Comparative Performance Studies on Biomethane Production from Biodegradable Wastes and Cattle Manure Based on Inoculums Source

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***Abstract*—Cattle manure (CM) is an excellent raw material for anaerobic co-digestion of organic wastes with low carbon content can improve the fermentation stability. Several comparative assays were conducted on the anaerobic co-digestion of cattle manure (CM) with three organic wastes (ORs), namely, cafeteria waste (CW), vegetable waste (VW) and fruit waste (FW), under different mixing ratios in absence and presence of inoculum. All digesters were implemented simultaneously under mesophilic temperature at (30 ±2 °C) with a total solid concentration of 8 to 15%. Result showed that the combination of CM with CW, VW or FW significantly improved biogas production at all ratios. The ratios CW:CM (50:50), VW:CM (50:50), and FW:CM (25:75) produced the highest biogas yields from different co-substrates (20585, 16037 and 16624 mL, respectively) after 45 days of fermentation. The highest average methane yields of CW:CM (50:50), VW:CM (50:50), and FW:CM (25:75) were 63%, 61.2%, and 61.3% which showed that 1.0, 1.03 and 1.02 times higher than that of CW:CM (50:50), VW:CM (50:50), and FW:CM (25:75) without inoculum, respectively. In this study, compared effects of inoculum in digestion of cattle manure and organic wastes treatments, biogas was generated slightly higher than without inoculums digestion. This result was caused by the high methanogenic bacteria content in co-digestion medium, which enhanced biodegradation.**

***Index Terms*—anaerobic co-digestion, methane, inoculums, cattle manure (CM), organic wastes (ORs).**

I. Introduction

The industrialization process and the current population growth have had an immense impact on the energy and environment. The demands on petroleum-based fuels are clear evidence of the increase on natural resources. The dependence on fossil fuels as primary energy source has led to global climate change, environmental degradation, and human health problems. 80% of the world’s energy consumption still originates from combusting fossil fuels [1]. Yet the reserves are limited; means do not match with the fast population growth, and their burning substantially increases the greenhouse gas (GHG) concentrations that contributed for global warming and climate change [2]. Conventionally, methane is one of the main GHG, by-product of municipal wastes and livestock based activities. Methane has an atmospheric life time of about 12 years and substantially contributes to stronger GHG effect in comparison with CO_2. Using a hundred year time horizon the greenhouse effect of 1 kg methane is 23 times stronger than of 1 kg of CO_2 [3]. So, bio-energy (energy production from biomass) can be seen as one of the key options. Among the many bio-energy related processes being developed, latter 20th century, anaerobic digestion (AD) gained popularity as a solution to environmental and energy concerns. AD embraces the concept of sustainability and proximity. Twenty years ago the process was mainly used for treatment of wastewater sludge. It is a complex bioconversion process (the use of microorganisms that degrade the material in the absence of oxygen) that can produce abundant benefits for treating organic wastes. However, anaerobic digestion of organic wastes to produce energy in the form of biogas is, arguably, the most likely option to be obstacle in utilization of lignocellulosic content and the subsequent low methane yield [4], provided that the economics were favourable. Therefore, more recently the farming sector, particularly in Asia and Europe embraced biogas technology co-digesting farm wastes with some imported feedstocks [5]–[7]. Co-digestion of organic wastes and animal manures could achieve a nutrient-balance and increase specific methane yield. Increasing number of studies for co-digestion of organic wastes and animal manures were focused on pretreatment, optimal parameters, and evaluation of methane production in batch mode [8]-[12]. Fruit and vegetable waste (FVW) has also been evaluated as a digester feed-stock by a number of workers [13], [14] with a methane production of 0.37 m^3/kg VS being reported [13]. However, it has been suggested that the nitrogen and phosphorus in FVW can be low and this is one reason why it has also been used in co-digestions with other wastes, for example, chicken manure [15]. Previously, a series of batch (1 L) co-digestions were used as screening trials to determine which wastes could best be used with cattle slurry (CS). These showed that chicken manure, fish offal and FVW

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were the most promising [16]. Food wastes also a desirable material to co-digest with dairy manure because of its high biodegradability [17]-[19]. Study on the biogas production potential of unscreened dairy manure and different mixtures of unscreened dairy manure and food waste using batch digesters at 35 ℃ showed that the methane yield of unscreened manure and two mixtures of unscreened manure and food waste (68/32 and 52/48), after 30 days of digestion, was 241, 282 and 311 L/kg VS, respectively [20].

This study was initiated to investigate the effectiveness of inoculums for biogas production from the organic wastes (ORs) namely cafeteria waste (CW), vegetable waste (VW) and fruit waste (FW) with cattle manure (CM) and the aims of the present research work were to determine the optimal conditions for improved production of biogas using co-digestion of cattle manure and organic wastes and also identify the key parameters influencing the increase of biogas and methane yield based on inoculums source.

II. Materials and Method

A. Sample Collection and Preparation

Three organic solid wastes (Cafeteria, vegetable and fruit) were collected August 2014. Cafeteria waste was collected from the cafeteria of Graduate School of Science and Technology at Kumamoto University, Japan. Cafeteria food waste contained non degradable impurities such as bones, eggshell, wastepaper, pineapple shell and plastics were removed manually after sampling. Raw vegetables and fruits wastes also separated from cafe food wastes. The vegetable and fruit waste were collected from Kokai vegetable market, Kumamoto, Japan. The waste was sampled on three consecutive days by manually collecting and placing the wastes in sealed plastic bags. The cafeteria food waste was reported to be rice, cooking beef, pork, potato, mushroom, chicken, corn, pasta, ramen, udon, soba, nodules, fish, ham, and other cooked vegetables. The vegetable waste consisted of melon rinds, capsicum, cucumbers, onions, radish, cauliflower, cabbage, potato, tomato, carrot, pumpkin and leaf vegetables. And fruit wastes are apple, nashi, khaki, banana, kiwi, malta and avogadro. Fresh cattle manure (CM) was collected from dairy farm, Fukuoka, Japan. In these sites there are special feeds and normal grazing cattle. The special feeds are provided with special type of feeding includes silage, concentrate, and hay forage, agricultural residues and different grass types, byproducts. On the other hand, normal grazers are not provided with special type of feeding program rather they graze grasses in the field and get only fodder and agricultural residues. Finally the CM from both types of cattle (special and normal grazers) was sorted separately on plastic containers. The cattle manure was sorted manually to prevent the inclusion of unwanted and possibly contaminant materials (such as straw, grass, stone etc.). Cattle manure from special feeds and normal grazers were mixed by weighing equal amount from each source. All collected feedstock were blended using mechanical blender to an average particle size of 2 mm and kept in a refrigerator at 4 ℃. The blended cattle manure and organic wastes were mixed separately with water in 1:5 (solid waste: water) volume ratio, in order to maintain the total solid in the digester between 8 to 15%, which is the desired value for wet anaerobic digestion. The properties of feedstock slurries used in the experiment are given in Table I.

TABLE I. Properties of Cafeteria Waste, Vegetable Waste and Fruit Waste Used in the Experiments

Parameters	Cafeteria waste (CW)	Vegetable waste (VW)	Fruit waste (FW)	Cattle manure (CM)
pH	5.7	5.5	4.8	6.8
Total solids (%, wb)	13.7	11.5	14.8	20.33
Volatile solids (% of TS, db)	93	92.57	95.4	75.47
Moisture content (%, wb)	86.3	88.5	85.2	79.67

B. Inoculum Preparation

Due to the presence of higher methanogenic bacteria in the anaerobic sludge taken from the bottom settlement of previous mesophilic anaerobic digester in thermal laboratory, Kumamoto University was used as inoculum. The digester was a 0.2 m^3 polypropylene tank fed with solid organic wastes. The sludge was kept in air-tight buckets under ambient conditions (about 25 ℃) after sampling. In five flasks the digestion inoculums effect tests, the feedstock and inoculum were loaded into the batch system at a feedstock/inoculums (F/I) ratio of 0.5.

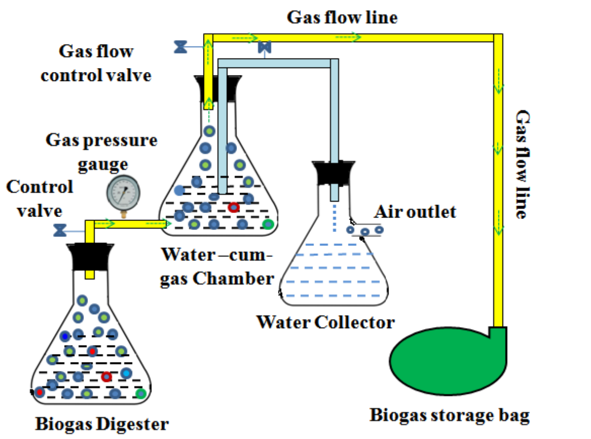


Figure 1. Schematic for generation of biogas from organic wastes and cattle manure

C. Experimental Set-Up and Design

A completely laboratory scale experiment was conducted in a series of ten glass flasks with 2 L capacity which was used as a anaerobic digesters at mesophilic temperature (30 ±2 ℃). A schematic for the whole setup is presented in Fig. 1. The working volume of each digester was 1.6 L. In five digesters, out of ten digesters anaerobic sludge was used as inoculum. Each digester was purged for 5 min (300 mL/min) with inert gas (N_2) to create an anaerobic environment. Cafeteria, vegetable, fruit waste, and cattle manure were separately examined in absence and presence of inoculum using co-digestion process. In co-digestion, the amount of organic wastes as well as that of cattle manure in each digester was varied when it was added. The CW:CM, VW:CM and FW:CM ratios of digestion were 0:100, 25:75, 50:50, 75:25 and 100:0 respectively in both conditions. To determine the performance of co-digestion, the co-digestion of cafeteria, vegetable, food waste, with cattle manure was compared in absence and presence of inoculum. In addition, to provide mixing of the digester contents, all digesters were shaken manually for about 1 minute once a day prior to measurement of biogas volume.

D. Data Measurements for Analysis

Biogas production from the digester was measured at daily basis using water displacement method. Gas composition was analyzed off line by gas chromatography (GC-8AIT / C-R8A SHIMADZU Corporation, JAPAN). The gas chromatograph was fitted with a Porapak N 80/100, 274 cm, 1/8 mesh 250×250×145 mm column, a molecular sieve (Mole sieve 5 A 60/80, 182 cm, 1/8), column oven maximum temperature 399 ℃ , temperature stability ±0.1 ℃ a stainless-steel column and a thermal conductivity detector. Detector type was TCD made by Tungsten rhenium filament. Maximum temperature and sensitivity of the detector was 400 ℃ and 7000 [mVmL /mg] respectively. Argon (Ar) was used as the carrier gas at a flow rate of 30 mL/min. The column temperature was 60°C and the injector temperature was 80 °C, with current 60 [mA]. For the batch tests, the entire content of the reactor was measured for pH, total solids (TS), and volatile solids (VS) at the digestion period. Total solids (TS) and volatile solids (VS) were determined at 104 °C to constant weight and by the loss on ignition of the dried sample at 550 °C, respectively [21]. The pH and moisture content was measured using digital pH meter (HM-25R) and moisture meter (MOC63u), respectively. The pressure was higher than atmospheric level measured by gas pressure gauge. Each constituents of the biogas was measured every day for 45 days digestion period.

III. Results and Discussion

A. Biogas Yields at Different Mixing Ratios without Inoculums Source

The daily biogas production by the co-digestion of cattle manure and organic wastes during 45 days of digestion was calculated under different mixing ratios as shown in Fig. 2. Samples from the mixing ratios of CW:CM 50:50, VW:CM 25:75 and FW:CM 25:75 were measured, and their peak yield values were 819, 625 and 753 mL/day on the 27th, 31th and 33th day, respectively (Fig. 2A, 2B & 2C). The digestion of single CM substrate (0:100) produced biogas 645, 531 and 610 mL/day which was generated on the 26th, 30th and 26th day, respectively.

By contrast, the digestion of any single CW, VW, and FW substrate (100:0) was produced (CW:CM 528, VW:CM 512 and FW:CM 584 mL/day) that occurred delay than the other combinations (32th to 34th day) and decreased rapidly after the 34th day (Fig. 2). However, the average biogas yields (CW:CM, VW:CM and FW:CM ratios of 0:100, 25:75, 50:50, 75:25 and 100:0) were 282, 319, 386, 302, 232, 248, 288, 250, 249, 207, 288, 347, 295, 288 and 225 mL/day, respectively. These results indicate that the co-digestion of cattle manure and organic wastes could the attainment of the highest gas production than single digestion.

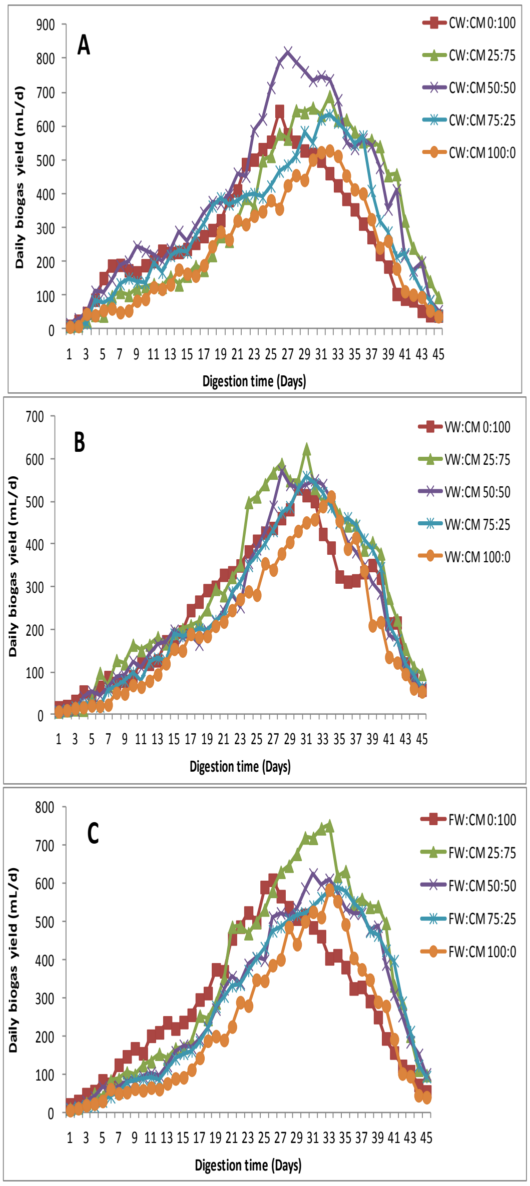


Figure 2. Daily biogas production from the co-digestion of CM with CW (A), VW (B) and FW (C) at different mixing ratios without inoculum

B. Biogas Production Rates at Different Mixing Ratios with Inoculums Source

The comparative daily biogas production rates from the co-digestion of cattle manure and organic wastes were observed in presence of inoculums under different mixing ratios as shown in Fig. 3. The biogas production process ran for 45 days until almost cease production was investigated. The results showed that the mixing ratios of CW:CM 50:50, VW:CM 25:75 and FW:CM 25:75 were produced biogas 997, 701 and 789 mL/day on the 31th, 34th and 31th day, respectively (Fig. 3A, 3B & 3C). However, in this experiment the ratio of VW:CM 50:50 was obtained highest biogas 764 mL/day on the 32th day. The digestion of single CM substrate (0:100) produced biogas greater than absence of inoculum and had relatively high peaks (759, 689 and 675 mL/day) (Fig. 3). Whereas, the digestion of any single CW, VW, and FW substrate (100:0) had small peak than single CM peak (CW:CM 715, VW:CM 632 and FW:CM 662 mL/day). The average biogas yields CW:CM, VW:CM and FW:CM ratios of (0:100, 25:75, 50:50, 75:25 and 100:0) were 400, 357, 457, 353, 311, 298, 346, 356, 315, 284, 337, 369, 358, 335 and 258 mL/day respectively as shown in Fig. 3. In both experiments the low biogas generation at the starting and the end might be due to the inhibition caused by the accumulation of volatile fatty acids (VFA) by the microorganism which hinders the releasing of the biogas.

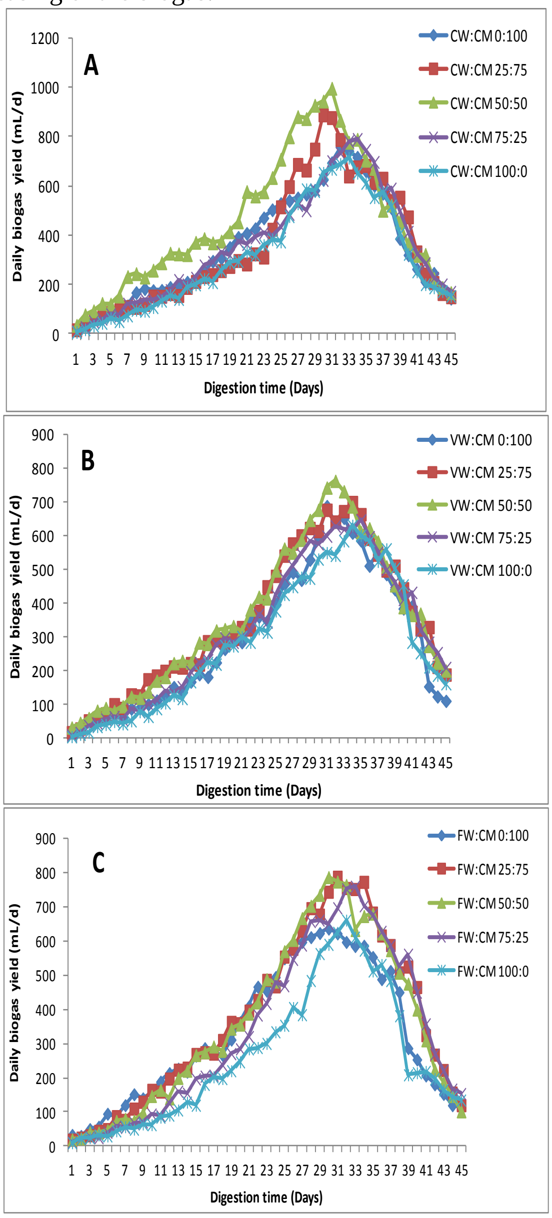


Figure 3. Daily biogas production from the co-digestion of CM with CW (A), VW (B) and FW (C) at different mixing ratios with inoculum

C. *Cumulative Biogas Production in Absence of Inoculums*

The final cumulative biogas productions by the co-digestion of CM and ORs at different mixing ratios are shown in Fig. 4. The cumulative biogas productions for CW:CM 25:75, 50:50, and 75:25 were 14387, 17383 and 13621 mL, respectively (Fig. 4A). These results showed an increase of 13%, 36% and 7% and 37%, 66%, and 30% compared with single CW (12713 mL) and CW (10469 mL) respectively. The same trends were observed for the VW:CM and FW:CM treatments, which had considerably higher increases (Fig. 4B & 4C). These data showed that the co-digestion of cattle manure and organic wastes greatly improved biodegradability and biogas production at most mixing ratios compared with single substrate digestion.

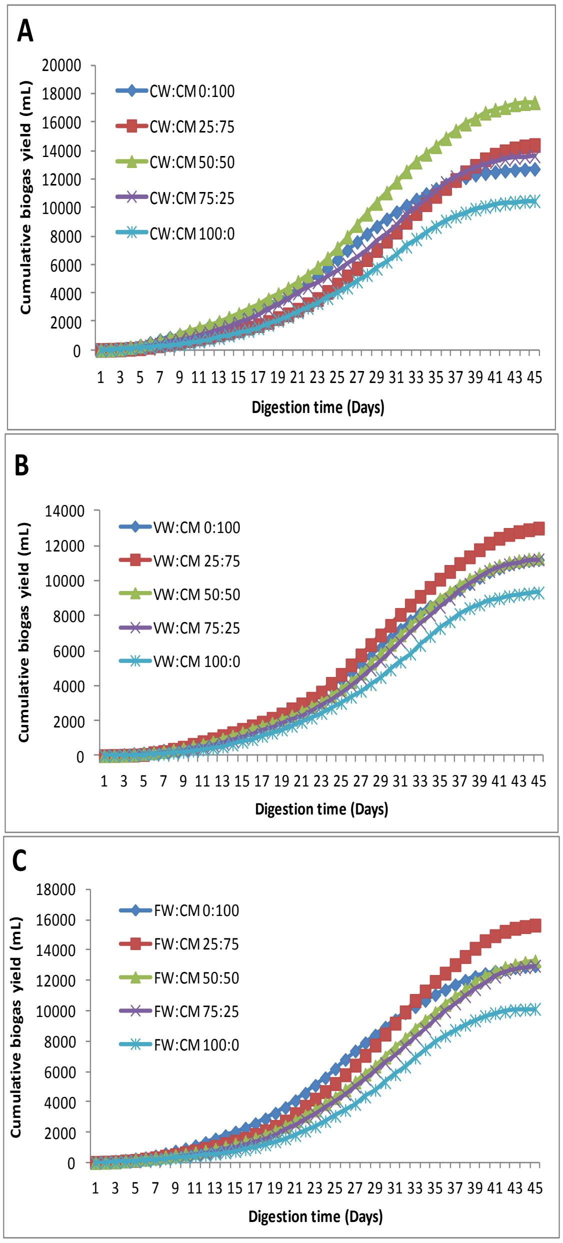


Figure 4. Cumulative biogas production from the co-digestion of CM with CW (A), VW (B) and FW (C) at different mixing ratios without inoculum

D. Cumulative Biogas Production in Presence of Inoculums

Fig. 5, shows that the effect of inoculums on cumulative biogas production during the digestion period. The results showed that approximately 65% of the cumulative biogas yields were achieved after the first 34 days of digestion. During the study period of 29-35 days, the highest cumulative biogas was observed. Consequently, the biogas production for CW:CM 25:75, 50:50, and 75:25 were 16090, 20585 and 15896 mL, respectively (Fig. 5A). In this study also shows the similar trends were observed for the VW:CM and FW:CM treatments (Fig. 5B & 5C). However, the results showed an increase of 1.5%, 30% and 0.3% and 14.8%, 46.9%, and 13.5% compared with single CW (15879 mL) and CW (14006 mL) respectively. Consequently, a highly active and concentrated inoculum source was critical to speed up the anaerobic digestion process.

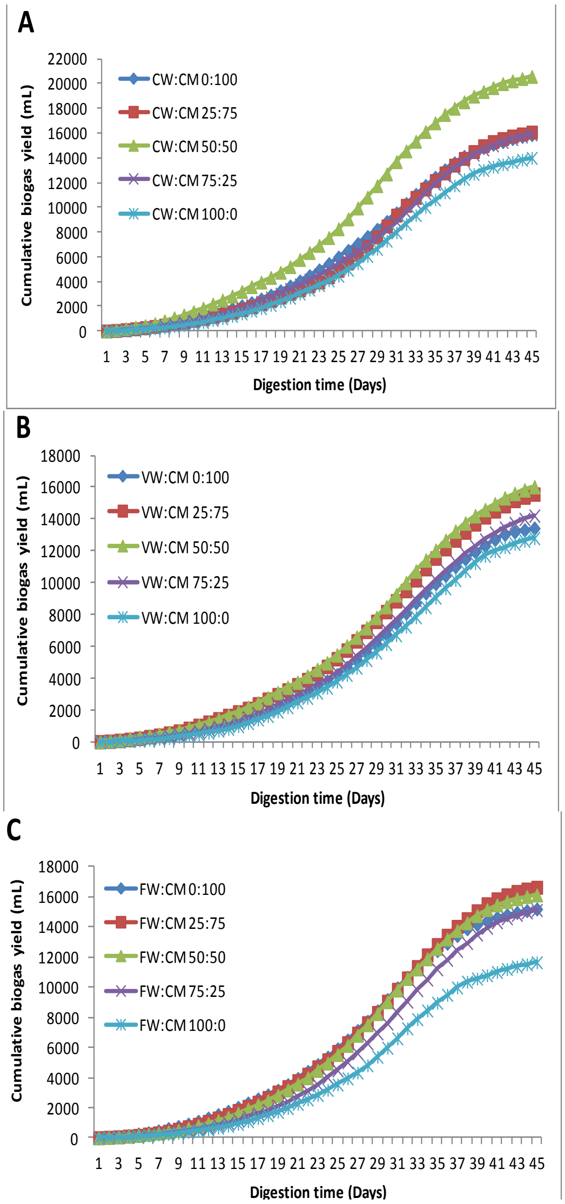


Figure 5. Cumulative biogas production from the co-digestion of CM with CW (A), VW (B) and FW (C) at different mixing ratios with inoculum

E. Inoculums Effect on Total Biogas Production

To compare the effect of inoculum in co-digestion with respect to cattle manure and organic wastes, the total biogas yield of each combination is shown in Fig. 6. The results showed that the ratios of CW:CM (50:50), VW:CM (50:50), and FW:CM (25:75) produced the highest biogas yields from different co-substrates (20585, 16037 and 16624 mL, respectively) after 45 days of fermentation presence of inoculum. This study showed that the total biogas productions of most co-digestion systems were higher than the absence of inoculum co-digestion of either cattle manure or organic wastes exhibited the highest total biogas yield of 20585 mL (CW:CM 50:50) in all treatments, which was 28.3% and 27.7% higher than that of VW:CM 50:50 and FW:CM 50:50, respectively. These results indicated that co-digestion with suitable cattle manure and organic wastes mixtures with inoculums is an effective way to prolong the period of the highest gas production and improve biogas yield.

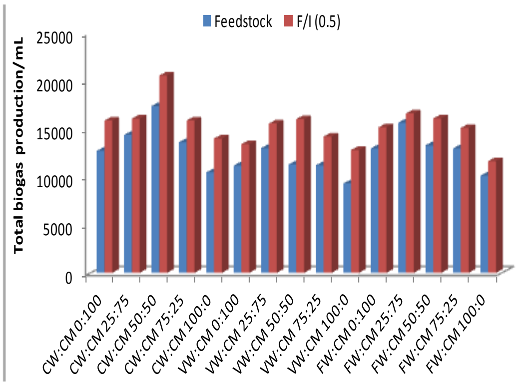
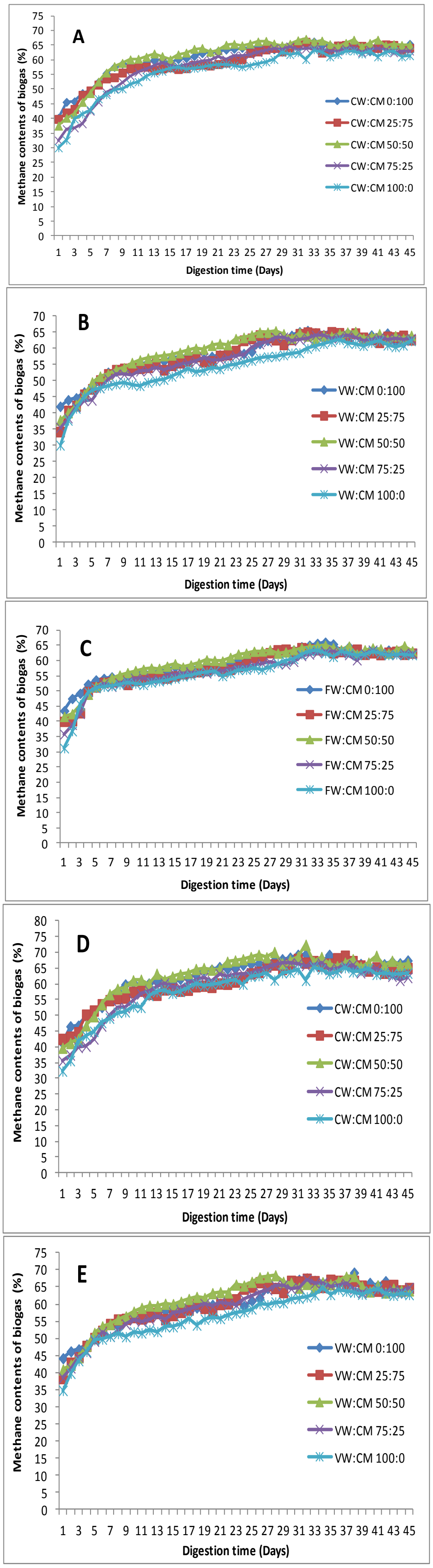


Figure 6. Total biogas production from the co-digestion of CM with CW, VW and FW at different mixing ratios without and with inoculum

F. Compositions of the Biogas during Co-Digestion Process

The methane concentrations of biogas produced from co-digestion of cattle manure with organic wastes at different mixing ratios are shown in Fig. 7. The result shows that the mixing ratios had significant effects on methane contents with inoculums source. The highest methane content of 72.4% was observed in the digestion system with CW:CM 50:50, on the 32th day which was comparable to the study of CW:CM 50:50 (without inoculum). The average methane content from the all digested ratios (CW:CM, VW:CM and FW:CM ratios of 0:100, 25:75, 50:50, 75:25 and 100:0) were 60%, 58%, 61%, 57%, 56%, 58%, 57%, 59%, 56%, 54%, 62%, 61%, 63%, 60%, 58%, 61%, 59%, 62%, 60%, 57%, 61%, 60%, 62%, 59% and 59% (Fig.7A-7F) respectively. With the addition of cattle manure, methane content of the biogas started to increase. The higher the composition ratio of cattle manure, the higher was the methane content in the digestion system. The higher methane content at higher composition ratios of organic wastes was probably caused by the high protein content contained in the food waste. However, the average methane content was 62% and 58% obtained with and without inoculums source respectively.



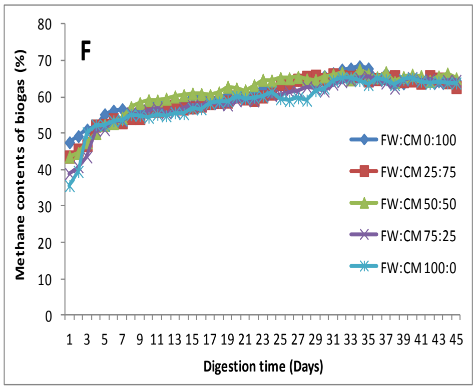


Figure 7. Methane content from the co-digestion of CM with CW , VW and FW (A-F) at different mixing ratios without ant with inoculum

IV. Conclusions

The optimal performance for co-digestion of cattle manure and organic wastes was achieved at their mixing ratio of CW:CM 50:50. Under this preferred ratio, the effect of inoculum content on anaerobic co-digestion was investigated in batch systems. The results indicate that methane concentrations (with inoculums) from co-digestion of cattle manure and organic wastes were higher or comparable to the output of (without inoculums). The study results showed that the anaerobic co-digestions of CM with CW, VW and FW were efficient and produced more cumulative biogas by adding inoculums source. The best ratios were CW:CM 50:50, VW:CM 50:50 and FW:CM 25:75. Therefore, the anaerobic co-digestion of CM and organic wastes with inculums is a promising way for improving biogas production. This co-digestion not only resolves the environmental problems caused by fossil fuel, but also overcomes energy crisis to enhance the AD process.

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