig. 8 shows the graphical representation of the variation of kinetic rate constant, *k* with temperature.

Comparing different values of *k* at different temperatures for 50 days HRT, it can be concluded that temperature plays a very important role in controlling the kinetic rate constant. Table 4 and Fig. 8 shows that in case of fresh cattle dung although the kinetic rate constant increases with increase in temperature but they are smaller at various temperature as compared to the bamboo dust mixture and saw dust mixture. For both bamboo dust and cattle dung mixture and saw dust and cattle dung mixture value of *k* is the highest at 55°C, followed by 35°C and then 45°C, but *k* value is the highest in case of saw dust and cattle dung mixture at temperature 55°C and the lowest in case of bamboo dust and cattle dung mixture at 45°C. So, for the same percentage of total solid and same amount of cattle dung mixed with the biomasses, reaction rate of saw dust and cattle dung mixture is faster at 55°C which eventually lead to the better biogas production.

Table 4 Substrate Concentration and Values of k at Different Temperatures

Substrates	**Influent TS gm**	**Influent VS gm**	**Kinetic rate constant, k**		
			55°C	**45°C**	**35°C**
Bamboo dust and cattle dung mixture	85.06	65.26	0.045	0.033	0.036
Saw dust and cattle dung mixture	84.24	63.86	0.061	0.032	0.041
Fresh Cattle Dung	84.00	55.608	0.0327	0.0181	0.0174

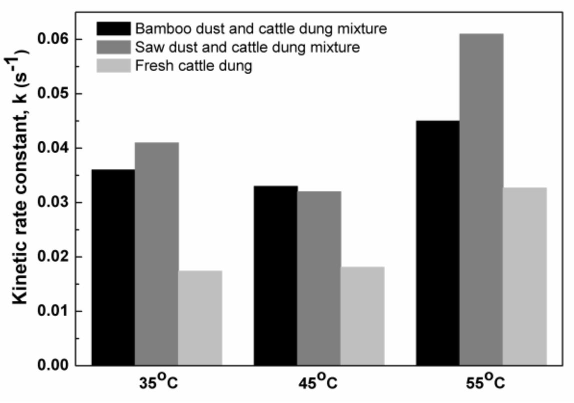

Fig. 8 Kinetic rate constants at different temperatures

6. CONCLUSION

From the present investigation it is concluded that biogas production rate from cattle dung can be improved by co-digesting with lignocellulosic biomass like bamboo dust, saw dust etc. On the other hand biogas production from lignocellulosic biomass can be improved by increasing the temperature of the slurry as thermal pre-treatment is one of the important factors to improve the anaerobic digestion of lignocellulosic biomasses [15]. In mesophilic condition biogas production rate at 35°C is higher as compared to that at 45°C; therefore for the same amount of biogas yield it is better to opt for 35°C temperature instead of going on increasing the temperature which will make the system more economic. Also kinetic rate constant at 55°C is the highest, followed by 35°C and 45°C for both the biomasses. In thermophilic condition biogas yield at 55°C is far better and faster, so if we can provide extra energy for increasing the temperature of feedstock, 55°C temperature is a very good option for best biogas production. Only disadvantage of thermophilic anaerobic digestion is that more energy is needed for heating the digesters.

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