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Anaerobic co-digestion of pressmud with vegetable waste in batch reactor for enhanced biogas production

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Abstract

This study investigates the co-digestion of pressmud, a residue from sugarcane processing, and vegetable waste, with cow dung serving as the inoculum. The aim is to explore the potential of this tripartite mixture to enhance biogas production, streamline waste management, and contribute to sustainable energy generation. In recent years, the escalating concerns surrounding environmental sustainability and waste management have prompted significant research into innovative and eco-friendly approaches. Anaerobic co-digestion has a potential to enhance biogas yields beyond what is achievable with individual substrates. The complementary nature of diverse organic materials can stimulate microbial activity, leading to increased methane production. Additionally, co-digestion can alleviate challenges associated with certain substrates, such as the presence of inhibitory compounds or imbalanced nutrient ratios, by leveraging the compensatory attributes of other materials. The anaerobic co-digestion was carried out through the substrate and inoculum ration of 1:1. The digestion of pressmud and vegetable waste was carried out at different ratio of PM:VW (100:0, 70:30, 50:50, 30:70, 0:100) in one litre reagent bottle. The batch study was conducted for the period of 30 days. The methane gas was measured directly by passing the biogas into the alkaline solution by water displacement method. The effect of pH was noted throughout the study. Results shows that least methane yield was obtained in the ration 50:50 (PM: VW) and maximum methane yield was obtained in the 30:70 (PM: VW).

Keywords: Anaerobic co-digestion, pressmud, vegetable waste, cow dung, Gompertz model and methane yield.

1.Introduction

The global landscape of waste management and sustainable energy generation has spurred an intensified exploration of innovative approaches to address these pressing challenges [1]. Anaerobic co-digestion, a novel biotechnological solution, has gained prominence as a promising method for simultaneously managing organic waste and producing renewable energy [2]. The pressing challenges of population growth, urbanization, and industrialization have accentuated the global demand for energy and aggravated the environmental burden of organic waste disposal [3], [4]. As a result, the search for sustainable and efficient waste management solutions has become increasingly critical in the 21st century [5]. A promising approach to handle both energy and waste management issues is anaerobic digestion, a biological process that naturally breaks down organic matter without oxygen [6], [7].

Anaerobic digestion has been employed for centuries to convert organic materials into biogas, a renewable energy source primarily composed of methane and carbon dioxide [8], [9]. Traditionally, anaerobic digestion systems have focused on treating specific types of organic waste, such as sewage sludge or agricultural residues[10]. However, advancements in technology and a growing understanding of microbial interactions have spurred interest in exploring more holistic approaches, such as anaerobic co-digestion [11].

Anaerobic co-digestion involves the simultaneous treatment of multiple organic substrates, which could be of diverse origin, composition, and complexity[12], [13]. By synergizing the digestion of various feedstocks, co-digestion holds the potential to improve biogas production rates, enhance process stability, and contribute to a circular economy model by valorising organic wastes [14], [15].

Pressmud, a byproduct of sugarcane processing, is an abundant residue that often poses challenges due to its moisture content and potential environmental impact [16]–[18]. In tandem, vegetable waste generated from agricultural, culinary, and processing activities contributes to the growing organic waste burden [19]–[22]. The global adoption of anaerobic co-digestion as a means to co-process these substrates signify a paradigm shift towards circular economy principles, wherein organic waste is transformed into a valuable resource [23], [24].

This research paper aims to know the best ratio of pressmud and vegetable waste in anaerobic co-digestion and its impact on biogas production efficiency and waste management practices. By investigating the synergistic effects of co-digestion and the factors influencing its performance, this study seeks to provide a comprehensive assessment of the viability and scalability of this approach.

2.Materials and methods

2.1.Substrate

The substrate 1 pressmud which was used in this study was collected from NSL sugar Ltd. Located near Maddur taluk, Mandya district and the substrate 2 vegetable waste was collected from the smart point supermarket present near Hosahalli metro station, Vijayanagar, Bangalore. The vegetable waste majorly consists of carrot, onion, tomato, cabbage, potato, cucumber, beans. The cow dung was used as inoculum which was collected from cattle shed present near Magadi road metro station, cholurpalya, Bangalore.

2.2.Experiment setup

The reactor design was followed as same mention in the [25]–[27].The test was carried out in 1 litre reagent bottle which was covered with cork to obtain air tight system, the cork had two openings one for measurement of gas and second for the collection of samples to analyse the pH. Fig.1 shows the design of the reactor followed and the water displacement setup used to measure the methane. The reactors had working volume of 800 ml and consists of different ratio of pressmud and vegetable refer **Error! Reference source not found.** for the details. The 200 ml space was left empty for the collection of the gas, the reactor was connected with drip set to measure the gas.

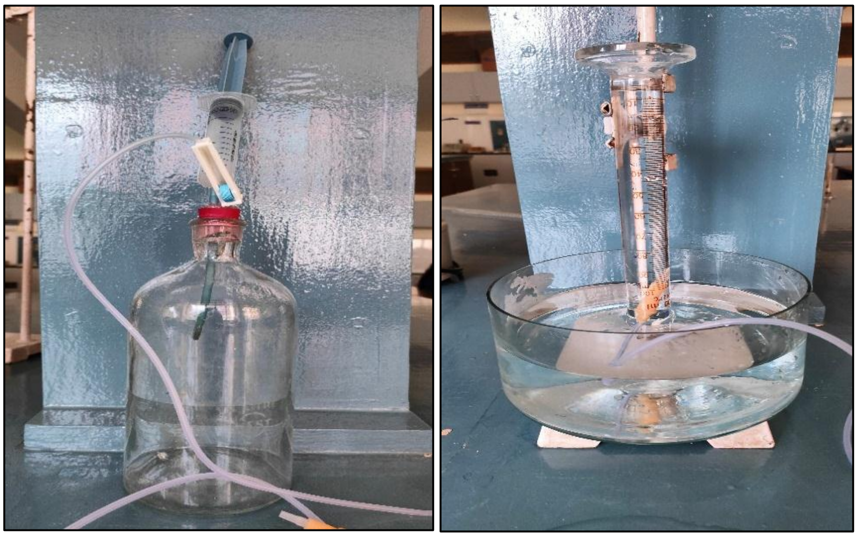

Figure. 1. Experiment setup (a) reactor and (b) water displacement setup

Table 1:-Fraction of the substrate and inoculum used in the batch reactors.

Reactor	Ratio (PM:VW)	Working volume (ml)	PM (ml)	VW (ml)	CD (ml)
R1	100□0	800	400	0	400
R2	70□30	800	280	120	400
R3	50□50	800	200	200	400
R4	30□70	800	120	280	400
R5	0□100	800	0	400	400

2.3.Analytical methods

The pH was analysed using a pH meter (systronics 361). The total solids (TS) and volatile solids (VS) test was carried out according to 2540 G standard method. The total alkalinity (TA) was measured using standard method 2320B. The liquid displacement method was used to measure the volume of gas, methane was measured directly by using 3% NaOH solution (alkaline solution) where the CO2 is observed by the alkaline solution remaining volume is considered as methane.

3.Results and discussions

3.1.Characterization of substrate and inoculum

Refer table 2 for physio-chemical characterization of substrate and inoculum

Table 2: Characterization of raw substrate and inoculum.

Parameters	PM	VW	CD
pH	6.4	4.7	8.3
Total Solids (%)	32.4	24.70	31.95
Volatile Solids (%TS)	78.37	84.70	96.75
VS/TS	0.78	0.85	0.96
Carbon (%)	14.10	11.62	17
Alkalinity (mg/L)	3880	900	ND
tCOD (mg/L)	134.4	68	ND

3.2.Characterization of mixtures

Initial characterization of mixtures are represented in table 3. The Fig. 2 shows the reactors filled with different ratio of mixture of pressmud and vegetable waste. The pH, alkalinity, total solids, volatile solids, VS/TS ratio were determined at first day of the study. The alkalinity, pH and VS/TS ratio were low where R5 containing 100% VW had the lowest values when compared to other reactors. The R1 containing 100% pressmud had greater value than R5 but they were also low when compared to optimum range. The R2, R3, R4 had the values which were not optimum initially.

Figure. 2. Reactors filled with different mixtures of PM: VW

Table 3: Initial characterization of mixture substrate at different ratio

Parameters	R1	R2	R3	R4	R5
pH	6.26	5.88	5.54	5.46	5.07
Alkalinity (mg/L)	3000	1500	1400	800	500
TS (%)	17.12	19.28	18.1	19.08	16.2
VS (%)	14.5	12.32	11.2	12.04	9.86
VS/TS (%)	0.85	0.64	0.62	0.63	0.61

3.3.Effect of pH on anaerobic co-digestion

The monitoring of pH is one of the important factors in anaerobic digestion, the methanogens are sensible to pH change, the favourable condition for methanogens to produce methane gas is pH range of 6.5 to 7.5. The below Fig. 3 shows the pH variation throughout the study, the pH of R3 was not in the range of optimum pH throughout the study which also yielded lowest methane yield. Initially pH of the reactors was low later during digestion process the pH was in optimum range.

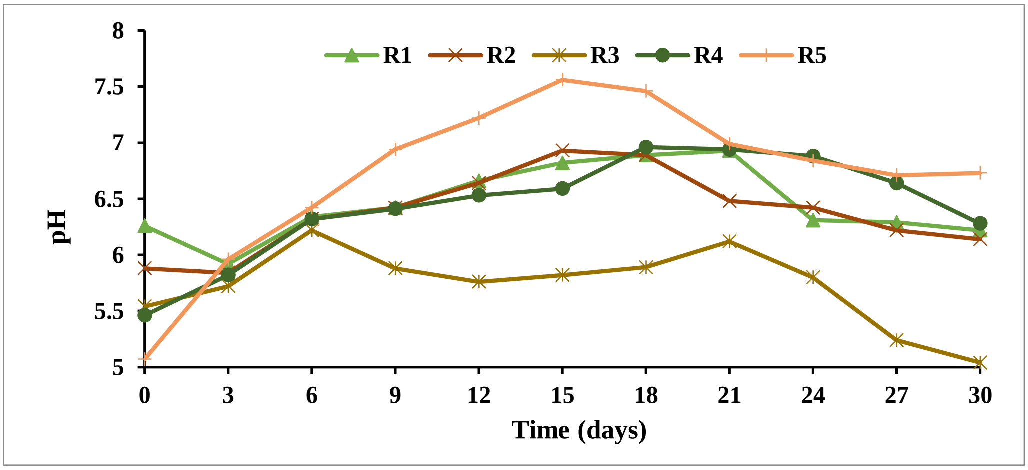

Figure. 3. pH variation for different mixtures of PM:VW

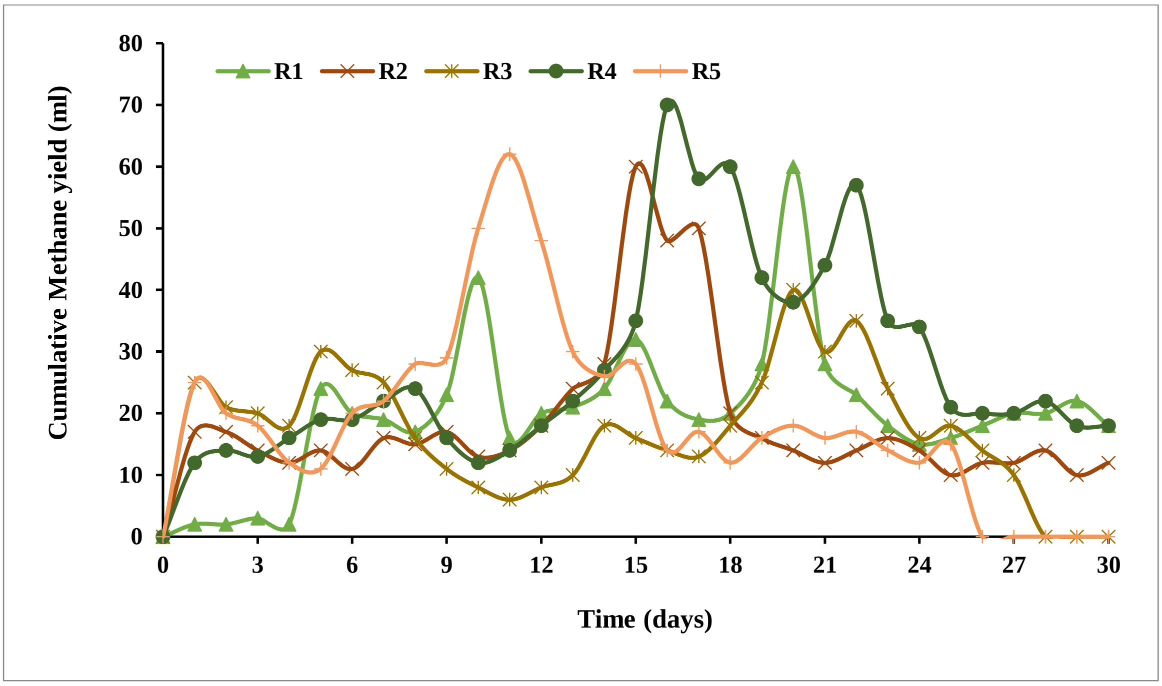

Figure. 4. Daily methane generation (ml) in reactor at different mixture ratios

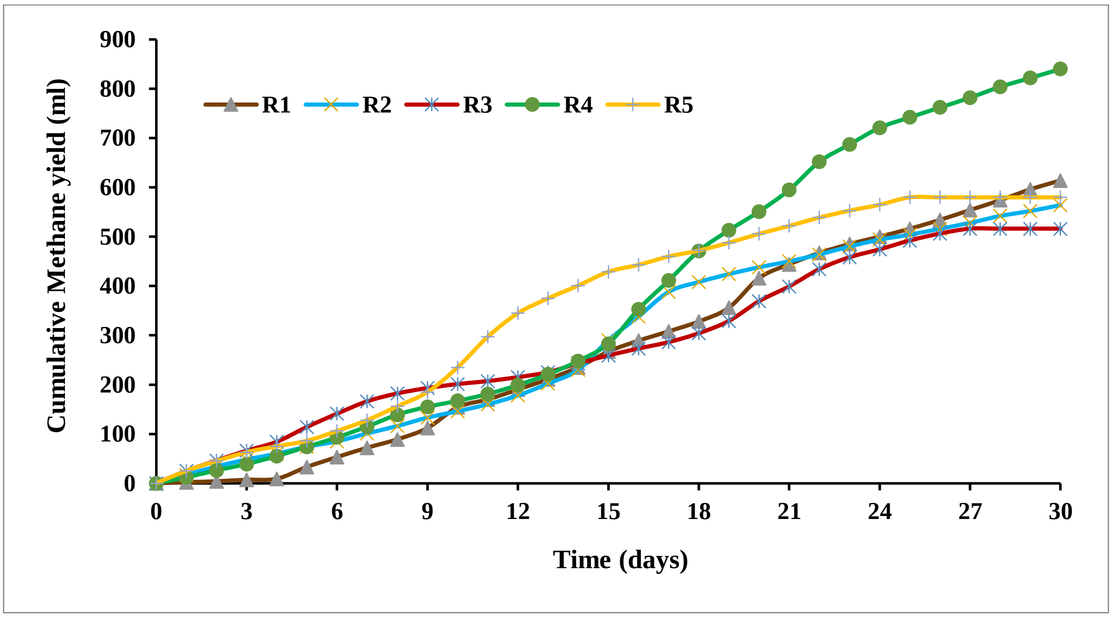

Figure. 5. Cumulative methane generation (ml) in reactor at different mixture ratios

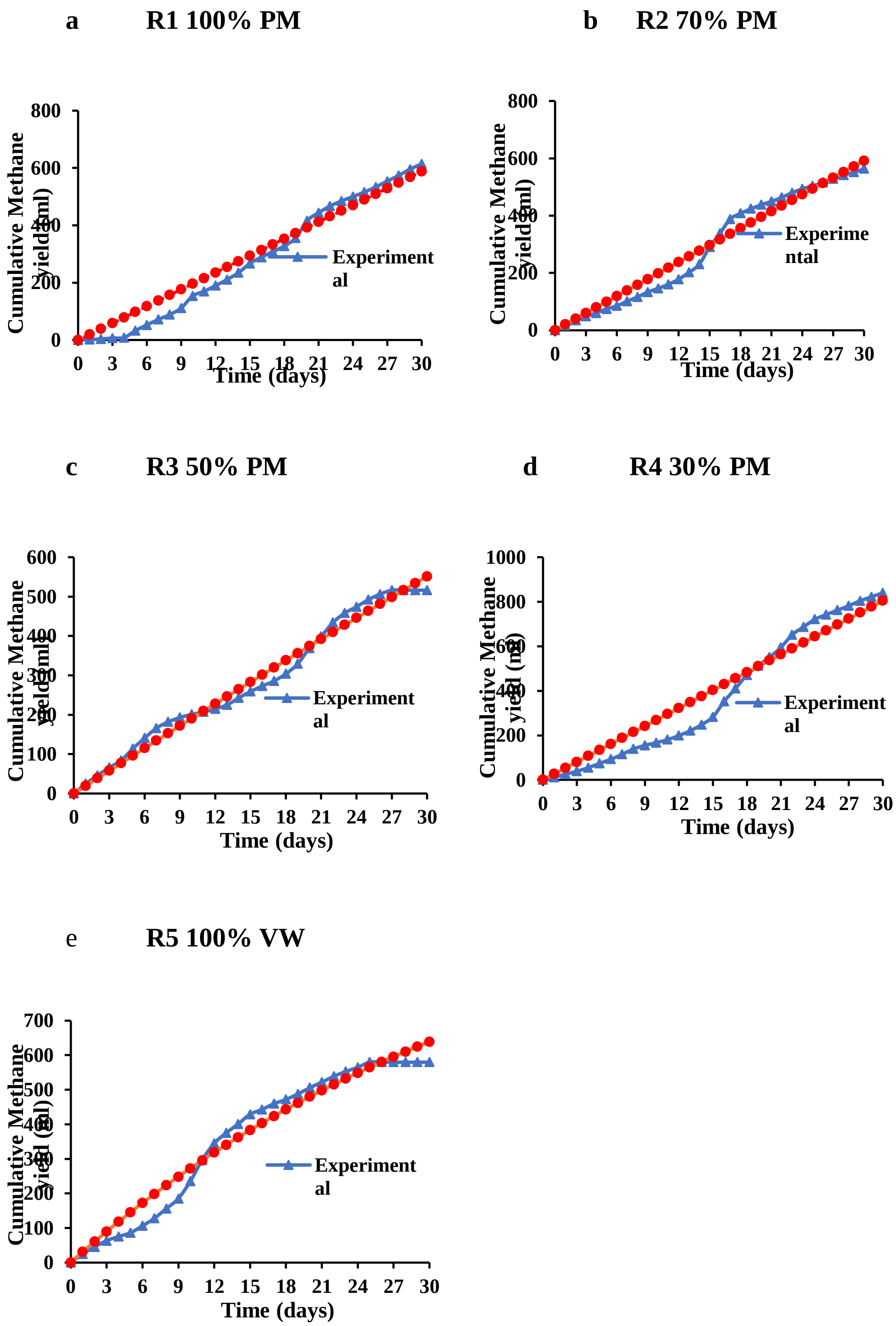

Figure. 6. (a-e) Comparison of predicted methane yield from First order model and experimental methane yield

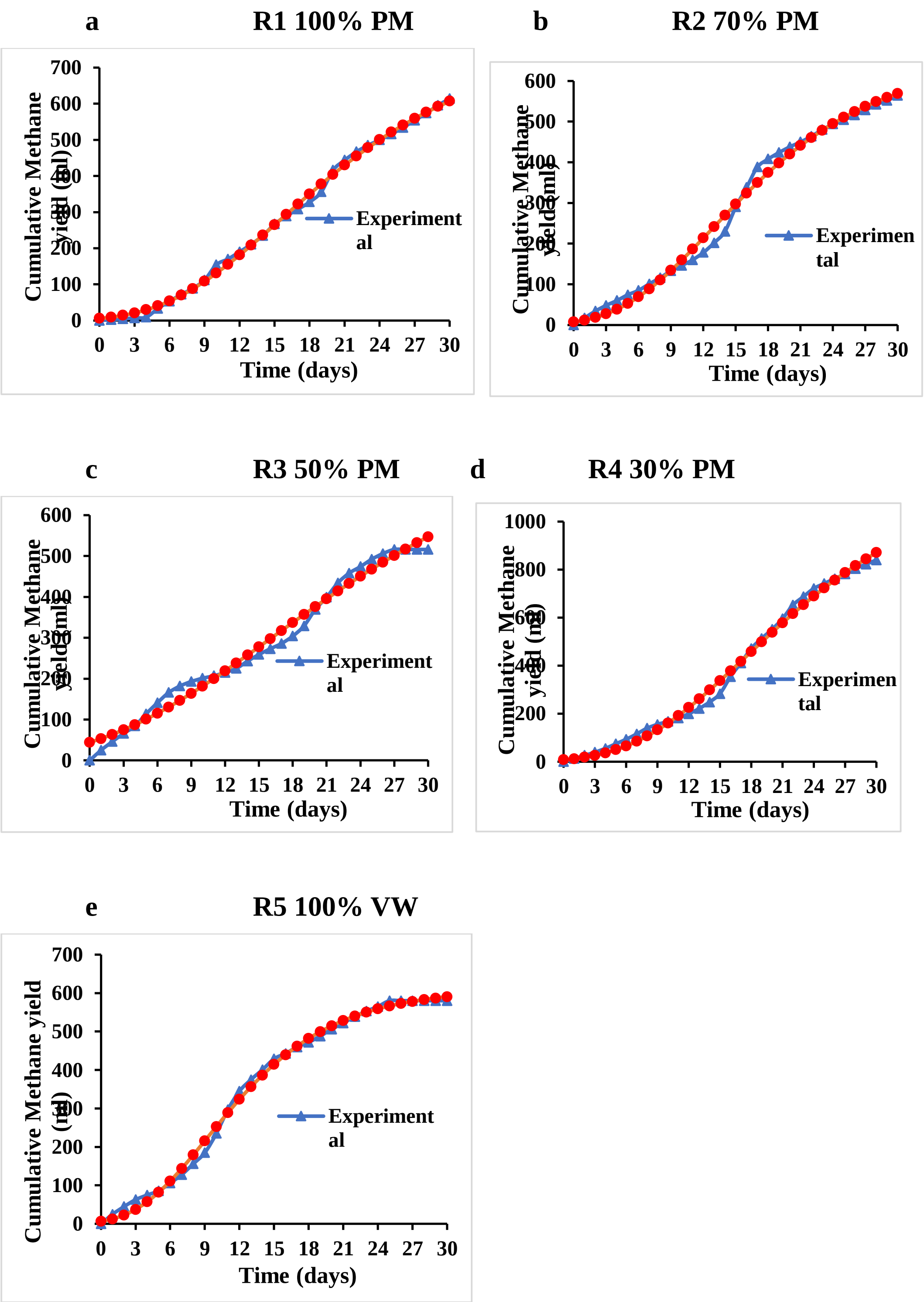

Figure. 7. (a-e) Comparison of predicted methane yield from modified Gompertz model and experimental methane yield

3.4.Methane gas generation at different mixture ratios

Fig.4 shows the daily methane gas generation of different mixture ratio. The methane generation was initially low the maximum methane generation was obtained between 12 to 20th day of the digestion. The maximum methane per day was generated in R4 of 70 ml similarly 60 ml of methane was generated in R1, R2, R5. Fig.5 shows the cumulative methane generation of different mixture ratio, the maximum methane yield of 840 ml was obtained in R4 which contained 30:70 (PM: VW) followed by 640 ml of methane gas in mono-digestion of pressmud (R1), 580 ml of methane ga in mono-digestion of vegetable waste (R5), 564- and 516-ml methane gas in R2 and R3 which had ratio of 70:30 and 50:50 (PM: VW) respectively.

3.5.Modelling of first order model and modified Gompertz model

The experimental results obtained from this study of methane generation at different mixture ratios of PM and VW were analysed using FO model and Modified Gompertz model. The following equation were used which were taken from [3], [28]. The FO model equation was taken as mentioned below

$$G\ (t) = g \times (1 - EXP(-k \times t))$$

Where G(t) is considered as methane production (mL), g is related to biodegradability of substrate and k is hydrolysis coefficient.

The modified Gompertz equation was as follow

$$G(t) = g \times EXP(-EXP\left(\left(\frac{R \times 2.7183}{g}\right) \times (L - t) + 1\right))$$

Where G(t) = cumulative methane production in mL, g — ultimate methane production potential (mL), R— maximum methane production rate (mL d−1), E— Exp (2.718), L— lag phase time (d).

The estimation of parameters for Gompertz model and first order model were obtained form the solver function in Microsoft excel 2019. The obtained parameters were applied in the equation and the predicted data were obtained from the SPSS software. The best fit of predicted data was obtained for Gompertz model with RSquare value greater than 0.95 for all five reactors.

4.Conclusion

The outcomes of this study showed that the optimum mix of 30:70 (PM: VW) provide maximum methane yield. The 50:50 (PM: VW) ratio provided the lowest methane yield and the pH of the reactor was unstable throughout the study average 6. When compared to mono-digestion of pressmud and vegetable waste the gas yield was increased by 37% and 45% respectively.

Acknowledgement

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