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Anaerobic Co-digestion of Cooked Food Waste, Paper Waste and Potato Peel Waste

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Abstract Conventional anaerobic digestion technology of mono substrate has certain limitations such as it has low waste to energy conversion efficiency, low degradation rate, low buffering capacity which leads to large volume of digester and high cost of biogas production So, in order to improve conversion efficiency and to accelerate biogas production, the researchers co-digested new combinations of various substrates like cooked food waste (CFW), crushed paper waste (CPW), dry & crushed potato peel waste (DCPPW) in different proportion using cow dung inoculum in the present study. This study was carried out under mesophilic temperature condition of 33°C in lab scale digesters. The results of study showed that maximum methane gas was produced at ratios of 2:2:4 CFW: CPW: DCPPW and at pH value of 7.1 while no biogas was produced at the ratios of 2:4:4, 4:2:2, 2:2:2 CFW: CPW: DCPPW due to deviation of pH value from ideal (6.8-7.2) that is required for survival and growth of methanogenic bacteria. By analyzing the data, it has been found that factor A (Cooked Food waste) had significant 59.3 % impact on methane gas yield which was followed by interaction factor ABC (CFW*CPW*DCPPW) 20.5%, interaction factor AB (CFW*CPW) 12.26%, interaction factor BC (CPW* DCPPW) 3.37% and factor AC (CFW*DCPPW) 2.99%. The factor B (Crushed paper waste) as well as C (Dry & Crushed potato peel waste) alone had negligible impact on methane gas yield. Using formulated regression model, optimum volume of predicted methane gas was found out which was 398.5 Nml.

Keywords: *bio waste, co-digestion, interaction factor, degradation rate*

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1. Introduction

Biowaste material is constantly increasing across the world due to human activities, urbanization, rapid growth of population and industrializations. Different waste to energy technologies like incineration and gasification are widely adopted across the world to treat biowaste. But usage of this technologies creates environmental and health impacts. The most common solution to manage waste, is to dispose of it in to landfills. But main problems with this is, most of landfills are running out of space and its dispose into land fill creates soil and ground water contamination. Mexico City produces nearly about 12500 tons of wastes daily and these wastes are sent into landfill that is running out of space [1,2]. Similar situation prevailing in many parts of the world.

In pyrolysis and gasification process, energy conversion efficiency decreases with increases in moisture content. Therefore, usage of these technologies requires pre-drying of biomass to reduce its moisture content. In contrast to this, anaerobic digestion process convert biomass into energy in fluidic environment. Anaerobic digestion is one of promising technologies to treat organic waste, to generate renewable energy, to solve problems of global warming, climate change issue, energy crisis wherein digestate material from the process can be used as fertilizer. The biogas is produced by anaerobic digestion and the methane is one of constituent of biogas. But anaerobic digestion of mono substrates has number of limitations such as acidification, weak buffering capacity, high ammonia nitrogen content, nutritional imbalance which affects process stability and biogas generation [3,4]. In order to overcome this problem and to enhance biogas production the researcher, co-digested various combination of new substrates using cow dung inoculum in the present study.

1.1. Anaerobic Co-digestion

Anaerobic co-digestion involves simultaneous digestion of two or more substrates, has been shown to be beneficial to alleviate problems of mono digestion such as toxic or resisting compounds in substrates, imbalance nutrients etc. and helps in increased in faster methane production by supplementing missing nutrients by co-substrates. A number of biowaste can be co-digested at a suitable blending ratio in order to optimize metabolic activity and biogas production. In order to avoid process instability, inhibition and improve biogas production, substrates having higher C/N ratio such as rice and wheat straw, corn stalks, algae etc. can be blended with the substrates having lower C/N ratio such as food and kitchen waste, pig manure, poultry manure and so on [5,6,7,8]. Co-digestion resolves the problems of mono digestion of resistive bio mass by providing necessary alkalinity and nutrients [9].

An inoculum source plays an important role in anaerobic digestion performance as it affects degradation rate, digester stability, biogas quality and substrate retention time in the digester [10,11,12]. Inoculum reduces hydraulic retention time, improves stability of anaerobic digestion process and is an economically viable solution to produce high quality biogas. Oviya et al. [13] investigated effect of cow dung and domestic sewage inocula on anaerobic digestion of municipal solid waste. They reported that cow dung produced optimum biogas with methane concentration of 70 % while domestic sewage inocula produced biogas with methane concentration of 63 % only. Thus, they concluded that cow dung inocula was most effective compared to domestic sewage sludge inocula. They carried out study at room temperature and with sixty days retention time. Nasir et al. [14] investigated effect of different ratio of palm mill effluent inoculum on anaerobic digestion of cattle manure. For this, they varied two ratios such as 5:1.5 and 5: 1 (cattle manure: pam mill effluent inoculum) and reported that out of these two ratios 5: 1.5 (cattle manure: pam mill effluent inoculum) gave better results. Elniski et al. [15] reported effect of cow dung inoculation on anaerobic digestion of office paper waste. Office paper and cow manure were mixed at solid concentration of 6% under a mesophilic temperature condition of 38.4^0 C for a retention time of 15 days. They reported that optimum biogas was produced at ratio of 2:1 (paper: cow dung inoculum) over a period of fifteen days. Yen HW, Brune DE. [16] co-digested algal sludge with paper waste to investigate its effect on biogas production. They reported that optimum biogas was produced at ratio of 50:50 (algal sludge to paper waste ratio on a volatile solid basis) and corresponding volume of methane gas was 1170 +/- 75 ml/Iday. The also reported that mono digestion of algal sludge produced 573 +/-28 ml/Iday of methane gas. Both digesters were operated at 4 g VS/l day, 35^0 C and 10 days of hydraulic retention time.

Borowski et al. [17] reported that co-digestion of swine manure (30%) with municipal sewage sludge (70%) increased biogas production by 40 % compared to sewage sludge alone. Alvarez et al. [18] co-digested bolivian waste like cattle and swine manure, slaughter house waste (rumen, paunch content, blood from cattle and swine) and fruit & vegetable waste under mesophilic condition in a semi continuous digester. The study concluded that with help of co-digestion process these wastes can be treated successfully which otherwise cannot be treated separately.

Rajput et al. [19] reported that highest biogas was produced from sunflower meal and wheat straw digesters under mesophilic temperature condition (at 35°C) using digested manure inoculum which was followed by acclimatized sludge and septic tank sludge inoculum. They found that sunflower meal inoculated with digested manure increased biogas yield by 102 % and 11 % compared to septic tank sludge and acclimatized sludge inoculum. Similarly, they observed that wheat straw inoculated with acclimatized sludge increased biogas yield by 87 and 40 % compared to septic tank sludge and acclimatized sludge inoculum. Hailin et al. [20] co-digestated kitchen waste with pig manure at different volume ratios to investigate its effects on biogas production. They found that optimum biogas was produced at ratio of 1 :1 (kitchen waste: pig manure) and corresponding volume of methane gas was 409.55 mL/gVS. They also noticed that when kitchen waste concentration was increased beyond 50 percent then severe methane inhibition occurred due to accumulation of volatile fatty acids.

Ranjitha et al. [21] carried out experimental investigation to compare biogas production from flower waste (jasmine, sunset flower, roselle African wattle, Nile tulip flower and silk tree mimosa) and vegetable waste (brinjal, cabbage, carrot, ladies finger). They use one litre anaerobic digester and cow dung as an inoculum for the study. They found that floral waste produces faster and more biogas compared to vegetable waste. They reported that floral waste produces 16.69 g/kg of biogas while vegetable waste produces 9.089g/kg of biogas. They also concluded that floral wastes have very good potential for biogas production.

Parawira et al. [22] co-digested potato waste with sugar beet leaves. They reported that co-digestion improves biogas yield by 31-62% compared to potato waste alone. Shah et al. [23] and Meiramkulova et al. [24] reported that co-digestion of pig manure with glycerol under mesophilic conditions at ratio of 24:1 increases biogas production by 400 % compared to mono digestion of pig manure alone. They also concluded that co-digestion of various substrates with animal manure can improve bio gas production from 25-400 %

In order to accelerate fermentation process and to enhance biogas production eight experiments were performed in a laboratory, using cooked food waste (CFW), crushed paper waste (CPW), dry & crushed potato peel waste (DCPPW) with different volume proportions using cow dung inoculum. The main objective of present investigation is to determine optimum mixing ratio at which co-digested substrates is able to produce optimum biogas so as to enable efficient utilization of organic bio mass and digester volume.

2. Materials and Method

2.1. Materials

All substrates used in this study and is shown in Table 1 of experimental design were collected from Goraj Village, Dist. Vadodara and Vadodara City, Gujarat, India.

In this study, cooked food waste consists of mixture of cooked cabbage waste, dal waste (made of Toor dal), roti/flat bread (made of wheat flour), rice waste, taken in equal proportions and crushed in domestic mixer as shown in Figure 1(a). The crushed paper waste as shown in Figure 1(b) consists of local newspaper (Gujarat Samachar) waste which was first cut in small pieces with the help of scissor and then after they are crushed in domestic mixer. The potato peel waste was firstly dry in sunlight for a period of

35 days and then after it was crushed in domestic mixer as shown in Figure 1 (c). The Inoculum used in this study and as shown in Figure 1 (d), was taken from actual biogas plant which is located near by Muni Seva Ashram, Goraj Village, Dist. Vadodara, Gujarat, India and operating on cow dung as substrate. This study was carried out in biogas laboratory of Muni Seva Ashram, Goraj Village, Taluka Waghodiya, Dist. Vadodara, Gujarat, India.

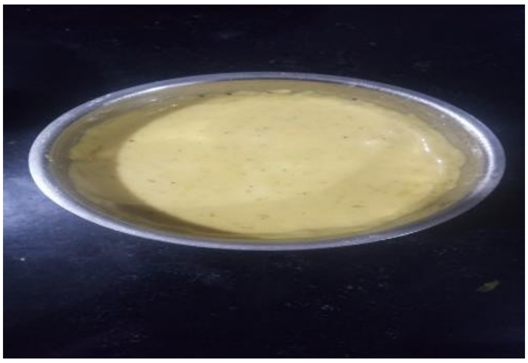

Figure 1 (a) Cooked Food Waste

Figure 1 (b). Crushed Paper Waste

Figure 1 (c) Dry & Crushed Potato Peel Waste

Figure 1 (d) Cow dung Inoculum

2.2. Description of Experimental Set up

The experimental set up as shown in Figure 2 is comprised of (i) Digester Unit (ii) Scrubber Unit (iii) Gas measuring Unit and (iv) Data acquisition Unit which are described as below.

Figure 2. Experimental Set Up

Digester Unit: comprised of digester reactors with each of total volume of 600 ml, thermostatic water bath, stirrer and electric motor. The thermostatic water bath is provided below the digester unit and desired temperature was maintained in it with the help of heating element provided for this purpose.

Scrubber Unit: comprising of fifteen glass tank/jar each having capacity of 100 ml. The glass jar was filled up to 60 ml water to absorb carbon dioxide, hydrogen sulphide gas etc. during the study.

Gas Measuring Unit: The automatic methane potential test system II model (AMPTS-II model) of bioprocess control Sweden based company was used in this study and as shown in Figure 2. Gas measuring unit comprising of fifteen load cell and it works on buoyancy & liquid displacement principle.

After absorbing carbon dioxide, hydrogen sulphide etc from produced biogas, the gas was then allowed to pass through gas measuring unit. When a definite quantity of gas was passed through gas measuring unit, a digital pulse was generated and it was then sent to embedded data acquisition system to record volume of gas.

Data Acquisitions System: With the help of automatic methane potential test system software and data logger, the volume of generated gas was recorded.

2.3. Methodology

The step by step procedure of conducting experiments was as follows

(a) First of all, various substrates as shown in design of experiments Table 1 were prepared, dry and crushed as stated in materials section.

(b) In a second step, substrates and cow dung inoculum were weighted using weighing machine and beaker respectively.

(c) The weighted substrates were mixed with distilled water and cow dung inoculum in ratios of 1:6 and then after they fed into digesters. Then after closed top cover of digesters to maintain anaerobic condition inside it. Before starting experiment, electrical motors were connected in series for stirring and also biogas reactors outlet were connected to scrubber unit.

After this procedure, scrubber unit was connected to biogas measuring unit. To avoid mistake, labelled on the biogas reactors, scrubbers were made. The scrubber unit and gas measuring units were filled up with distilled water up to certain level (marking is provided for this purpose) before starting experiments.

(d) In a next step, constant stirrer RPM of 160 should be maintained inside the digester with the help of d. c motor for a period of one hour so that through mixing of substrates with water and cow dung inoculum took place.

The mixture was retained inside the digester for a period of 35 days and a constant temperature of 33°C was maintained in each digester by means of thermostatic water bath provided for this purpose. The produced gas was measured with the help of AMPTS based data acquisition system and laptop. After completion of every seven days, again constant stirrer RPM of 160 should be maintained inside the digester for period of ten minutes. pH value and biogas generation were measured at interval of every seven days.

2.4. Design of Experiment

Various Substrate in different ratios were co-digested according to 2^n factorial design and is shown in Table 1. Here n = 3 and is equal to number of factors such as factor A (Cooked Food Waste), factor B (Crushed Paper Waste), factor C (Crushed Paper Waste). Base two in 2^n is levels of factors i.e., Low level (2.0 gram) and High Level (4.0 gram) for all three factors. Low level is specified by (-1) and High Level is by (+1) in the Table 1**.**

3. Results and Discussion

From Figure 3, Effect of retention time vs methane gas yield, it is clearly seen that methane gas generation increase up to retention time of seven days in Reactors R2, R8, R6, R3 & R4 then after there was no increase in methane gas production means methane gas generation remains constant after retention time of 7 days. It was also observed that during first seven days of fermentation, methane gas generation was highest and faster in reactor R2 which was followed by reactor R8, R6, R3 & R4. The order of methane gas production was R2>R8>R6>R3>R4.

From the Figure 4 Effect of pH vs methane gas yield, it is seen that maximum methane gas was produced in reactor R2 at ratio of 2:2:4 (Cooked food waste (CFW): Crushed Paper Waste (CPW): Dry & Crushed Potato Peel waste (DCPPW) and at pH value of 7.1 which was followed by reactors R8 (317.9 Nml), R6 (255.6 Nml), R3 (163.6 Nml), R4 (100.8 Nml) at pH value of 7.1, 7.2, 7.0,7.2 respectively. In the reactors R1, R5, R7 no biogas was generated due to process inhabitation and acidic or alkaline solutions which inhibit anaerobic digestion process. It was also observed that pH value which was measured during the study remains constant.

Table 1. Standard Run of 2^3 Factorial Design, pH Value & Cumulative Methane gas Yield

Run	Reactors	Factor A	Factor B	Factor C	Cow Dung Inoculum in ml Inoculum to Substrate Ratio 6.0	pH	Cumulative methane gas Yield in Nml
		Cooked Food Waste in Gram	Crushed Paper Waste in Gram	Dry & Crushed Potato Peel Waste in Gram			
(1)	R1	2.0	4.0	4.0	60.0	8.5	0.0
(2)	R2	2.0	2.0	4.0	48.0	7.1	425.5
(3)	R3	4.0	4.0	2.0	60.0	7.0	163.6
(4)	R4	2.0	4.0	2.0	48.0	7.2	100.8
(5)	R5	4.0	2.0	2.0	48.0	6.5	0.0
(6)	R6	4.0	2.0	4.0	60.0	7.2	255.6
(7)	R7	2.0	2.0	2.0	36.0	8.0	0.0
(8)	R8	4.0	4.0	4.0	72.0	7.1	317.9

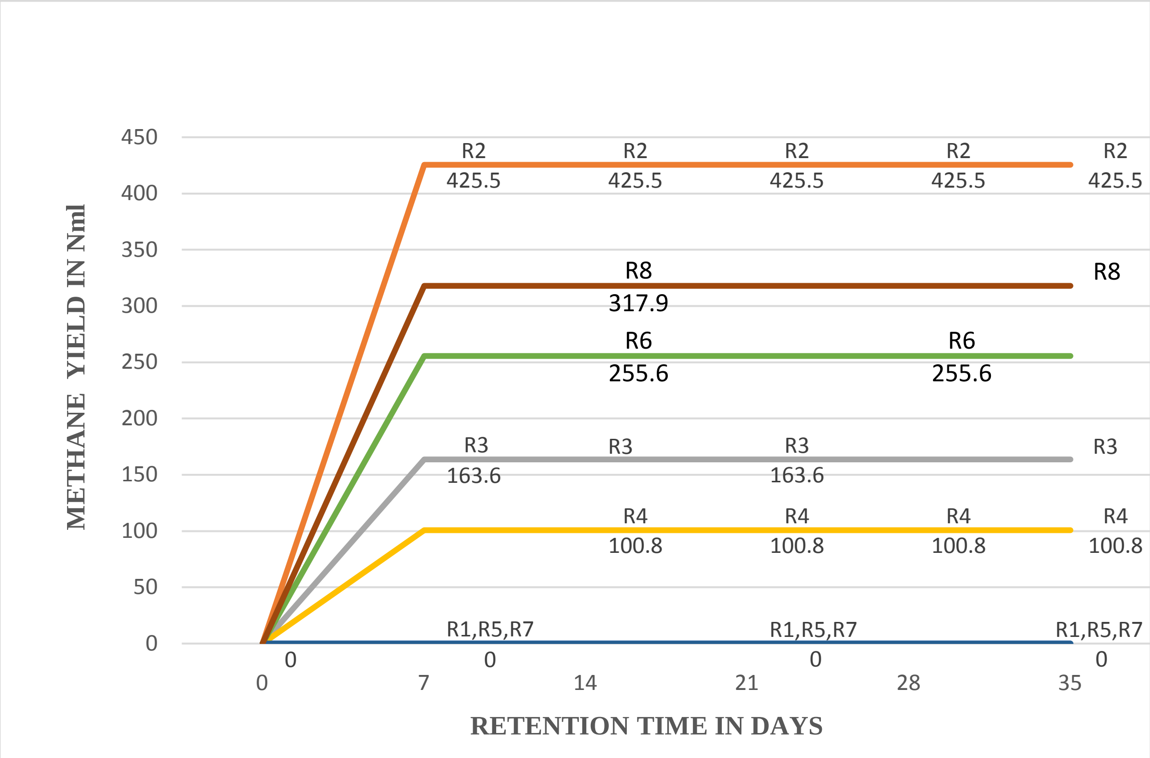

Figure 3. Effect of Retention Time on Methane gas Yield

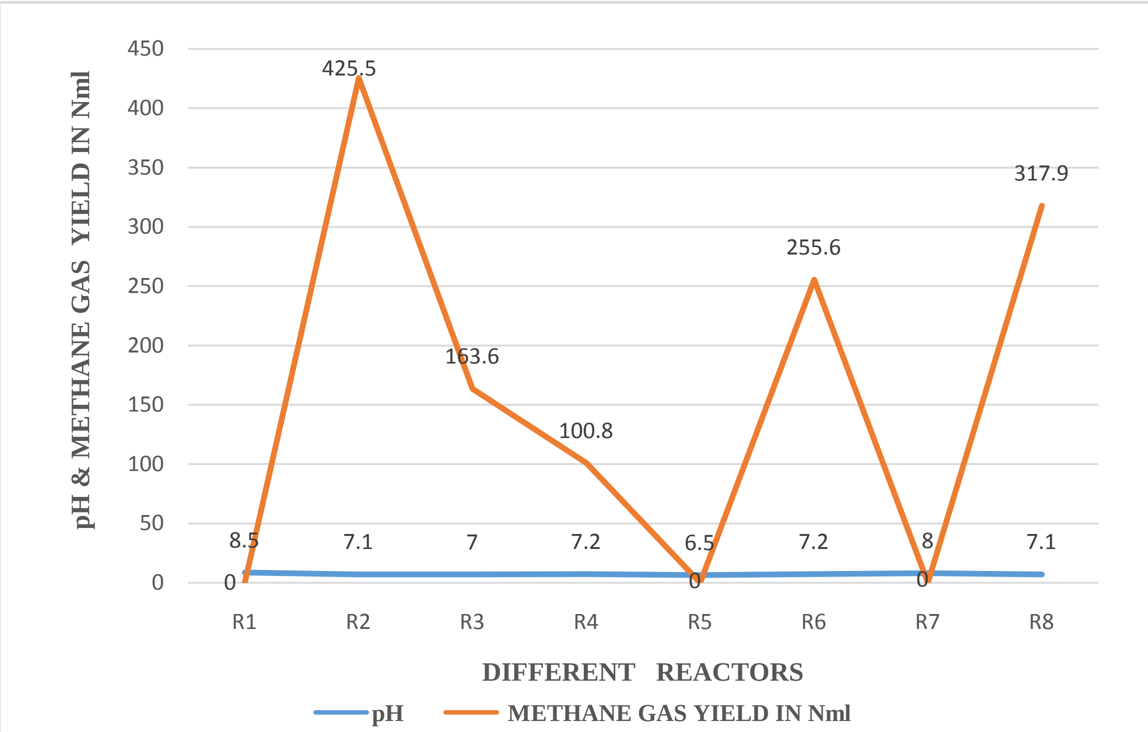

Figure 4. Effect of pH on Methane gas Yield in Different Reactors

3.1. Statistical Analysis

The 2^3 factorial design is used to analyzed this study and effect of various factors on methane gas is calculated by finding average of each factor. In this study researchers varied proportion of three factors say cooked food waste (factor A), crushed paper waste (factor B), dry & crushed potato peel waste (factor C) from two grams to four grams and investigates its effects on methane gas production using cow dung inoculum. The variation caused by each factor is calculated by analysis of variance.

Variation due to Factor A (Cooked food waste) on methane gas yield is calculated as follows:

$$SS_A = 2^3\left[Effect\right]^2 = 2^3\left[117.0\right]^2 = 109512\ Nml^2 \quad (1)$$

Similarly, variation caused by factor B (Paper Waste), factor C (Dry & Crushed Potato Peel waste), Interaction factor AB (Cooked Food Waste* Paper waste), factor BC (Paper waste*Dry & Crushed Potato Peel Waste), AC (Cooked Food Waste * Dry & Crushed Potato Peel Waste), factor ABC (all three waste) are calculated and sum of variation (SS_T) caused by each factor gives you total variation

The Fraction of variation caused by factor A is given by

$$\begin{aligned} &= SS_A / SS_T = 109512 / 184674.56 \\ &= 0.5930 = 59.30\% \end{aligned} \quad (2)$$

Similarly, fraction of variation caused by other factors are calculated and is shown in pareto chart.

From the Figure 5, it is clearly seen that factors A (Cooked Food Waste), factor ABC (all three Waste), factor AB (Cooked Food Waste & Crushed Paper Waste), BC (Crushed Paper Waste & Dry and Crushed Potato Peel Waste), factor AC (Cooked Food Waste & Dry and Crushed Potato Peel waste) have significant impact on methane gas yield except factor C (Dry & Crushed Potato Peel Waste) & factor B (Crushed Paper Waste) therefore prediction equation becomes.

Predicted methane gas Yield Y is given by

$$\begin{aligned} &= q_0 + q_A X_A + q_{AB} X_{AB} + q_{BC} X_{BC} \\ &\quad + q_{AC} X_{AC} + q_{ABC} X_{ABC} \\ &= 157.9 + 117\ X_A - 53.2\ X_{AB} \\ &\quad + 27.9\ X_{BC} + 26.3\ X_{AC} + 68.8\ X_{ABC} \end{aligned} \quad (3)$$

Where q_0, q_A, q_{AB}, q_{BC}, q_{AC}, q_{ABC} = mean and effect of Factor A, Interaction Factor AB, BC, AC and ABC respectively.

X_A, X_{AB}, X_{BC}, X_{AC}, X_{ABC} = Levels of Factor A, Interaction factor AB, BC, AC and ABC respectively i.e., Low Level (-1) and High Level (+1).

Table 2. Calculation of Effects of Various Factors on Methane gas Yield

Run	Factor A	Factor B	Factor C	Interaction Factor				Methane gas Yield in Nml
	Cooked Food Waste	Crushed Paper Waste	Dry & Crushed Potato Peel Waste	AB	BC	AC	ABC	
1	-	-	-	+	+	+	-	0.0
2	+	-	-	-	+	-	+	425.5
3	-	+	-	-	-	+	+	163.6
4	+	+	-	+	-	-	-	100.8
5	-	-	+	+	-	-	+	0.0
6	+	-	+	-	-	+	-	255.6
7	-	+	+	-	+	-	-	0.0
8	+	+	+	+	+	+	+	317.9
Total	936.2	-98.8	-116.4	-426.0	223.4	210.8	550.6	1263.4
Effect	117.0	-12.3	-14.5	-53.2	27.9	26.3	68.8	157.9

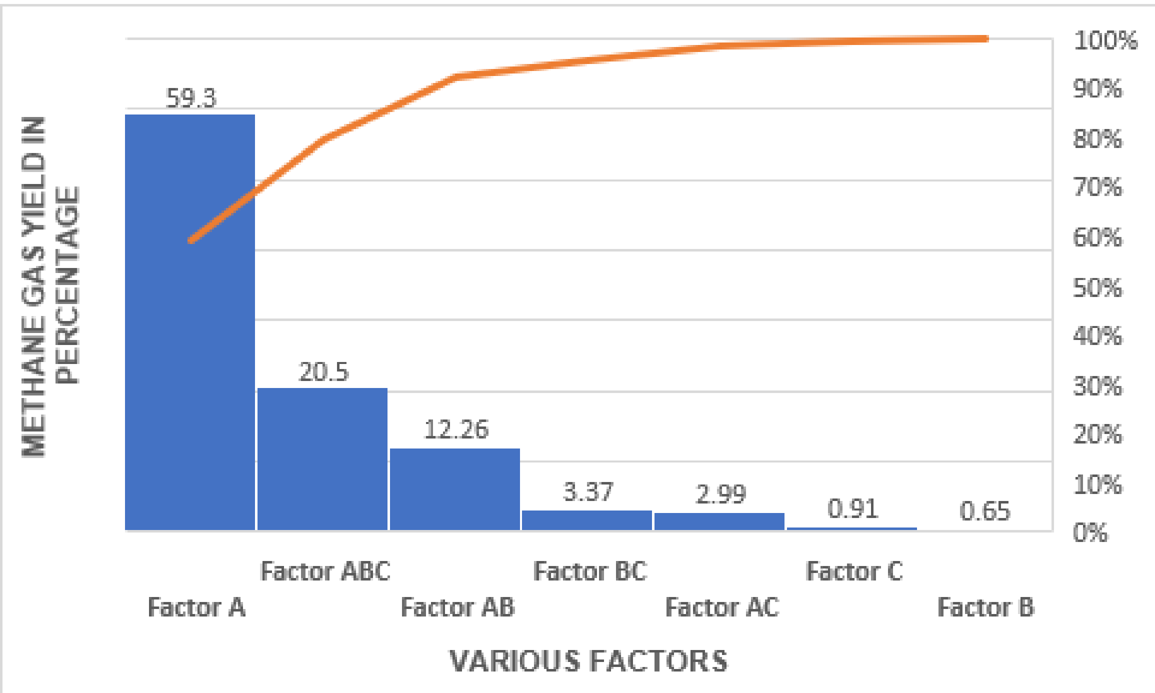

Figure 5. Effects of Various Factors on Methane gas Yield

The results of study showed that
(i) Mean Performance was 157.9 Unit.
(ii) Factor A i.e., Cooked Food Waste had ± 117unit (59.30%) impact on methane gas yield.
Its higher value increased methane gas yield by 117 unit while Lower value of factor A decreased methane gas yield by 117 unit.
(iii) Factor B (Crushed Paper Waste) and Factor C (Dry & Crushed Potato Peel Waste) alone had negligible 0.65 & 0.91 % impact on methane gas yield respectively.
(iv) Interaction Factor AB i.e., Cooked Food Waste & Crushed Paper Waste had ± 53.2 unit (12.26%) impact on methane gas yield.
Its lower value increased methane gas yield by 53.2 unit while its higher value decreased methane gas yields 53.2 unit.
(v) Interaction Factor BC i.e., Crushed Paper Waste & Dry and Crushed Potato Peel Waste had ± 27.9 unit (3.37%) impact on methane gas yield.
Its higher value increased methane gas yield by 27.9 unit while its lower value decreased methane gas yield by 27.9 unit.
(vi) Interaction Factor AC i.e., Cooked Food Waste & Dry and Crushed Potato Peel waste had ± 26.3 unit (2.99%) impact on methane gas yield.
Its higher value increased methane gas yield by 26.3 unit while its lower value decreased methane gas yields 26.3 unit.
(vii) Interaction Factor ABC (All three Waste) had ± 68.8 unit (20.50%) impact on methane gas yield.
Its higher value increased methane gas yield by 68.8 unit while its lower value decreased methane gas yields 68.8 unit.
(viii) Maximum volume of generated methane gas was 425.5 Nml at pH value of 7.2 and corresponding retention time was seven days. After this retention time, no further increased in methane gas generation was observed. No methane gas was produced in Reactors R1, R5 and R7 due to process inhibition.

4. Conclusion

Different substrates have different nutrients value so if they are co digested, anaerobic digestion process improves by supplying missing nutrients by co-substrates. It has been concluded that new combination of co-digestion of various substrates like cooked food waste (CFW), crushed paper waste (CPW) and dry & crushed potato peel waste (DCPPW) with cow dung inoculum resolves problem of mono digestion to some extent by providing buffering capacity and missing nutrients. However, no biogas was produced in the reactors R1, R7 at ratios of 2:4:4, 2:2:2 (CFW: CPW: DCPPW) due to alkaline environment. The results of study also showed that no biogas was produced in the reactor R5 at ratios of 4:2:2 (CFW: CPW: DCPPW) due to acidic environment in the reactors. So, these ratios should be avoided in order to avoid process inhibition. Optimum volume of methane gas was produced in reactor R2 at ratios of 2:2:4 which was followed by reactors R8 (317.9 Nml), R6 (255.6 Nml), R3 (163.6 Nml), R4 (100.8 Nml) at pH value of 7.1, 7.2, 7.0, 7.2 respectively.

Methane gas production can be optimised by selecting higher concentration of factor A (Cooked Food Waste), lower concentration of factor B (Crushed Paper Waste), lower concentration of factor C (Dry & Crushed Potato Peel waste), lower concentration of interaction factor AB (Cooked Food Waste * Crushed Paper Waste), higher Concentration of BC (Crushed paper Waste * Dry and Crushed Potato Peel Waste), lower concentration of AC (Cooked Food Waste * Dry and Crushed Potato Peel Waste) and higher concentration factor ABC (All three Waste).

Predicted Optimum Methane gas Yield

$$\begin{aligned} Yoptimum &= 157.9 + 117\ X_A - 53.2\ X_{AB} \\ &+ 27.9\ X_{BC} + 26.3\ X_{AC} + 68.8\ X_{ABC} \\ &= 157.9 + 117(1) - 53.2(-1) \\ &+ 27.9(1) + 26.3(-1) + 68.8(1) \\ &= 398.5\ Nml \end{aligned}$$

This is corresponding to run 2 of experimental design.

In this research work, low level of substrate was taken as 2.0 gram while high level of substrates was taken as 4.0 gram and substrates to cow dung inoculum and substrates to water ratios were taken as 1:6 (on volume basis). Therefore, to find optimum biogas generation at other levels of substrates and others ratios of substrate to inoculum, substrates to water ratio more and more investigations needs to be carried out.

Conflicts of Interest

There are no conflicts of interest to be declare under this manuscript.

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