

Studies On The Utilization Of Fruit And Vegetable Waste For Generation Of Biogas

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ABSTRACT : As fossil fuels like coal and petroleum are depleting in India, so alternative sources of energy is the requirement of the present day. One amongst the major challenging source of energy is biogas being produced from biomass. At the same time, enormous amount of garbage produced in India is a huge problem in terms of disposal and handling. Therefore, an effort have been made here to utilize fruit and vegetable waste (FVW) for generation of bio-methane by anaerobic digestion (AD) method. Experiments have been carried out separately at four different slurry concentrations at three different temperatures respectively. Essentially all experiments have been performed by dry anaerobic digestion basis and five different catalysts have been added to promote the digestion process. From the study it is inferred that process with 4% slurry concentration at 37°C gave best results out of all processes. Productions of biogas yield, and ultimate methane yield have been presented.

KEYWORDS: anaerobic digestion, bio-methane, slurry concentration, temperature, catalyst.

I. INTRODUCTION

India is a heavily populated country and this is the only reason for enormous wastes being produced regularly out of household & industrial activities like peeling and cutting of raw FVW prior to processing, eating, cooking. Serious environmental and health problems are related to inadequate solid waste disposal. Garbage dumped in open places cause heavy pollution due to soil, groundwater and surface waters [1, 2]. FVW is generally stale or spoilt, not fit for human consumption. These materials are usually high in fiber content and are of different sizes and forms. Vegetable wastes have a high moisture content of 80-89%. Three fourth of the total solids present are volatile solids. Their biodegradability varies accordingly with the state of hardening and kind of waste material. Carbon to nitrogen ratio varies in each vegetable, however for mixed variety it may be around 1:20 to 1:30. The origin of biogas is traced back to the Persians. They discovered that organic matter such as rotting vegetables gave a flammable gas that could be used for other purposes. Anaerobic digestion of sorted organic wastes from municipal solid waste (MSW) especially food waste is a cost effective technology [3,4]. Methane fermentation is a complex process. The general process of anaerobic digestion is a series of processes like enzymatic hydrolysis, acidogenesis, acetogenesis and methanogenesis [5] and each metabolic stage is assisted by a series of micro organisms. Amongst the four stages, hydrolysis is the rate limiting stage for FVW [6, 7].

The acid forming microbes convert macromolecules like carbohydrates, proteins, starches, cellulose etc to organic acids (step 1 and 2). In the 3rd step, organic acids are converted to acetate & finally in the 4th step the acetate is converted to CH₄ and CO₂ by the methanogens. The time needed for step 1 and 2 is more and this consumes most of the time. However, experiments conducted in batch processes are usually lengthy in terms of more retention or detention time. Carbohydrate rich substrates like FVW are quicker producers of volatile fatty acids (VFAs) [8] and leads to excess acid accumulation leading to acidity, low pH and process inhibition. So, higher concentration of substrates for FVW leads to lowering of pH and thereby produces less biogas. Nevertheless, an important factor affecting AD process is temperature [9,10]. Generally AD process is operated under mesophilic or thermophilic condition in which thermophilic digestion is reported as more efficient method [11, 12]. Compared with wet AD process, dry AD process is much beneficial to compact digester with high organic loading rate and its energetically effective performance [13, 14]. Literature review shows that India stands second in the production of fruits and vegetables in the world. It contributes about 10 and 14 % of fruit and vegetable in the world production [15]. Vegetable wastes are created by marketing, processing, harvesting, transportation etc., that deteriorate easily and cause foul smelling. Many researchers studied anaerobic digestion of vegetable wastes in one stage systems in laboratory scale reactors.

Reactions involved in the anaerobic digestion process are as follows:

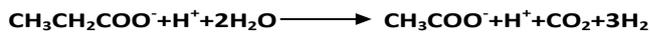
Hydrolysis :



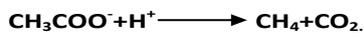
Acidogenesis :



Acetogenesis :



Methanogenesis:



1.1 Chen-Hashimoto Kinetic model for anaerobic digestion

Chen-Hashimoto model was used for kinetic analysis of the experimental data. In a completely mixed digester the rates of cell mass and substrate concentration are expressed by the following equation (XIII):

$$\frac{dX}{dt} = \mu X - X / \theta \quad (I)$$

$$\frac{dS}{dt} = -r + (S_0 - S) / \theta \quad (II)$$

Where X is the concentration of the cell mass, μ is the specific microbial growth rate, θ is the hydraulic retention time, S_0 is the concentration of the substrate in the effluent, and r is the volumetric substrate utilization rate.

The relationship between r and μ is defined by the following equation:

$$\mu = Yr / X \quad (III)$$

Where Y is the yield coefficient (cell mass/ substrate mass) is considered constant.

In the steady state, $\frac{dX}{dt} = 0$ and $\frac{dS}{dt} = 0$, hence

$$\mu = 1 / \theta = D \quad (IV)$$

Where D is the dilution rate .

$$r = (S_0 - S) / \theta \quad (V)$$

$$X = Y/(S_0 - S) \quad (VI)$$

Substituting these expressions in Contois equation we get:

$$\mu = \frac{\mu_{\max} S}{\beta X + S} \quad (VII)$$

Where μ_{\max} is the maximum specific microbial growth rate and β is a dimensionless kinetic parameter.

$$\frac{S}{S_0} = \frac{K}{(\mu_{\max} \theta - 1 + K)} \quad (VIII)$$

Equation (8) shows that the effluent substrate concentration depends on the influent substrate concentration.

The minimum retention time indicating when the washout of micro organism occurs is numerically equal to the reciprocal of the maximum growth rate:

$$\theta_{\min} = \frac{1}{\mu_{\max}} \quad (IX)$$

To study the kinetics of methane fermentation of complex substrates, the approach used is to find the rate limiting substrate for the kinetic evaluation.

If B denotes the volume(in litres) of methane produced under normal conditions of pressure and temperature per gram of substrate at the infinite retention time or for complete utilization of substrate, the biodegradable substrate concentration in the reactor is directly proportional to $(B^0 - B)$, and B^0 will be directly proportional to the biodegradable substrate loading (XIV).

Therefore from equation (VIII) one obtains:

$$(B^0 - B)/B^0 = K/(\mu_{\max} \theta - 1 + K) \quad (X)$$

From equation (10) one obtains :

$$\theta = \frac{1}{\mu_{\max}} + \frac{K}{\mu_{\max}} \frac{B}{B^0 - B} \quad (XI)$$

To obtain the parameter B_0 one can uses the following equation which is easily derived from equation (X):

$$B = B_0 \left[1 - \frac{K}{\mu_{\max} \theta - 1 + K} \right] \quad (XII)$$

Such that when $\theta / \theta_{\min} = \mu_{\max} \theta \gg 1 - K$, the graphs of B vs. $1/\theta$ are straight lines in which B coincides with B^0 when the retention time is infinite, which is to say the intercept of the lines coincides with B^0 .

Since B is the methane production per gram of substrate added, the volumetric methane production rate (δ) equals to B multiplied by loading rate :

$$\delta = BS_0 / \theta = (B_0 S_0 / \theta) \left[1 - \frac{K}{\mu_{\max} \theta - 1 + K} \right] \quad (XIII)$$

Where δ is the dimensionless of volume CH_4 per volume of digester per unit time. Taking the derivative of δ in terms of θ and equating it to zero obtain the maximum volumetric methane production rate, δ_{\max} . So,

$$\delta_{\max} = (B_0 S_0 / \theta_{\min}) \{ [1 - (K / (K + K^{1/2}))] / (1 + K^{1/2}) \} \text{ (XIV)}$$

The objective of this paper is to study the biogas yields at different slurry concentrations at three different temperatures. Essentially Chen Hashimoto kinetic model have also been used to evaluate kinetic parameters and ultimate bio-methane yields in each case and presented accordingly.

II. MATERIALS AND METHODS

2.1 Collection & preparation of sample

Fruit and vegetable wastes have been collected from local market and also collected from regular household activities like peeling and cutting prior to cooking. These wastes included peels and wastes portions of vegetables and fruits. They have been subjected to sun drying for 4 to 5 days followed by grinding to form fine powdered waste and passed through standard size reduction equipment for a particular particle size and finally stored in container for use in anaerobic digestion process.

2.2 Characterization of wastes

Waste sample have been characterized and results have been tabulated as follows:

<i>Parameters</i>	<i>Results</i>
<i>Moisture content (%)</i>	8.51
<i>Volatile matter (%)</i>	77.16
<i>Ash (%)</i>	7.07
<i>Fixed Carbon(%)</i>	7.25
<i>Calorific value (cals/gm)</i>	1913.4
<i>C:H:N</i>	83:12:5

2.3 Methods

All experiments have been performed in 1L batch digesters essentially made of glass. A set of 12 digesters have been used at a time for experimentation. Working volume of the process was 750ml and experiments have been conducted preparing a mixture of water and wastes in a ratio that gives a final solid concentration of 3%, 4%,5% and 6% at temperatures of 20,27 and 37°C. Pre-digested waste have been used as a source of mixed bacterial community for anaerobic digestion process. After all necessary additions the digesters have been rubber corked and allowed to stand still for 3 days and after that gas volume have been checked at an interval of 24hrs by method of downward displacement of water.



Fig: Experimental set up.

2.4 Limitations

As all the experiments have been conducted in batch process, the composition of slurry was measurable only once before and after experiment. Intermediate concentrations of substrate during reaction steps could not be measured.

III. RESULTS AND DISCUSSIONS

3.1 Comparison of bio gas yield for four different slurry concentrations using five different catalysts

Essentially experimental values of biogas yield (L/Kg) have been represented in fig 1. Here five different catalysts have been used to enhance the digestion process at 37°C temperature. pH have been maintained at 6.9 and retention for the process was 15 days respectively. All the catalysts have been added to the process at a concentration of about 0.5 g/L respectively.

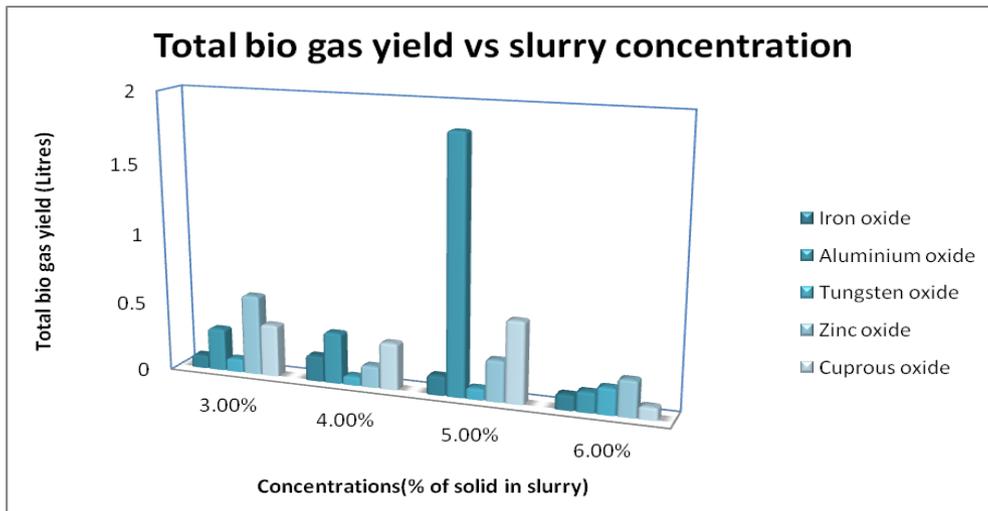


Fig 1

In fig 1, it can be seen that at 5% slurry concentration the yield of biogas is maximum with aluminium oxide as catalyst whereas all other catalysts have an average yield of biogas at the same conditions.

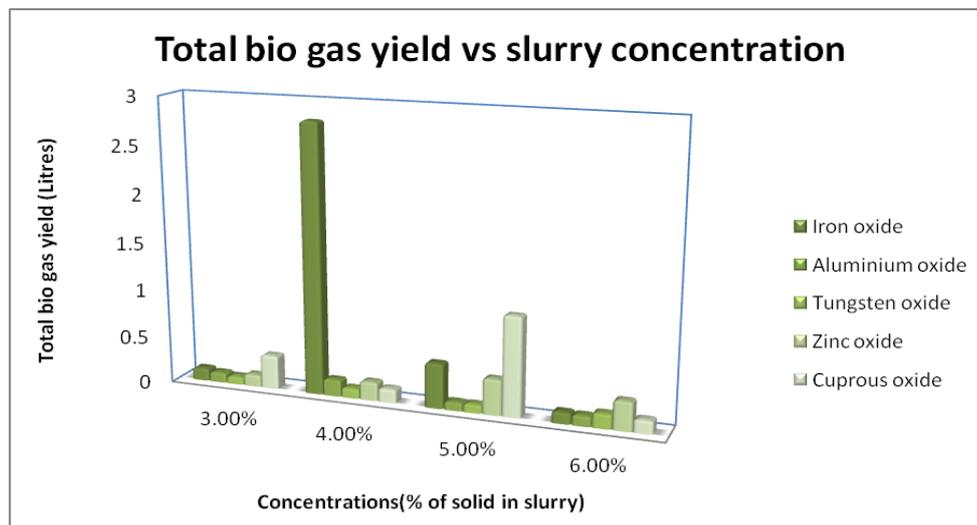


Fig 2

In the above fig 2, catalysts have been added @ 1g/L and maximum yield have been obtained for process with 4% slurry concentration and iron oxide catalyst while the yield was average for other catalysts only a slight higher yield for cuprous oxide at 5% slurry concentration. The retention time for the process with maximum yield have been observed to reduce by 4 to 5 days upon addition of catalyst.

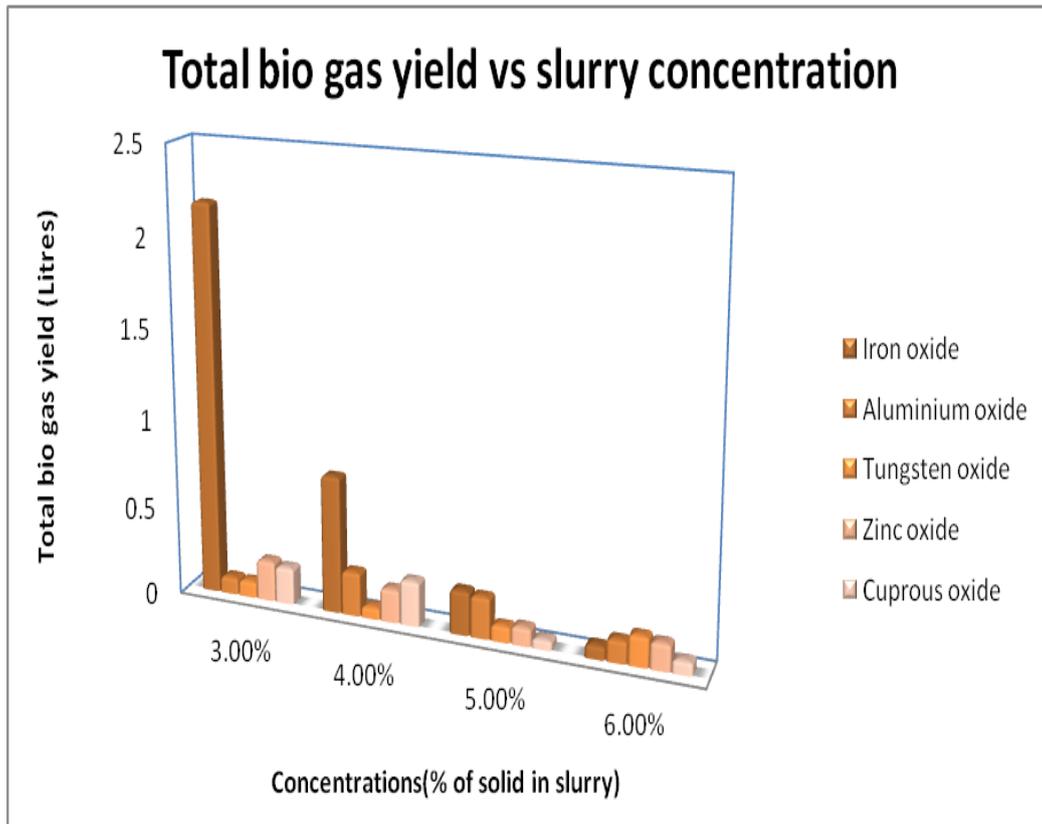


Fig 3

In the above fig 3, catalyst have been added @ 1.5g/L and yield is maximum for process with 3% slurry concentration and iron oxide as catalyst. Comparing all three figures we can say that overall yield of biogas is higher for process with iron oxide as catalyst at 4% slurry concentration & 0.5g/L of catalyst concentration. The next highest yield have been obtained for process with iron oxide at 3% slurry concentration and 1.5g/L of catalyst concentration. Aluminium oxide have been observed to have acted upon as good catalyst in terms of AD process at 5% slurry concentration & 0.5g/L of catalyst concentration.(fig 1).

3.2 Effect of concentration

3.2.1 Variation of ultimate gas yield with concentration

Different experiments have been done using no catalyst as well as with catalysts namely aluminium oxide, iron oxide, tungsten oxide, zinc oxide and cuprous oxide for the production of biogas. Experimental per day methane yield have been obtained and the values have been used for evaluating cumulative yield (B). Experimental cumulative methane yield have been plotted against $1/T$. From the graphs, intercept of each line (B^0 values) have been evaluated as shown in table A. Ultimate methane yields (B^0) have been evaluated in each case and tabulated in table A.

The values obtained for B^0 in $L\ CH_4\ STP/g$ are as follows:

TABLE A

Slurry Conc	B^0					
	No catalyst	Aluminium oxide	Iron oxide	Tungsten oxide	Zinc oxide	Cuprous Oxide
3%	0.226	0.348	2.737	0.126	0.599	0.566
4%	0.351	0.466	3.560	0.131	0.278	0.446
5%	0.182	2.272	0.520	0.164	0.504	0.914
6%	0.113	0.176	0.148	0.207	0.384	0.230

Table A shows ultimate maximum and minimum methane yields for four different slurry concentrations (3%, 4%, 5%, 6%) with no catalyst & five different catalysts as mentioned above. B^0 is a good parameter to determine the complete biodegradability of wastes at infinite retention time.

From the above table it is found that the ultimate methane yield is maximum for Iron oxide at 4% concentration followed by the second highest yield of the same at 3% concentration. For aluminium oxide the maximum yield was obtained at 5% slurry concentration where as zinc oxide and cuprous oxide resulted in higher yields at 3% and 5% concentrations respectively. For tungsten oxide the yield was maximum at 6% concentration and it was found that yield gradually increased with increase in slurry concentration for the same. Overall, it was found that the ultimate yield of methane increased with the use of catalysts for the process of anaerobic digestion because comparatively the ultimate yield of methane for process with catalyst is much higher than process with no catalyst. Amongst the maximum ultimate methane yields of all processes with catalysts at respective slurry concentrations, the highest yield have been obtained for process with Iron oxide as catalyst at 4% slurry concentration.

3.2.2 Variation of kinetic parameters with concentration

The two kinetic parameters maximum specific microbial growth rate, μ_{max} and saturation constant, K have been determined for all processes without catalyst as well as with catalysts. As per model equation (XI), $B/(B^0 - B)$ have been evaluated using B^0 values from tables A. Again T have been plotted against $B/(B^0 - B)$. The kinetic parameters μ_{max} and K have been calculated from the slope of straight line as shown in table B. Specifically $\mu_{max} = 1/\text{intercept}$ and $K = \text{slope}/\text{intercept}$. The values obtained for μ_{max} and K for each case have been tabulated in table B as follows:

TABLE B

Slurry conc	No catalyst		Aluminium oxide		Iron oxide		Tungsten oxide		Zinc oxide		Cuprous Oxide	
	μ_{max}	K	μ_{max}	K	μ_{max}	K	μ_{max}	K	μ_{max}	K	μ_{max}	K
3%	0.28	0.94	0.41	0.75	0.25	1.09	0.26	1.17	0.32	0.08	0.29	1.18
4%	0.34	1.28	0.25	0.84	0.26	1.37	0.32	1.31	0.29	1.21	0.25	0.70
5%	0.29	0.83	0.25	1.12	0.47	0.63	0.43	1.03	0.23	0.88	0.30	0.30
6%	0.27	0.94	0.29	0.80	0.31	1.12	0.40	0.74	0.21	0.63	0.42	0.42

Table B shows the variation of kinetic parameters μ_{max} and K for six different processes at respective slurry concentrations (3%, 4%, 5%, 6%).

From the above table it was found that the maximum specific growth rate is maximum for iron oxide at 5% slurry concentration. The significance of this kinetic parameter is that, the higher the value, the more will be the rate of growth of microbes and greater will be the bioconversion of materials. At 3% slurry concentration, the value is maximum for aluminium oxide while minimum for iron oxide. Similarly at 4% slurry concentration the value is maximum for no catalyst and minimum for both aluminium oxide and cuprous oxide. At 5%, the value is maximum for iron oxide while minimum for zinc oxide. At 6% concentration, the value is maximum for cuprous oxide and minimum for zinc oxide. The growth rate of microbes are totally dependant upon the slurry concentration and use of catalysts and the maximum value for μ_{max} was obtained for process with iron oxide at 5% slurry concentration. The kinetic parameters μ_{max} and K are interdependent. From the above figure it is found that K value is maximum for iron oxide at 4% slurry concentration. Higher K value can lower down the value of μ_{max} and viceversa.

3.3 Effect of temperature

3.3.1 Variation of ultimate gas yield with temperature

Different experiments have been done at three different temperatures namely 20°C, 27°C and 37°C at a fixed slurry concentration of 4% (30g/l) for production of biogas. Ultimate methane yield (B^0) have been evaluated in each case and tabulated in table C as follows:

TABLE C

Temperatures	B^0
Temp 1(20°C)	0.131
Temp 2(27°C)	0.178
Temp 3(37°C)	0.335

Table C shows the maximum and minimum ultimate methane yield for three different temperatures at a fixed slurry concentration of 4%. From the above table it is found that ultimate methane yield is maximum for 37°C and minimum for 20°C. At 27°C, the yield is intermediate between other two operating temperatures. So it is clear that ultimate methane yield increases with increasing temperature and viceversa. As rate of growth of microorganisms increases with increasing temperature within mesophilic range so rate of biomethane conversion increases with microbial growth.

3.3.2 Variation of kinetic parameters with temperature

Values of two kinetic parameters μ_{max} and K have been evaluated for processes operating at three different temperatures using values of cumulative methane yields and ultimate methane yields respectively. The values of μ_{max} and K have been tabulated as follows:

TABLE D

Temperatures	μ_{max} (per day)	K
20°C	0.23	1.11
27°C	0.33	0.94
37°C	0.32	1.03

Table D shows the maximum and minimum values of μ_{max} and K for three different operating temperatures.

The above table shows the variation of kinetic parameters with temperatures. The two kinetic parameters μ_{max} and K are interdependent. Higher K value (saturation constant) slows down the maximum specific growth rate μ_{max} . K value is maximum for 20°C and minimum for 27°C. So, higher the K value lower will be the μ_{max} and viceversa.

IV. CONCLUSION

Present study provides information about the useful utilization of FVW by anaerobic digestion process for the production of biogas. Study shows that how yield of biogas have been enhanced by the addition of catalyst and thereby how a kinetic model have been used to validate the yield of biogas being obtained. Certain process parameters have been found to be more effective than one another like slurry concentration, catalyst concentration and temperature. These parameters have been verified by the evaluated kinetic parameters that justify the optimum conditions for maximum yield of biogas.

V. ACKNOWLEDGEMENT

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Nomenclature

B = Volume of methane produced under normal conditions of temperature and pressure per gram of substrate used (L CH₄ STP/gram of substrate added)

B⁰ = Volume of methane produced under normal conditions of temperature and pressure per gram of substrate added at infinite retention time (L CH₄ STP/gram substrate added)

HRT = Hydraulic retention time (days)

θ or T = Hydraulic retention time (In kinetic model) (days)

μ = Specific microbial growth rate (per day)

μ_{max} = Maximum specific growth rate (per day)

S = Substrate concentration in the effluent (g/l)

S₀ = Feed substrate concentration (g/l)

R = Volumetric substrate utilization rate(g/l/day)

D = Dilution rate (h⁻¹)

K = Dimensionless kinetic parameter

B = Dimensionless kinetic parameter

X= Concentration of biomass (g VSS/l)

Y= Cell yield coefficient (g VSS/gram of substrate)

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