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# ANAEROBIC DIGESTION OF CATTLE MANURE AFTER ULTRASONIC PRETREATMENT UNDER DIFFERENT CONDITIONS

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**ABSTRACT:** The ultrasonic pretreatment (UP) is one of the common pretreatment technologies applied in biogas production. In this study, UP was applied to cattle manure (CM) with different intensity and different intervals. The UPs were applied to the intensity of 0.1, 0.5, 1.0, 3.0, 5.0 and 10.0 W/mL and respectively for each pretreatment intensity 5, 10, 20, 30 for 60 min. Biogas production was carried out in batch reactors under mesophilic conditions (30 ± 2 °C) and 5.0 % total solids (TS). As a result of the UP, soluble chemical oxygen demand removal increased from 41.0 % to maximum 67.0 %. The biogas production in this reactor was 270.6 mL/g TS. Thus, 59.0 % incremental biogas production was realized. In this reactor, cellulose and hemicellulose removal was 20.6 % and 16.9 %, respectively. The UP led to the dissolution of cellulose and hemicellulose molecules in water at the anaerobic digestion stage. The optimum times of 0.1, 0.5, 1.0, 3.0, 5.0 and 10.0 W/mL pretreatments were determined. Cumulative biogas prodiction curves of all reactors successfully fitted to the modified Logistic model and the modified Von Bertalanffy model.

**Keywords:** Biogas, anaerobic digestion, ultrasonic pretreatment, modified Logistic Model, modified Von Bertalanffy model.

## 1. INTRODUCTION

Anaerobic digestion (AD) is an important treatment technology in terms of disposal of organic wastes and recovery of energy. Many agricultural and industrial wastes are also evaluated in AD [1]. AD is attractive for the removal of waste, for the production of organic fertilizers from waste and for the production of clean energy from waste [2]. Cattle manure (CM) is one of the most widely used substrates in AD [3]. Nearly 50% of the fiber in fresh CM covers 40-50 % of the total solids [4]. The high fiber content in the CM together with the high moisture content significantly affect the biogas yield. 20 $m^3$ of methane is obtained from 1 ton of CM [5]. In biogas production studies from CM, pretreatment applications increase the production efficiency.

Most of the previous research on biogas production has been directed towards the application of pretreatment technologies. These pretreatments are thermal, physical and chemical pretreatments. Thanks to pretreatments, AD times has shortened and biogas efficiency increases. The pretreatments are remarkable in terms of low cost and significantly increase biogas yield [6].

Ultrasound is a sound wave between 20 KHz and 10 MHz frequency range, which has a wide range of applications. In previous studies, ultrasonic pretreatments (UPs) were applied in the low frequency ranges of anaerobic sludge before AD and promising results were obtained [7,

8].UP from pretreatment technologies is a physical pretreatment. In biogas production studies, ultrasound pretreatments was frequently applied [9]. The cost of UP is attractive in terms of being less than the benefit it provides [10]. Previous UP work was generally applied to wastewater treatment sludge [7, 11-13]. In one study, UP was applied to municipal solid wastes and 24 % incremental biogas yield was achieved in 45 days [14]. In another study, biodegradability of co-fermentation was increased after UP applied to dairy CM and corn straw mixtures [15]. In a study [16] 19 % incremental biogas yield was achieved as a result of 5000 kJ/kg TS UP applied to CM. Although previous studies applying UPs in the literature are generally used in the treatment of wastewater treatment sludge or sewage sludge, their application to CM is limited. In addition, there is no study in the literature showing whether cellulose and hemicellulose, which are lignocellulosic components, are hydrolyzed in the anaerobic fermentation phase after the UPs.

The purpose of this article was give information about the interpretation of AD result cellulose and hemicellulose after UP application. Another aim was to show the changes in soluble chemical oxygen demand (sCOD) removal after UP was applied and to interpret the increases in further biogas production. In this context, after UPs, incremental water dissolution analyzes and sCOD analyzes were performed and the amounts of biogas produced after different UPs were analyzed.

## 1. MATERIAL AND METHODS

### *2.1. Organic Raw Material and Anaerobic Digestion Setup*

CM was collected from Giresun (Turkey). After CM was collected as raw, it was prepared for AD by separating it from foreign materials (stalk, straw, stone, gravel, etc.) [17]. 500 mL flasks (batch reactors) were used for AD processes. The effective volume of the reactors is 400 mL and a headspace of 100 mL is left [1]. Dry matter ratio was taken as 5% w/w. Oxygen in the headspace was removed after a 5-min sweep with nitrogen gas and an airless system was installed. A water bath was set as the heating device and the outer surface temperature was set at 30 ± 2 °C. The volume of biogas produced with AD was determined with 0.1-1 liter gas collection bags attached to the reactors. Biogas volume was measured every 5 days and the AD process was stopped when the biogas volume became constant for 3 consecutive days [18].

### *2.2.Ultrasonic Pretreatment*

The UP equipment was a Sonopuls ultrasonic homogenizer (Bandelin–Sonopuls HD 2200, Berlin, Germany) (Fig.1). This apparatus was equipped with a KE 76 titanium tapered tip probe with a constant operating frequency of 20 ± 0.2 kHz, amplitude of 80 µm, different kj and min.

**Fig.1** The ultrasound wave form used in the study

For each experiment, volumes of 500 mL of sample were placed in a glass beaker and the ultrasonic probe was submerged into the sample to a depth of 5 cm. Each UP was applied to a 400 mL slurry at different densities in the range of 0.1-10 W/mL. UP was applied for 5-60 min

for each ultrasound density. The temperature of the treated samples was kept at 25 °C. sCOD after each UP was also determined. The water solubility of CM was tested by means of glass cottons brought to a constant weight after the UPs applied to the puzzle [19].

### *2.3. Analytical Methods*

Volatile solids (VS), total solids (TS), ash, pH, carbon-nitrogen ratio (C:N), sCOD and lignocellulosic contents were analyzed before initiating AD into CM. TS, sCOD and VS were determined according to standard methods [20]. The lignocellulosic contents were determined with fiber analyzer [21]. The C:N ratio of the CMs was determined by the COSTEC elemental analyzer [22]. The content of biogas produced at the end of AD of the pretreated and untreated samples was analyzed by volume % by IRCD4 Multiple Gas Detection Alarm Manual Instruction. A Hitachi SU-1510 (Hitachi, Ltd. Tokyo, Japan) scanning electron microscope (SEM) was used to scan the surfaces of the CM. In Table 1 are shows the results of the physicochemical analysis performed on the CM.

**Table 1.** Physicochemical properties of cattle manure

| **Parametres** | **Cattle manure** |
|---|---|
| TS ( % w/w) | 17.97 ± 0.9 |
| VS (% TS) | 83.10 ± 0.6 |
| Moisture ( % w/w) | 81.01 ± 0.9 |
| Ash ( % w/w) | 3.10 ± 0.2 |
| sCOD (mg $O_2/L_{slurry}$) | 14,280 ± 155 |
| pH | 6.86 ± 0.05 |
| Hemicellulose ( % w/w) | 17.82 ± 2.1 |
| Cellulose ( % w/w) | 22.11 ± 0.9 |
| Lignin ( % w/w) | 11.85 ± 0.9 |
| % C ( % w/w) | 31.09 ± 0.9 |
| % N ( % w/w) | 1.59 ± 0.19 |
| C/N | 19.55 ± 0.2 |

### *1.4. Kinetic Study*

Biogas data produced as a result of AD of CM with UP was simulated with the kinetic model. After the cumulative biogas production (CBP) data measured at 5-day intervals were defined to the SPSS program, estimated CBP values for modified Logistic model (MLM) and Modified Von Bertalanffy model (MBM) were obtained. The Von Bertalanffy function was first developed by Von Bertalanffy in 1934 and later changed by Beverton and Holt (1957). MBM has been described for growth [23]. The MLM is used in sigmoidal growth curves [24]. The MLM is widely used for biogas [24]. These equations are given in Table 2.

**Table 2.** Modified Logistic and Bertalanffy models [25]

| **Models** | **Equations** |
|---|---|
| Modified Logistic model | $y = \frac{A}{[1 + e^{\frac{4\,\mu_m(\lambda - t)}{A} + 2}]}$ |
| Modified Bertalanffy model | $y = -\frac{1}{27} A \left[ -3 + e^{\frac{2}{3} + \frac{9\mu_m}{4A}.(\lambda - t)} \right]^3$ |

Where; y is the biogas production (mL / g TS), with respect to time t (days), A is maximum biogas production quantity (mL / g TS), λ is lag phase (days) and e is an equal to 2.71828.

In this study, the Statistical Package for the Social Sciences (SPSS 23.0) program was used to calculate the estimated values of the kinetic parameters (A, λ and μm) of the models. In

evaluating the model performance, it was chosen as the most suitable kinetic model with the highest coefficient of determination ($R^2$).

## 2. Results and Discussion

### *3.1. Anaerobic digestion of untreated and ultrasonic pretreated cattle manure results*

Table 3 shows the biogas production rate, % incremental biogas production and % sCOD removal as a result of the UPs applied to different time intervals. The ultrasound density was applied to the ultrasound wave frequency of 0.1, 0.5, 1.0, 3.0, 5.0 and 10.0 W/mL. As a result of the UPs applied to different time intervals and densities, the highest biogas production was 275.4 mL/g TS in the reactor which had a pretreatment of 3.0 W/mL and 20 min of pretreatment. There was 61.9 % incremental biogas production in this reactor and sCOD removal was 68.9 %.

After the UPs was applied, the water solubility of the samples varied to the density of the ultrasound wave and the exposure time. Generally, as the ultrasound wave intensity and exposure time increased, water solubility increased. At least solubility was 2.1 % and 15.1 % in $R_2$ and $R_{18}$ respectively. Biogas production rate increased in direct proportion to water solubility.

**Table 3.** Untreated and ultrasonic pretreatment results

| Ultrasonic density (W/mL) | Ultrasonic Times (min) | Incremental dissolution (%) | Reactor | Biogas production (mL/g TS) | Incremental production (%) |
|---|---|---|---|---|---|
| - | - | - | $R_1$ | 170.1 ± 4.7 | - |
| 0.1 | 5 | 2.1 ± 1.1 | $R_2$ | 190.1 ± 4.1 | 11.7 |
| | 10 | 3.4 ± 1.4 | $R_3$ | 195.2 ± 3.2 | 14.7 |
| | 20 | 6.5 ± 1.2 | $R_4$ | 208.4 ± 2.9 | 22.5 |
| | 30 | 7.1 ± 1.3 | $R_5$ | 211.5 ± 4.9 | 24.3 |
| | 60 | 4.0 ± 1.0 | $R_6$ | 198.5 ± 5.1 | 16.6 |
| 0.5 | 5 | 4.1 ± 1.0 | $R_7$ | 198.5 ± 6.2 | 16.8 |
| | 10 | 4.8 ± 0.5 | $R_8$ | 201.5 ± 5.4 | 18.4 |
| | 20 | 3.2 ± 1.4 | $R_9$ | 196.9 ± 3.8 | 15.7 |
| | 30 | 6.1 ± 0.9 | $R_{10}$ | 208.5 ± 4.2 | 22.5 |
| | 60 | 8.3 ± 1.2 | $R_{11}$ | 212.4 ± 6.0 | 24.8 |
| 1.0 | 5 | 8.1 ± 0.9 | $R_{12}$ | 212.2 ± 5.5 | 24.7 |
| | 10 | 8.2 ± 0.7 | $R_{13}$ | 215.4 ± 4.9 | 26.6 |
| | 20 | 9.5 ± 1.4 | $R_{14}$ | 222.5 ± 5.2 | 30.8 |
| | 30 | 7.5 ± 1.5 | $R_{15}$ | 214.3 ± 4.8 | 26.0 |
| | 60 | 6.4 ± 0.4 | $R_{16}$ | 209.5 ± 4.9 | 23.1 |
| 3.0 | 5 | 12.5 ± 1.1 | $R_{17}$ | 241.4 ± 5.2 | 41.9 |
| | 10 | 15.1 ± 1.2 | $R_{18}$ | 258.5 ± 3.8 | 51.9 |
| | 20 | 14.5 ± 0.9 | $R_{19}$ | 275.4 ± 4.1 | 61.9 |
| | 30 | 12.4 ± 1.9 | $R_{20}$ | 262.5 ± 2.2 | 54.3 |
| | 60 | 11.4 ± 1.8 | $R_{21}$ | 258.4 ± 1.3 | 51.9 |
| 5.0 | 5 | 8.9 ± 1.5 | $R_{22}$ | 222.2 ± 2.9 | 30.6 |
| | 10 | 9.5 ± 1.4 | $R_{23}$ | 232.4 ± 5.7 | 36.6 |
| | 20 | 12.1 ± 1.2 | $R_{24}$ | 233.3 ± 6.6 | 37.1 |
| | 30 | 12.3 ± 1.8 | $R_{25}$ | 235.9 ± 4.2 | 38.6 |
| | 60 | 11.1 ± 1.6 | $R_{26}$ | 233.5 ± 5.5 | 37.2 |
| 10.0 | 5 | 10.5 ± 0.9 | $R_{27}$ | 235.4 ± 4.3 | 38.3 |
| | 10 | 9.8 ± 0.6 | $R_{28}$ | 242.6 ± 3.9 | 42.6 |
| | 20 | 13.1 ± 1.8 | $R_{29}$ | 270.6 ± 2.8 | 59.0 |
| | 30 | 12.5 ± 1.4 | $R_{30}$ | 255.6 ± 5.1 | 50.2 |
| | 60 | 11.0 ± 1.8 | $R_{31}$ | 241.5 ± 4.7 | 41.9 |

The biogas production of the ultrasound waves applied to low energy values were significantly increased. There was no significant increase in biogas production when ultrasound application time was over 20 min. Similarly, there was no significant increase in biogas production to intervals above 3.0 W/mL. Thus, optimum UP conditions were determined as 3.0 W/mL for 20 min. The results of UP comparison with the current literature are given in Table 4. Accordingly, biogas production increased by at least 6.3 %. There has been an increase of 84.0 % in the literature. In this study, the highest increase was 61.9 %. In a study, in the organic sample of 1.2 W/mL density was applied UP [26]. In this study, a wave intensity of 0.4 W/mL was applied. Similarly, in a study [27] UP at a density of 2 W/mL resulted in 6.3 % incremental biogas production. As a result, the effect of ultrasound wave has changed according to the type of organic matter.

**Table 4.** Comparison of ultrasonic pretreatment results with literature

| **Ultrasonic pretreatment conditions** | **Results (incremental biogas production)** | **Organic matter species** | **Reference** |
|---|---|---|---|
| 3.0 W/mL and 20 min (25 W) or (0.125 W/mL) | 61.9% | CM | This study |
| 0.4 W/mL and 10 min | 20.0% | Olive wastewater | [28] |
| 520 kJ/kg TS | 36.9% | CM | [29] |
| 600 W/L | 40.0% | Landfill leachate | [30] |
| 130 W and 30 min | 10.12% | Chicken manure | [31] |
| 60 W and 50 mL | 84.0% | Sewage sludge waste | [26] |
| 360 kJ/L and 30 min | 31.0% | Sewage sludge waste | [32] |
| 200 W and 100 mL | 6.3% | Wastewater treatment sludge | [27] |
| 100 W and 900 mL | 32.0% | Activated sludge | [33] |

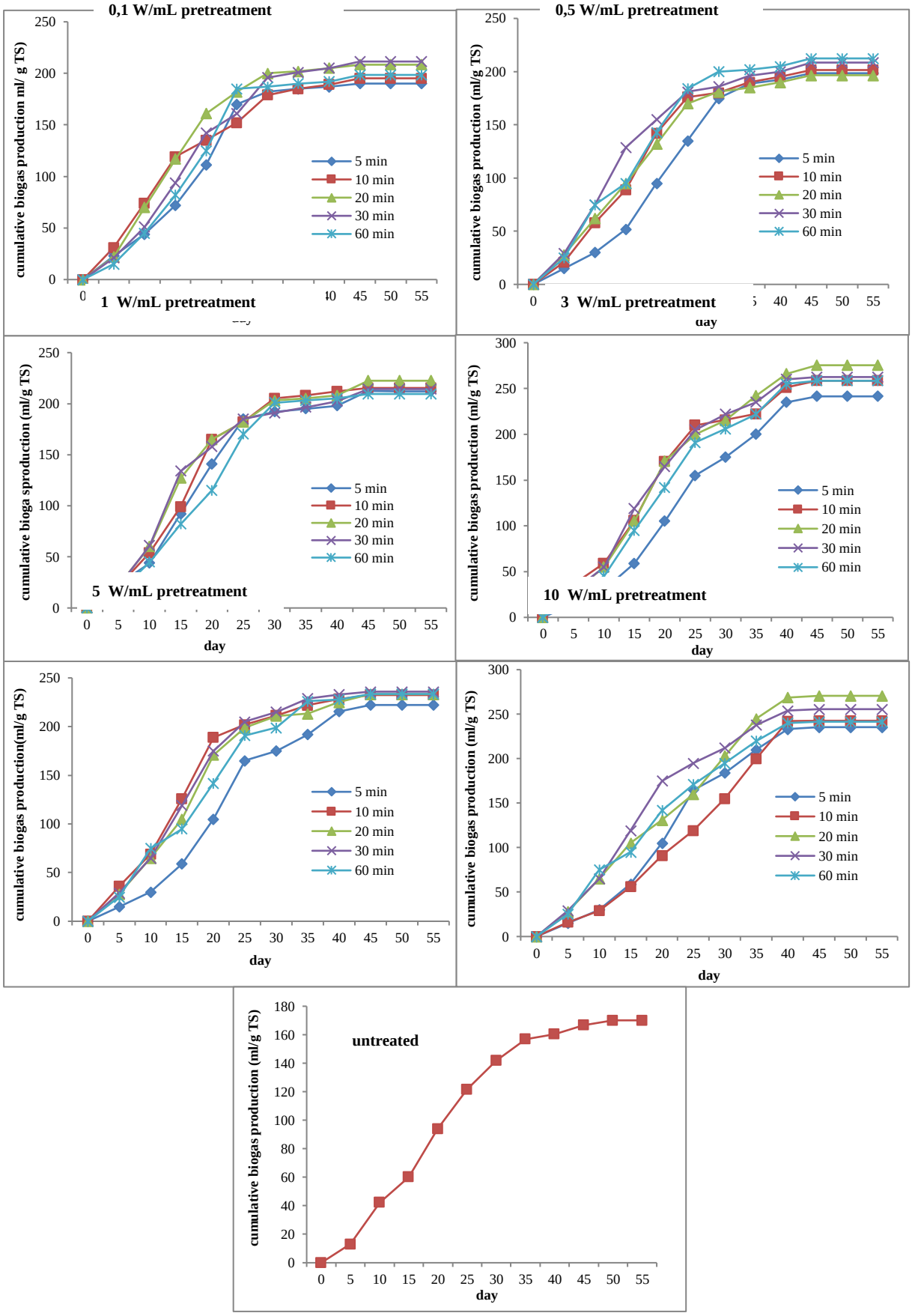


**Fig. 2** Cumulative biogas production of all reactors during ultrasonic pretreatment

The CBP of the reactors applied UP are given in Fig. 2. The CBP continued to increase in general. The average digestion times was equilibrated after 45 days in $R_1$, while it equilibrated after 35 days in all pretreated reactors. Pretreatment period decreased from 45 days to 35 days. While biogas production started to accelerate for 5-10 days in untreated reactor, biogas production started to accelerate after 5 days as a result of UP.

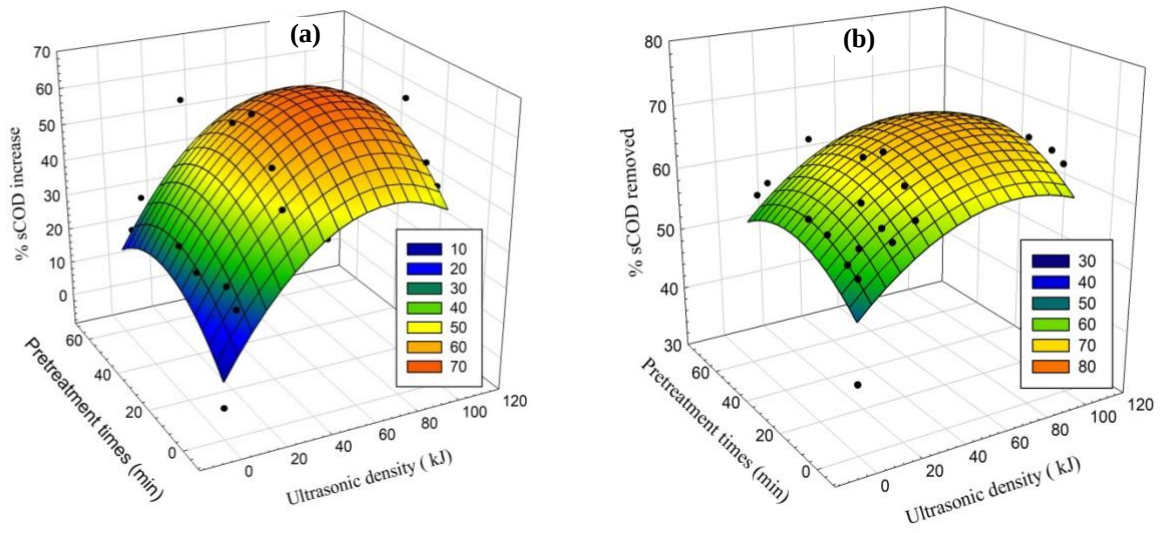


**Fig 3.** (a) sCOD increase by ultrasonic pretreatment time and density; (b) sCOD removal after anaerobic digestion after pretreatment.

Fig 3 was created by the Sigma Plot Scientific Data Analysis and Graphing Software program. In according to Fig 4.(a), the sCOD removal was decreased as ultrasound and pretreatment decreased. At the ultrasonic density in the range 5.0 to 10.0 W/mL, the maximum sCOD increase was achieved. While the pretreatment time was among 20 and 40 min, the % sCOD increase was maximum. As shown in Fig 4.(b), sCOD removal was maximum when the ultrasonic density was among 5.0 and 10.0 W/mL. The pretreatment time increased the sCOD removal after 20 min. The highest sCOD removal was 68.9 % in the 3.0 W/mL ultrasonic density and 20 min pretreatment time ($R_{19}$). The highest sCOD increase was 65.1 % in this reactor.

**Table 5.** Removal of cellulose and hemicellulose with biogas content untreated and ultrasonic pretreatment

| Reactor | $CH_4$ % (v/v %) | $CO_2$ % (v/v %) | $H_2S$ (ppm) | Cellulose removel (w/w %) | Hemicellulose removel (w/w %) |
|---|---|---|---|---|---|
| $R_1$ | 60.2 ± 1.1 | 39.4 ± 1.7 | 351 ± 5 | 1.4 ± 1.0 | 1.1 ± 0.5 |
| $R_2$ | 62.5 ± 1.5 | 37.2 ± 1.2 | 366 ± 12 | 10.3 ± 1.1 | 8.6 ± 1.8 |
| $R_3$ | 62.9 ± 1.3 | 37.0 ± 0.8 | 375 ± 18 | 12.3 ± 0.9 | 9.8 ± 1.1 |
| $R_4$ | 63.6 ± 1.4 | 36.1 ± 0.7 | 400 ± 8 | 10.9 ± 1.2 | 9.9 ± 4.2 |
| $R_5$ | 64.5 ± 0.8 | 35.2 ± 0.7 | 365 ± 9 | 13.2 ± 0.7 | 10.0 ± 2.1 |
| $R_6$ | 63.6 ± 0.8 | 36.2 ± 0.9 | 451 ± 12 | 13.1 ± 1.5 | 10.1 ± 1.8 |
| $R_7$ | 65.2 ± 1.0 | 34.5 ± 1.8 | 385 ± 22 | 12.5 ± 2.0 | 9.0 ± 1.2 |
| $R_8$ | 62.1 ± 0.5 | 37.6 ± 1.4 | 257 ± 65 | 12.7 ± 1.9 | 9.8 ± 2.1 |
| $R_9$ | 61.9 ± 1.8 | 37.6 ± 1.3 | 315 ± 41 | 13.2 ± 1.8 | 9.5 ± 1.8 |
| $R_{10}$ | 63.6 ± 2.1 | 36.1 ± 1.4 | 386 ± 35 | 13.4 ± 1.7 | 9.9 ± 1.4 |
| $R_{11}$ | 64.5 ± 1.5 | 35.1 ± 1.4 | 298 ± 27 | 13.7 ± 0.5 | 10.5 ± 0.8 |
| $R_{12}$ | 63.5 ± 0.6 | 36.2 ± 1.5 | 321 ± 12 | 13.0 ± 1.4 | 10.9 ± 1.4 |
| $R_{13}$ | 64.5 ± 0.5 | 35.2 ± 1.7 | 351 ± 21 | 13.4 ± 1.4 | 11.2 ± 0.8 |

| | | | | | |
|---|---|---|---|---|---|
| $R_{14}$ | 62.8 ± 0.4 | 37.8 ± 1.6 | 324 ± 23 | 13.7 ± 1.8 | 11.8 ± 0.7 |
| $R_{15}$ | 64.9 ± 1.2 | 34.9 ± 1.8 | 391 ± 25 | 13.7 ± 1.2 | 11.9 ± 1.3 |
| $R_{16}$ | 63.5 ± 2.5 | 36.2 ± 2.0 | 402 ± 10 | 13.8 ± 1.6 | 11.8 ± 2.1 |
| $R_{17}$ | 61.6 ± 0.8 | 38.0 ± 1.5 | 343 ± 32 | 19.5 ± 2.1 | 15.6 ± 1.7 |
| $R_{18}$ | 60.9 ± 1.2 | 39.0 ± 1.6 | 359 ± 24 | 20.2 ± 2.3 | 15.9 ± 1.5 |
| $R_{19}$ | 63.5 ± 1.5 | 36.1 ± 1.4 | 376 ± 22 | 21.4 ± 1.5 | 15.8 ± 1.6 |
| $R_{20}$ | 65.0 ± 1.2 | 34.8 ± 1.6 | 385 ± 25 | 22.5 ± 1.4 | 16.5 ± 2.0 |
| $R_{21}$ | 62.8 ± 1.4 | 37.1 ± 0.8 | 452 ± 28 | 22.4 ± 1.6 | 17.0 ± 1.0 |
| $R_{22}$ | 62.9 ± 0.8 | 36.8 ± 0.5 | 385 ± 35 | 18.7 ± 1.7 | 14.5 ± 1.2 |
| $R_{23}$ | 62.5 ± 1.7 | 37.0 ± 0.8 | 395 ± 32 | 19.5 ± 1.5 | 13.5 ± 2.1 |
| $R_{24}$ | 63.2 ± 0.7 | 36.3 ± 1.5 | 399 ± 12 | 19.0 ± 1.6 | 14.4 ± 1.2 |
| $R_{25}$ | 63.6 ± 0.4 | 36.1 ± 1.8 | 385 ± 9 | 19.7 ± 1.7 | 14.5 ± 1.7 |
| $R_{26}$ | 64.5 ± 0.3 | 35.2 ± 1.5 | 369 ± 17 | 20.0 ± 0.9 | 15.8 ± 1.5 |
| $R_{27}$ | 65.2 ± 1.8 | 34.5 ± 1.3 | 402 ± 27 | 17.4 ± 1.8 | 13.5 ± 1.8 |
| $R_{28}$ | 66.4 ± 2.2 | 33.3 ± 1.1 | 405 ± 36 | 19.5 ± 2.1 | 14.3 ± 2.1 |
| $R_{29}$ | 64.9 ± 2.4 | 35.0 ± 0.9 | 355 ± 27 | 20.6 ± 2.2 | 16.9 ± 1.2 |
| $R_{30}$ | 63.8 ± 1.8 | 36.0 ± 0.7 | 328 ± 24 | 21.0 ± 1.8 | 16.5 ± 0.9 |
| $R_{31}$ | 65.1 ± 1.9 | 34.5 ± 0.8 | 421 ± 23 | 20.8 ± 2.5 | 16.4 ± 1.8 |

Table 5 shows the content analysis of biogas resulting from different ultrasonic density and different pretreatment times. $CH_4$, $CO_2$ and $H_2S$ values changed as a result of pretreatment of ultrasound wave applied at different intensity and time intervals. The $CH_4$ content was at 60.2 % (v/v) in the untreated reactor (in $R_1$). The highest content of $CH_4$ occurred at $R_{28}$. In the reactors with UP $CH_4$ content was among 60.9 % and 66.4 % (v/v). The $CO_2$ value ranged from 33.3 % to 39.4 % (v/v). $H_2S$ values ranged from 257 to 452 ppm.

As a result of AD after the Ups pretreatment, hemicellulose and cellulose amounts were removed. Cellulose removal was eliminated by 1.4 % in the untreated reactor, while hemicellulose was removed by 1.1 %. No significant removal of the pretreatment reactors was occurred. However, after pretreatment, cellulose was removed among 10.3-22.4 %. Similarly, hemicellulose removal ranged from 8.6 to 17.0 %.

As a result of the pretreatments applied at different ultrasound intensities, optimum reactors were determined as $R_5$, $R_{11}$, $R_{14}$, $R_{19}$, $R_{25}$ and $R_{29}$. SEM images of these reactors and untreated reactor are shown in Fig 4.

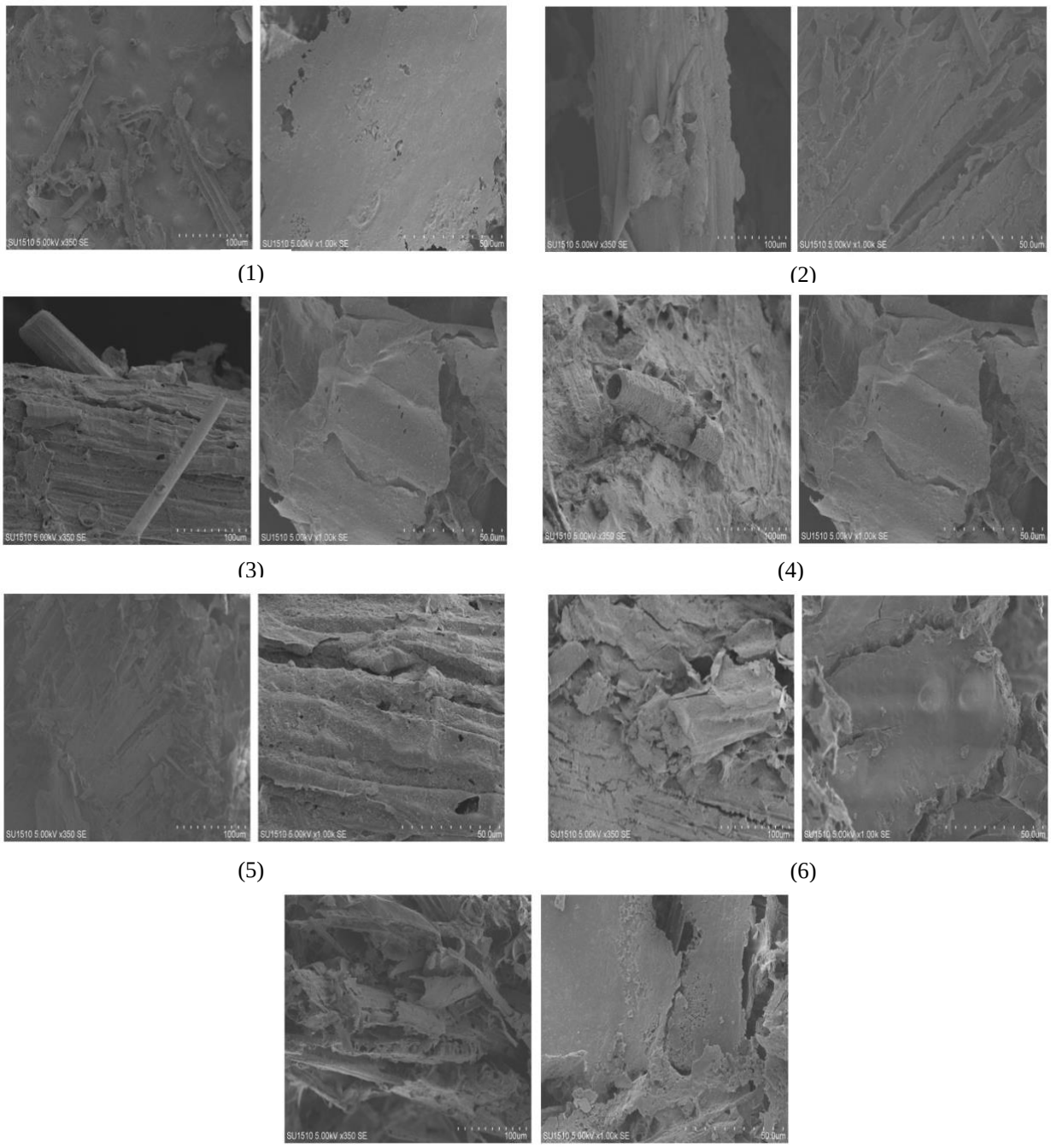

**Fig 4.** SEM images of organic matter untreated and ultrasonic pretreatment, (1) untreated, (2) 0.1 W/mL and 30 min pretreatment, (3) 0.5 kJ and 60 min pretreatment, (4) 1.0 W/mL and 20 min pretreatment, (5) 3.0 W/mL and 20 min pretreatment, (6) 5.0 W/mL and 30 min pretreatment, (7) 10.0 W/mL and 20 min pretreatment.

In Fig 4, the preformed organic matter appears to have a crystalline structure in the surface morphology and the surface is composed of a hard layer. While the pretreatment density was 0.1 W/mL, it was observed that the surface crystal was present. As the pretreatment intensity was reached from 0.5 W/mL to 10.0 W/mL, it was observed that the fractures and cracks in the surface morphology started to increase gradually. This is probably due to the use of UP in a study on CM [29], UP due to fractures and cracks are highlighted.

### *3.2. Kinetic Study Results*

MBM and MLM were implemented to the reactors which give optimum results for each UP density ($R_5$, $R_{11}$, $R_{14}$, $R_{19}$, $R_{25}$ and $R_{29}$). Interpretation of CBP curves obtained as a result of AD processes is usually done with kinetic models [34].

**Table 6.** Determined constants of Von Bertalanffy equations and Modified Logistic with experimental data

| | **Modified Logistic model** | | | | **Modified Bertalanffy Model** | | | |
|---|---|---|---|---|---|---|---|---|
| Reactors | $\lambda$ (day) | $\mu_m$ (mL/g TS) | $A$ (mL/g TS.d) | $R^2$ | $\lambda$ (day) | $\mu_m$ (mL/g TS) | $A$ (mL/g TS.d) | $R^2$ |
| $R_5$ | 5.414 | 9.469 | 209.257 | 0.995 | 4.235 | 9.399 | 220.300 | 0.996 |
| $R_{11}$ | 4.200 | 9.479 | 210.642 | 0.991 | 2.928 | 9.398 | 220.276 | 0.990 |
| $R_{14}$ | 4.872 | 11.586 | 211.613 | 0.992 | 4.025 | 11.522 | 219.700 | 0.996 |
| $R_{19}$ | 5.162 | 10.516 | 262.897 | 0.988 | 3.705 | 10.041 | 285.989 | 0.995 |
| $R_{25}$ | 5.010 | 11.920 | 232.577 | 0.997 | 3.898 | 11.730 | 242.128 | 0.996 |
| $R_{29}$ | 4.597 | 8.350 | 280.696 | 0.990 | 2.373 | 7.768 | 323.684 | 0.995 |

Kinetic constant of lag phase showed the lag time needed by bacteria to adapt in the substrates [35]. Table 6 shows the MBM and MLM characteristics as a result of the optimum reactors. In this study, the lag phase ranged between 4.200 and 5.414 in the MLM. In the MBM, the lag phase ranged from 2.323 to 4.235. Rajput vd. [36] CBP as a result of lag phase ranged between 2.78 - 20.27 days values. Specific biogas production ranged from 8.350 to 11.920 ml/gTS.d in MLM. It ranged from 7.768 to 11.522 for the MBM. It is seen that the estimated $\mu_m$ values of the models are proportional to the actual biogas yields for all reactors. In a study [37], the specific biogas production for the logistic model ranged from 3.728 to 5.407 mL / g VS value. Maximum biogas production varied among 209.257 and 280.696 mL/g TS values. In the MBM, maximum biogas production ranged from 220.276 to 323.684 mL/g TS. MBM predicted maximum biogas production rates were higher for all reactors. The MBM for the $R_5$, $R_{14}$, $R_{19}$ and $R_{29}$ reactors showed greater compatibility with the CBP than the logistic equation. In other reactors, the suitability of the MLM was greater.

In a study [38] was reported that fitting CBP Modified Gompertz and MLM. The $R^2$ values for the MLM were among 0.9954 and 0.9363. For the Modified Gompertz Model, $R^2$ values were among 0.7587 and 0.9854. In this study, $R^2$ values for MLM were found among 0.988-0.997. $R^2$ values for MBM were found among 0.990-0.996.

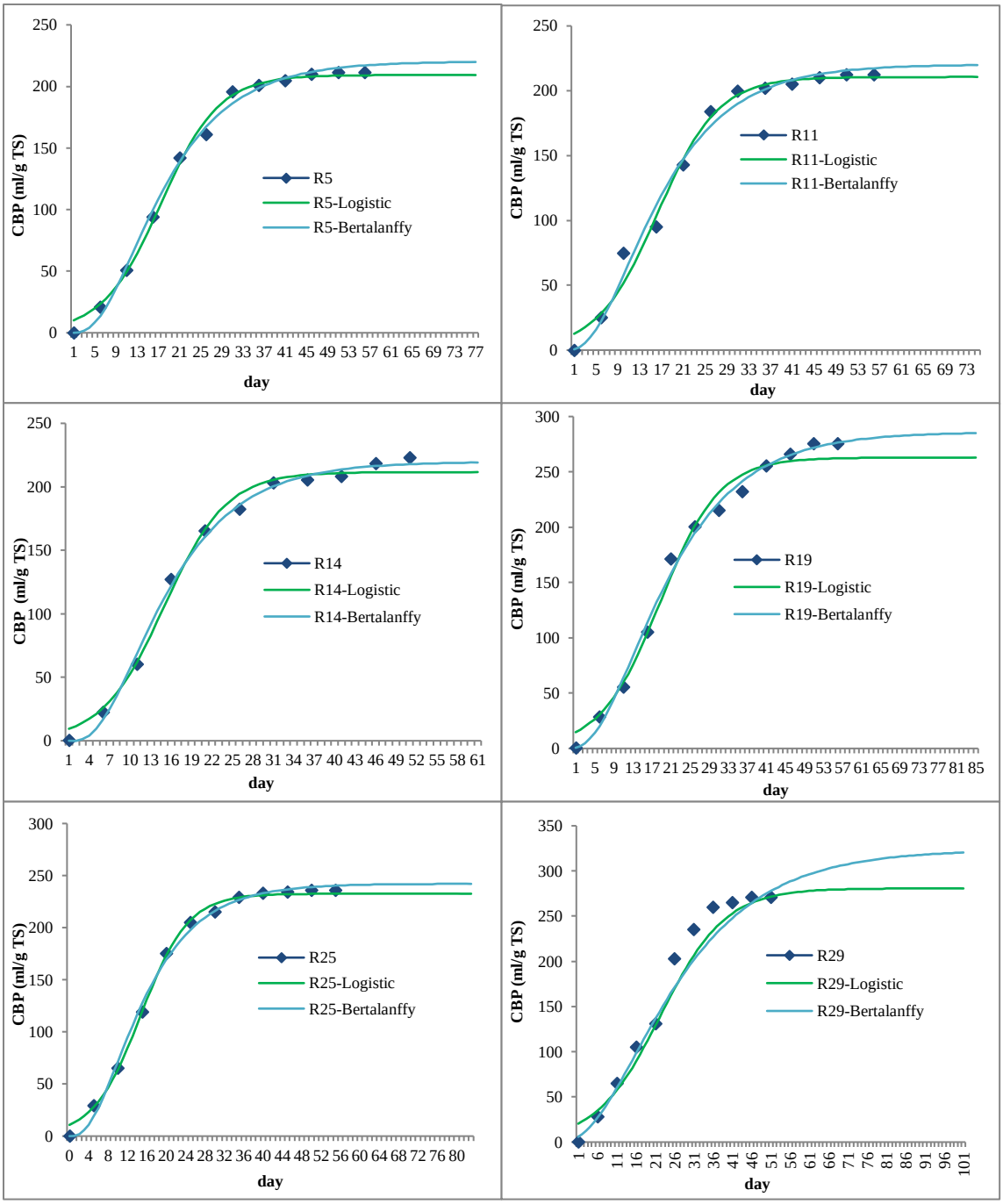


**Fig 5.** Compatibility of CBP of optimum reactors with Von Bertalanffy and Logistic equations

Fig. 5 shows the estimated CBP of optimum reactors with UP applied. Dark blue dots show real biogas production. The light blue color refers to the MBM curve. The green color shows the MLM curve. Looking at the figures, it is seen that the models have been successfully simulated to optimum reactors.

## 3. CONCLUSION

Biogas production process was investigated as a result of UP of CM containing lignocellulosic components. The ultrasound density (W/mL) was kept constant at 0.1, 0.5, 1.0, 3.0, 5.0 and 10.0 W/mL. AD was initiated after applying different time intervals in this density value. The highest water solubility and the highest biogas production was the result of 3.0 W/mL UP. As a result of 1.0, 3.0 and 10.0 W/mL UPs, the highest biogas production occurred as a result of 20 min application time.

The removal of cellulose and hemicellulose in CM did not show a significant change as a result of UP. However, in the AD stage of treated organic matter, some of cellulose and hemicellulose were removed. Cellulose was eliminated at a rate of 22.5 % (w/w) and hemicellulose was eliminated at 17.0 % (w/w). Thus, the ultrasound wave pretreatment is a physical pretreatment and has not contributed chemically to water solubility. However, it can be said that the ultrasound wave pretreatment provides a suitable environment for the water dissolution of cellulose and hemicellulose in AD, and the appropriate cavities for hydrolytic bacterial enzymes. It can be said that ultrasound waves create a loosening of the lignocellulosic rigid cellulose and hemicellulose bonds and that the anaerobic microorganisms facilitate the hydrolysis process due to the fact that the organic samples which are applied to ultrasound wave do not directly change the amount of cellulose and hemicellulose but the decrease after AD was observed.

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