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Effect of Temperature on Biogas Production from Rice Straw and Rice Husk

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Abstract. The objective of this paper is to investigate the effect of temperature on anaerobic digestion of two very common lignocellulosic biomasses such as rice husk and rice straw. Rice husk and rice straw are abundant in south East Asia. They are not effectively used for any fruitful purpose rather they are disposed of in the open environment polluting the atmosphere and causing serious health problem. In this paper the rice husk and rice straw were first characterized to see their potentiality for biogas production and then pretreated to make the biogas production achievable. The anaerobic digestion was considered at three different operating temperatures, namely, 45 °C, 50 °C and 55 °C, respectively. Effect of temperature on kinetic rate constant was also studied. It was observed from the investigation that biogas production increases with increase in temperature. The kinetic rate constant plays a significant role to indicate the digestion process.

1. Introduction

With the depletion of fossil fuels cost of petrol and diesel is increasing day by day because of which development of alternate fuel source is getting emphasized now-a-days. Currently biogas production from cattle dung is getting a very good response due to its economical, eco-friendly usage and readily digestible nature. But cattle dung which is worldwide used for biogas production is not abundant in south Asian countries like India. Whereas various bio-wastes or agricultural wastes with high cellulose content like rice husk and rice straw 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 [1]. 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.

One of the major problems in utilizing these materials is their low-digestibility. The lignin to cellulose ratio is normally used to define the degree of digestibility of the biomasses [2]. The digestibility of lignocellulosic biomasses can be improved by pretreatments [3, 1]. Pretreatments involve the alteration of cellulose structure of the biomass rendering fast hydrolysis of both the cellulose and hemicellulose producing biogas in short span of time. Various pretreatments methods that can be applied include mechanical/physical, chemical and biological pretreatments. The most significant physical pretreatment include the particle size reduction [1], which eventually leads to the increase in available surface area and the release of intracellular components [3,4].

The effectiveness of anaerobic digestion naturally depends upon the intensity of bacterial activity which is affected by various factors [5]. Among the many factors, temperature is one important factor

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which affects the anaerobic digestion. 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 [6]. Mackie and Bryant, 1995 [7] 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 [8]. The objective of the present study is to investigate the effect of temperature on biogas production rate of rice husk and rice straw each mixed with cattle dung.

2. Materials and Methods

The biomasses rice husk and rice straw were collected locally, cleaned and dried under sun. Then they were dried in the hot air oven for 24 hours and separately ball milled to reduce the particle size.
Total solid and volatile matter were determined following standard test methods ASTM E1756-08, and E872-82 (Reapproved 2006) respectively. Carbon and Nitrogen content of the biomasses was determined by using Energy dispersive x-ray (EDX) spectroscopy.

Table 1. Characterization of Rice Husk and Rice Straw [9]

	Rice Husk	Rice Straw	Cattle Dung
Total Solid (%)	89.41	87.33	19.02
Volatile Solids (%)	74.07	65.15	66.2
Carbon (%)	32.79	32.19	35
Nitrogen (%)	0.40	0.98	1.6
C:N ratio	81.97	32.84	21.8
Hemicellulose (%)	24	35	2.3
Cellulose (%)	28	30.2	4.7
Lignin (%)	25	22	2.7
Lignin/cellulose ratio	0.892	0.728	0.574

Table 1 presents the results of the characterization of rice husk, rice straw and cattle dung on dry weight basis. Total solid (TS) of rice husk and rice straw were 89.41 and 87.33% respectively and that of cattle dung was 19.02%. The C:N ratio of rice husk and rice straw was 81.97 and 32.84 whereas that of cattle dung was 21.8:1. Hills and Roberts, 1981 [10] 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 [11] stated that TSs content of 7.4 and 9.2% in cattle dung exhibit the best performance for digestibility. Mahanta et al., 2004 [12] 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 rice husk and rice straw, 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 bio-digester 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 bio-digester. 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.

A weighing balance was used to measure the required mass of cattle dung and biomasses. The mercury-in-glass thermometer (range -10 °C to 110 °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. Two sets of digesters, each having three samples were prepared. In one set substrate was bamboo dust and cattle dung mixture and in the other set substrate was saw dust and cattle dung mixtures. 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. The filled in digesters were kept in water bath at 35 °C, 45 °C, and 55 °C temperatures respectively to study the effect of temperature on gas production from 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.

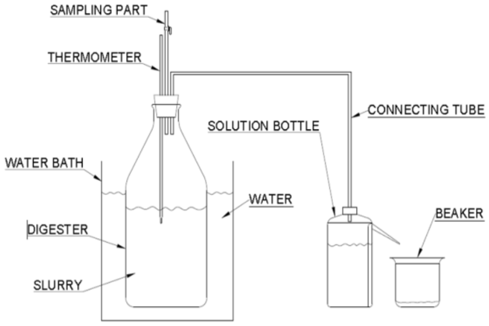

Figure 1. Schematic diagram of experimental set-up

Table 2. Properties of biomass cattle dung mixtures.

	Total Solid (%)	C:N ratio
Rice straw and cattle dung mixture	8.9	24.06
Rice husk and cattle dung mixture	9.1	26.49

Table 2 shows the influent TS (%) and C:N ratios of rice straw and cattle dung mixture and rice husk and cattle dung mixture. It is seen that influent total solid and C:N ratio of rice straw and cattle dung mixture were found to be 8.9% and 24.06 respectively; and for rice husk and cattle dung mixture they were 9.1% and 26.49 respectively which is a favorable condition for good biogas production.

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 bio-digester [11, 13].

4. Kinetic Model

The kinetics of digestion process is crucial in determining the rate of gas production per unit mass of volatile solid. Using chemical engineering theory, a description of batch digestion kinetics is obtained [14, 1]. For first order kinetics, the rate of degradation of the volatile solids is given by-

.

$$\frac{dC_B}{dt} = -kC_B \tag{1}$$

where C_B is the substrate concentration or concentration of biodegradable volatile solids (VS), k is the first order kinetic rate constant and t is the time. Rearranging Eq. (1)

$$\frac{dC_B}{C_B} = -k\,dt \tag{2}$$

Integrating both sides we get,

$$\int_{C_0}^{C_t} \frac{dC_B}{C_B} = -\int_0^t k\,dt \tag{3}$$

$$or, \ln\left(\frac{C_t}{C_0}\right) = -kt \tag{4}$$

$$or, \frac{C_t}{C_0} = \exp(-kt) \tag{5}$$

According to B. Linke, 2006 [15], the transformation of biodegradable solids (*C*) into biogas (*y*) at time *t* can be correlated as shown in Eq. (6).

$$\frac{y_m}{y_m - y_t} = \frac{C_0}{C_t} \tag{6}$$

$$or, \frac{y_m - y_t}{y_m} = \frac{C_t}{C_0} \tag{7}$$

Now, replacing $\frac{C_t}{C_0}$ in Eq. (5) with $\frac{y_m - y_t}{y_m}$,we have

$$\frac{y_m - y_t}{y_m} = \exp(-kt) \tag{8}$$

$$or, y_t = y_m\{1 - \exp(-kt)\} \tag{9}$$

where y_t = volume of biogas produced per unit mass of volatile solids fed at any time, *t* (ml/gm); y_m = volume of biogas produced per unit mass of volatile solids converted at maximum time (ml/gm); *k* = kinetic rate constant (day^{-1}) and *t* = time of digestion (days).

Eq. (9) was linearized to evaluate the substrate bio-degradability and kinetic rate constant [15]. Differentiating Eq. (9),

$$\frac{dy_t}{dt} = y_m k \exp(-kt) \tag{10}$$

Taking natural logarithm on both sides of the equation,

$$\ln\left(\frac{dy_t}{dt}\right) = (\ln y_m + \ln k) - kt \tag{11}$$

This equation was further reduced to the following form,

$$\frac{1}{t}\ln\left(\frac{dy_t}{dt}\right) = \frac{1}{t}(\ln y_m + \ln k) - k \tag{12}$$

Which is analogous to a straight line equation, *y=mx+c*, where $(\ln y_m + \ln k)$ represents the slope and (-*k*) represents the intercept of the graph of $\frac{1}{t}\ln\left(\frac{dy_t}{dt}\right)$ versus inverse of the hydraulic retention time. Thus the first order kinetic rate constant can be easily determined from the plot of $\frac{1}{t}\ln\left(\frac{dy_t}{dt}\right)$ versus inverse of the hydraulic retention time.

The term (-*k*) is a measure of the rate of removal of the biodegradable fractions as the biogas production increases with time. According to Eastman and Ferguson, 1981 [17], the first order kinetic constant *k* is a pure empirical function which represents the cumulative effects of many parameters such as pH, temperature, quantity and quality of substrate, rate of removal of biodegradable fractions, rate of inhibition by other components of the substrate e.g. lignin or by-product of the reaction process such as fatty acids etc. The more negative the value of *k*, the faster the rates of removal of the biodegradable fractions while more the positive value of *k*, the slower the rate of removal of the biodegradable fractions [16]. Thus Eq. (12) can be used to detect anaerobic digestion whether it is progressive or regressive.

5. Results and Discussion

5.1 Effect of temperature on cumulative biogas production

The gas production rate for the biomass mixtures, rice straw and cattle dung mixture and rice husk and cattle dung mixture at 45 °C, 50 °C and 55 °C temperatures were recorded on daily basis for a period of 50 days. Khandelwal and Mahdi, 1986 [18] have reported that for the northeast India, 55 days retention time is recommended.

Comparison of gas production rate of rice straw and cattle dung mixture and rice husk and cattle dung mixture at three different temperatures is shown in Table 3. It is clear from the table and the graph that although biogas production from both the biomass mixtures were increasing with increase in temperature of the digester but the biogas production from rice husk and cattle dung mixture was consistently lower than that of the rice straw and cattle dung mixture at all the temperatures.

Table 3. Cumulative biogas production in 50 days at different temperatures.

	Gas production in ml/gm VS (50 days)		
	45 °C	50 °C	55 °C
Rice straw and cattle dung mixture	18.24	30.73	32.93
Rice husk and cattle dung mixture	13.41	19.41	22.74

Figure 2-4 show the comparison of cumulative biogas production rate of rice straw and rice husk each mixed with cattle dung at 45 °C, 50 °C and 55 °C respectively. It is seen that the biomasses mixed with the cattle dung has the highest biogas production rate at 55 °C, followed by 50 °C and 45 °C. In case of both the biomasses as temperature increases biogas production rate increases. But biogas production rate from rice husk is quite low as compared to that of rice straw mixed with cattle dung. The reason may be due to the high lignin content (25%) as well as silicon content of rice husk. Lignin content of rice straw (22%) is also high but here as rice straw is mixed with cattle dung; it is getting utilized as support medium for the biogas producing microorganisms. Support media is nothing but a bio-film carrier which provide surface on which microbial bio-films can attach and grow, increasing digester stability, and reducing the amount of microorganisms that are washed out of the digester. Andersson and Björnsson, 2002 [19] studied the behaviour of straw as support media for bacteria and found that it increased methane production more than glass or plastic carriers. On the other hand as temperature increases biogas production rate from both the biomasses increases. Also at thermophilic digestion, biogas production starts earlier as compared to 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. The large amount of biogas production at 55 °C in thermophilic condition is due to the large microbial activity in thermophilic temperature range [20].

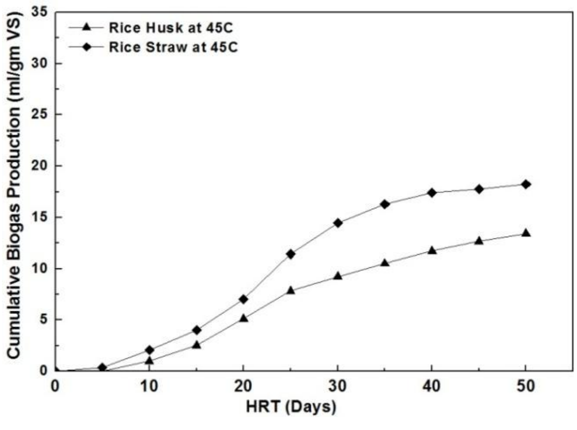

Figure 2. Cumulative biogas production at 45 °C

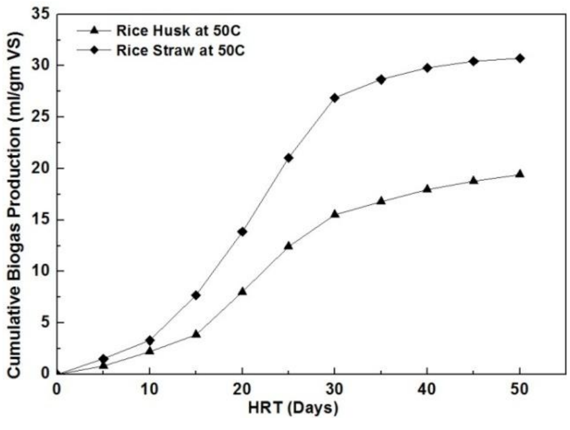

Figure 3. Cumulative biogas production at 50 °C

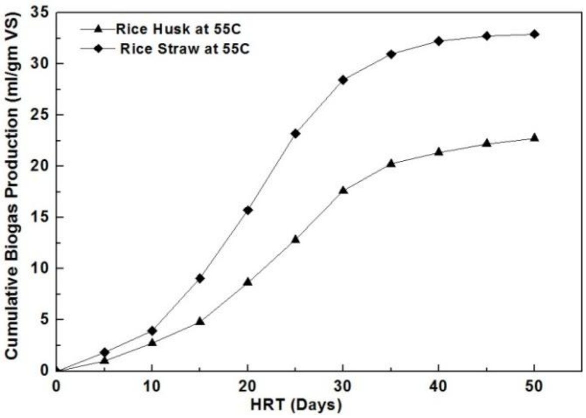

Figure 4. Cumulative biogas production at 55 °C

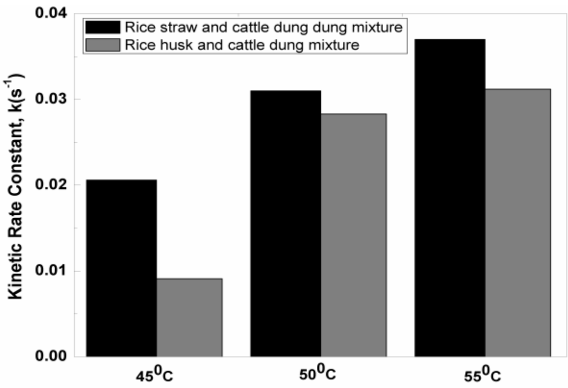

Figure 5. Kinetic rate constants at different temperatures.

5.2 Effect of temperature on kinetic rate constant

Here 56.25 gm of rice straw, 168.75 gm of cattle dung and 675 ml of water were mixed thoroughly and fed to the 1000 ml capacity borosilicate digester. In the same proportion three samples were prepared for three different temperatures. At five day interval, biogas production was measured with the help of water displacement method as discussed in the section III (Experiential Set-Up and Procedure). After plotting the data of biogas production rate in the form of $\frac{1}{t}\ln\left(\frac{dy_t}{dt}\right)$ against inverse of the hydraulic retention time and fitting the curve, kinetic rate constant, k at three different temperatures was obtained.

Similarly 56.25 gm of rice husk, 168.75 gm of cattle dung and 675 ml of water were mixed thoroughly and fed to a separate 1000 ml capacity borosilicate digester. In the similar proportion three samples for three different temperatures were Biogas production was measured in the same manner as is done for rice straw mixture. After plotting the data of biogas production rate in the form of $\frac{1}{t}\ln\left(\frac{dy_t}{dt}\right)$ against inverse of the hydraulic retention time and fitting the curve, kinetic rate constant, k for rice husk mixture at three different temperatures was obtained.

Table 4 shows the values of kinetic rate constant, *k* at temperatures 45 °C, 50 °C and 55 °C respectively. Figure 5 shows the graphical representation of the variation of kinetic rate constant, *k* with temperature.

Table 4. Substrate concentration and kinetic rate constants at different temperatures

Substrates	Influent TS, gm	Influent VS, gm	Kinetic rate constant, k		
			45 °C	50 °C	55 °C
Rice straw and cattle dung mixture	84.56	55.46	0.0206	0.031	0.037
Rice husk and cattle dung mixture	84.93	60.71	0.0091	0.0283	0.0312

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. For both rice straw and rice husk each mixed with cattle dung value of *k* is the highest at 55 °C, followed by 50 °C and 45 °C. It is observed that the kinetic rate constant of rice straw is higher than that of the rice husk mixed with cattle dung irrespective of temperature effect. This is due to the presence of lignin as well as silica in rice husk. On the other hand higher kinetic rate constant in case of rice straw is due to its behaviour as support media for microorganisms. So, for the same percentage of total solid and same amount of cattle dung mixed with the biomasses, reaction rate of rice straw and cattle dung mixture is faster which eventually lead to the better biogas production.

6. Conclusion

From the present investigation it is concluded that biogas production rate can be improved by increasing the temperature of the slurry as thermal pre-treatment is one of the important factor to improve the anaerobic digestion of lignocellulosic biomasses [21]. 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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