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Research Article
Implementation of Upflow Anaerobic Sludge Blanket Digester to Produce Household-scale Biogas

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Abstract
Objective: The objective of study was to create digester (reactor) design by using the Upflow Anaerobic Sludge Blanket (UASB) technology for manure handling to produce household-scale biogas. **Methodology:** The digester consisted of a plastic tank with three rooms. There was the main room, the second room and the gas-solid separator or cross-section room. The volume of the digester was 179 L. The hydraulic retention time was 20 days. It was conducted in two phases: batch phase for 20 days and continuous phase for 21 days. **Results:** During the batch phase, the average discharge of Total Suspended Solids (TSS) were 4856.67 mg L^{-1}, Volatile Suspended Solids (VSS) were 8520 mg L^{-1} and Chemical Oxygen Demand (COD) was 14911 mg L^{-1}. During the continuous phase the average discharge of TSS were 13374.29 mg L^{-1}, VSS were 26642.86 mg L^{-1} and COD were 41653.57 mg L^{-1}. The removal efficiency of TSS, VSS and COD during the batch phase were 55.4, 79.8 and 17.4%, respectively, while this did not occur during the continuous phase. The biogas production began to increase at the beginning and during the continuous phase. The continuous phase had a higher average of biogas production than the batch phase. The highest speed of biogas production occurred at 8 am to 12 pm with a temperature of $34.97\pm3.18°C$ and pH of 5.67 ± 0.04. The average volume of biogas production per day during the batch phase was 2,534 mL and during the continuous phase was 22,519.05 mL. Methane content in the biogas on day 10, 21, 30 and 41 were 2.65; 38.12; 78.99 and 76.97% mol, respectively. Sedimentation occurred during the batch phase while the continuous phase had no sedimentation at all. **Conclusion:** The implementation of UASB design to process cow manure by handling to produce household-scale biogas had the advantages of upward flow, a gas-solid separator and the sedimentation process. The upflow and gas-solid separator has the roles to help remove and separate the biogas bubble from the sludge's solids and liquids and the highest methane content during production achieved in the continuous phase. It can be applied efficiency and massively to manage livestock waste in household-scale in remote areas, especially in disadvantaged villages.

Key words: UASB digester, cow manure, influent and effluent characteristics, biogas production, batch and continuous phase

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Livestock industry alone contributes to 18% of the total greenhouse gas emissions caused by human activities. It refers to large enough to be noticed. Methane is 20 times stronger a heat-trapping gas in the atmosphere than CO_2 or carbon dioxide[1,2]. Processing livestock manure with anaerobic digesters can reduce its negative impact on the environment and in addition, it can produce biogas. Biogas, which is composed of CH_4, CO_2, NH_3, water and other gasses in small amounts, can be used as fuel. Anaerobic wastewater treatment has become the most attractive method due to its low production of biomass, low-cost effectiveness and low energy demand[3]. Since the early 90's, solutions based on Upflow Anaerobic Sludge Blanket (UASB) reactors have begun to be developed[4]. The Upflow Anaerobic Sludge Blanket (UASB) is a type of reactor that is used widely in the world, especially in the anaerobic treatment of industrial wastewater and many characteristics of the waste. These systems have been traditionally employed, given the interesting results achieved in terms of treatment efficiencies and energy recovery through the production of biogas, for the treatment of high strength industrial wastewaters produced for example by sugar and dairy industries, manure and urine of cattle, slaughterhouses, distilleries, breweries, pulp and paper, food industries, etc.[5-20]. The UASB reactor has probably designed to treat high concentration of wastewater[5]. Various studies have widely been conducted in the field of wastewater treatment within employing UASB reactor[5,21].

In developing countries, the UASB reactor in many cases and usefulness, the only treatment applied after preliminary mechanical treatment, although the importance of completing the treatment process with a final oxidative biological treatment is widely recognized. In fact, despite the great advantages presented by UASB reactors, such as biogas production, the quality of the treated effluents generally, does not comply with discharge standards. The following removal efficiencies have been reported for UASB: 43-47% for COD, 55-77% for BOD and 18-85% for suspended solids[16,22-24]. Therefore, the effluents from UASB reactors usually require a post-treatment step in order to comply with the limits established by the environmental legislation in force in order not to alter the quality of the receiving water bodies. The implementation of UASB reactor's work principle or basic concept on small-scale digesters needs to consider the condition of cattle farms in Indonesia in which most people are smallholder farmers, so necessary adjustments are needed. The size and shape adjustment in applying the basic concepts of UASB digester (reactor) so it can be used on small-scale digesters is the background to modify the digester design in this study. Therefore, the main purpose of this study was to describe the digester design created using the Upflow Anaerobic Sludge Blanket (UASB) technology for manure handling to produce household-scale biogas.

MATERIALS AND METHODS

Time and place of research: This experiment was conducted in "UPT Ternak Perah", Faculty of Animal Science, Universitas Gadjah Mada. Analysis of samples was conducted in Laboratory of Chemistry, "Balai Besar Teknik Kesehatan Lingkungan dan Pemberantasan Penyakit Menular Yogyakarta"; Laboratory of Chemistry, "Balai Penyelidikan dan Pengembangan Teknologi Kegunungapian Yogyakarta"; and Laboratory of Nutritional Biochemistry, Faculty of Animal Science, Universitas Gadjah Mada.

Preparation of materials: This study used the packing material from the mixture of cow manure and water. Stuffing material made by mixing Friesian Holstein cow manure and water volume with a proportion of 1:2. One liter of cow manure mixed with 2 L of water.

In this study, the digester (reactor) design that used UASB system has the volume of 179 L. The substrate loading rate was 8,950.00 mL day^{-1}, with a hydraulic retention time of 20 days. It was conducted in two phases, namely: batch phase for 20 days and continuous phase for 21 days. The substrate used as the effluent has the average organic content of COD 18,053.00 mg L^{-1} and VSS 42,185.00 mg L^{-1}. The loading rate of organic material (organic loading rate) in this study amounted to COD 902.65 mg L^{-1} day^{-1} or VSS 2,109.25 mg L^{-1} day^{-1}.

Method of data analysis: The data obtained from the observation (Total Suspended Solids (TSS), Volatile Suspended Solids (VSS), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), potential of hydrogen (pH), temperature, biogas production, production rate) and analyzed descriptively then presented in graphical form. Beside that tested the average production of biogas in batch phase and continuous phase with mean comparison method of Independent Sample t-test using Statistical Program for Social Science (SPSS) version 16.0.

RESULTS AND DISCUSSION

Influent and effluent characteristics: The UASB bio-digester design based on the up-flow feeding of wastewater through the sludge bed at the bottom of digester. Gas-liquid-solid separator is equipped at the top of digester to separate the solution contents i.e. the liquid as treated effluent, the solids particle is trapped and returned back downward and the gas is collected from the top of digester in the form of biogas. On the other hand, the successful operation of UASB digester requires good contact between the substrate of influent and the biomass in sludge bed. Whereby the start-up period of operation includes the microbes communities immobilization through continuous feeding of wastewater into seeded sludge to be developed to granules aggregations which are considered as the key success of the process[25,26].

Influent characteristics: Substrate takes part in the design of waste digester[7,27]. Such as organic matter content, dry matter content, the contents of volatile fatty acids in cow manure were some of the parameters that have a role in the design of biogas digester and also in the production of methane in the biogas.

The results of this study have an average influent wastewater characteristics of dairy cow manure showed in Table 1 and graph of the influent characteristics showed in Fig. 1. It was higher than previous results by Raboni *et al.*,[4] COD 548.00-1224.60 mg L^{-1}; BOD 281.10-568.00 mg L^{-1} and SS 295.60-522.80 mg L^{-1}. Characteristics of influent wastewater dairy cow manure in this study classified as high strange sewage[27].

Some of the results of previous studies mention dairy cows 635 kg (1,400 pounds) excrete 50.8 kg (112 pounds) manure, containing 6.35 kg (14 pounds) dry weight TS, 4.98 kg (11 pounds) dry weight VS and 1.14 kg (2.5 pounds) COD[28]. Masse *et al.*[29] stated that Volatile Fatty Acids (VFA) and ammonia will affect the production of methane because acetic acid is a direct precursor of methane and ammonia is an inhibitor of the formation of methane.

Effluent characteristics: The total suspended solids in batch phase had a better TSS reduction efficiency compared to the one in the continuous phase. It also looked more stable than the one in the continuous phase. The TSS reduction efficiency was 55.4% in batch phase. The Total Suspended Solids (TSS) of the effluent began to increase on day 34, which was already in the continuous phase, amounted to 6,210.00 mg L^{-1}. The TSS had the highest increase from day 34 (6,210.00 mg L^{-1}) to day 36 (40,100.00 mg L^{-1}), which was more than a sixfold increase. The reduction of TSS occurred after day 36 (40,100.00 mg L^{-1}) until it reached 20,640.00 mg L^{-1} on day 41.

The total suspended solids reduction efficiency did not occur in the continuous phase. On the contrary, the TSS was accumulating. The accumulation was indicated by the average influent TSS which was smaller than the average effluent TSS in substrate processing during the continuous phase. The average influent TSS in continuous phase was 10,890.00 mg L^{-1} and the average effluent TSS was 13,374.29 mg L^{-1} (Table 2). The TSS accumulation was 22.81% of the influent. The visual observation of the effluent characteristics indicated that starting from day 29, the sludge which came out of the outlet was thicker and denser than the sludge in batch phase.

The total suspended solids reduction efficiency occurred in batch phase and there was no accumulation or reduction efficiency in the continuous phase. This might indicate that:

- A good sedimentation occurred in batch phase so that the sludge of the effluent became thinner than the one of influent

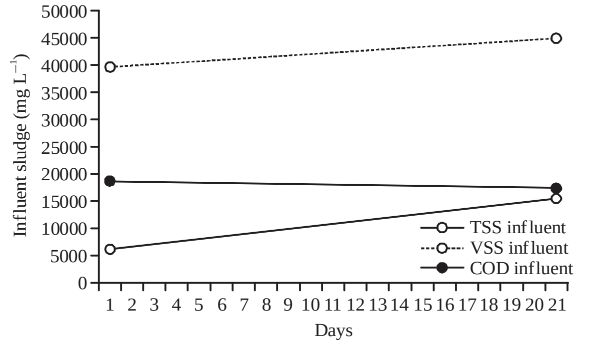

Fig. 1: Characteristics of influent sludge of cow manure

Table 1: Characteristics of influent sludge of cow manure

	Values (mg L^{-1})		
Parameters	Minimum	Maximum	Average
TSS influent	6,270.00	15,510.00	10,890.00
VSS influent	39,580.00	44,790.00	42,185.00
COD influent	17,400.00	18,706.00	18,053.00

TSS: Total suspended solid, VSS: Volatile suspended solid, COD: Chemical oxygen demand

Table 2: Characteristics of influent and effluent sludge as the result of UASB digester processing in continuous phase

	Values (mg L^{-1})		
Parameters	Minimum	Maximum	Average
TSS influent	6,270.00	15,510.00	10,890.00
VSS influent	39,580.00	44,790.00	42,185.00
COD influent	17,400.00	18,706.00	18,053.00
TSS efluent	4,880.00	4,010.00	13,374.29
VSS efluent	8,380.00	4,439.00	26,642.86
COD efluent	16,400.00	8,480.00	41,653.57

TSS: Total suspended solid, VSS: Volatile suspended solid, COD: Chemical oxygen demand

Table 3: Characteristics of influent and effluent sludge as the result of UASB digester processing in batch phase

	Values (mg L^{-1})		
Parameters	Minimum	Maximum	Average
TSS influent	6,270.00	15,510.00	10,890.00
VSS influent	39,580.00	44,790.00	42,185.00
COD influent	17,400.00	18,706.00	18,053.00
TSS efluent	4,810.00	4,930.00	4,856.67
VSS efluent	7,540.00	9,490.00	8,520.00
COD efluent	12,462.00	18,000.00	14,911.00

TSS: Total suspended solid, VSS: Volatile suspended solid, COD: Chemical oxygen demand

- Solids loading rate into the reactor was faster than the rate of sedimentation
- The solid-state digestion took longer time than the hydraulic retention time

The reduction efficiency of Volatile Suspended Solids (VSS) occurred in the batch phase until day 30 (the continuous phase). The VSS was stable until the continuous phase on day 24. The average influent VSS was 42,185.00 mg L^{-1} and the average effluent VSS amounted to 8,520.00 mg L^{-1} during the batch phase (Table 3). The VSS reduction efficiency during the batch phase was 79.8% and VSS reduction efficiency still continued from the end of the batch phase (day 20) up to day 30 of the continuous phase.

The volatile suspended solids were stable again on day 34 of the continuous phase, where no reduction efficiency occurred. The average VSS from day 34 until day 41 had the same amount to the average of influent VSS. The VSS was the parameter of the organic-matter content in the substrate and sludge. In addition to using volatile solids as an indicator, we also used chemical oxygen demand. During the continuous phase, the organic material in the digester was accumulating and this was also the case with the Total Suspended Solids (TSS). The organic material in the effluent began to surge on day 24 of the continuous phase.

The loading rate of organic material (organic loading rate) in this study was greater than the bacteria's ability to digest organic material in the digester. This too high loading rate of organic material was characterized by the lack of reduction efficiency of organic material (VSS and COD) in the continuous phase. The organic loading rate was optimum for the mesophilic reactor to process cow manure between 2.5-3.5 kgVS m^{-3} day^{-1}, cow manure and mixed materials between 5.0-7.0 kgVS m^{-3} day^{-1} and between 3.0-3.5 kgVS m^{-3} day^{-1} to pig manure[30].

During the batch phase, the organic-matter content of the effluent, which was analyzed with Chemical Oxygen Demand (COD) parameter, remained stable at the average of

Table 4: Volume of biogas production in cow manure processing using UASB digester in batch and continuous phases

	Values (mL)		
Parameters	Minimum	Maximum	Average
VBP	0	4,840.00	2,534.00
VCP	6,730.00	33,450.00	22,519.05

VBP: Volume in batch phase, VCP: Volume in continuous phase

COD 14,911.00 mg L^{-1}, but COD reduction efficiency was relatively low at 17.4%. Organic-matter loading that did not occur during the batch phase had an impact on the organic-matter content which was relatively stable. The COD reduction efficiency was smaller than TSS and VSS reduction efficiency. The COD remained stable from the beginning of batch phase until day 27 of the continuous phase. The COD increased very quickly from day 27 (20,200.00 mg L^{-1}) to day 36 (84,800.00 mg L^{-1}). The same thing happened to TSS and VSS, which showed a higher rate of organic matter loading than the bacteria's ability to decompose organic matter in the reactor. The highest increase of COD occurred on day 30-36. The COD began to decrease after day 36 (84,800.00 mg L^{-1}) until day 41 (47,200.00 mg L^{-1}).

The chemical oxygen demand decreased on day 15 and increased the next day, as well as VSS. The decline of organic-matter content on day 15 showed the occurrence of sedimentation, as well as the activity of anaerobic bacteria which had started decomposing organic matter. The increase and the decrease of VSS and COD have the same pattern. It showed a positive correlation between them.

Performance of biogas production: The production of methane in form of biogas includes the organic materials conversion under anaerobic conditions that is represented in wastewater treatment by employing UASB reactor. This process mainly required some kinds of bacteria to be done. The conversion by bacteria can be achieved throughout the following phases: hydrolysis, acidogenesis, acetogenesis and methanogenesis[31-33], also depending on solution pH and temperature[34]. Under low pH, no gas production can occur considering that at low pH the methanogens bacteria are not active, in addition to VFA accumulation phenomenon which indicated to its gas production inhibition, the phase stability can be lost. Microbial methanogens responsible to organics biodegradation that resulted in biogas production.

The results of the study indicated the presence of differences between the average production volume in batch phase with the one in the continuous phase ($p<0.05$) (Table 4).

Increased production of biogas is beginning to look at the continuous phase (day 21) can also show the role of the flow

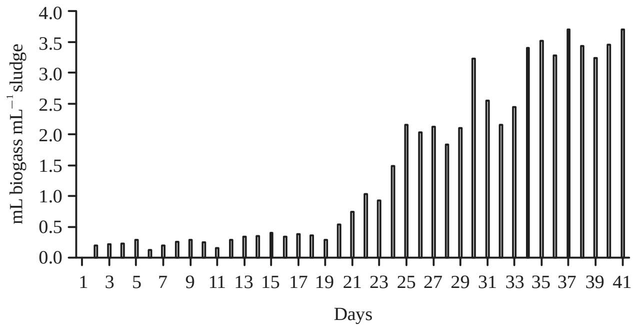

Fig. 2: Conversion of cow manure into biogas in use UASB digester design

Table 5: Average conversion of cow manure into biogas in batch phase and continuous phase

	Value (mL biogas mL^{-1} sludge)		
Parameters	Minimum	Maximum	Average
CSBP	0.00	0.54	0.28
CSCP	0.75	3.74	2.52

CSBP: Conversion in batch phase, CSCP: Conversion in continuous phase

of sludge that flows from the bottom toward the top. Flow upward (upflow) assist gas is formed and is still diffused in the mud, through a compartment separate gas separator, solids and liquids (gas-solid separator/GSS). Upward flow will push the bottom sludge and biogas is still stuck in the mud bottom toward the top. Sludge containing diffusion of biogas leading up to the GSS, the most watered sludge advance through the GSS and the bubble will burst during the biogas through biogas GSS and off toward the shelter space. A critical element of the design is the UASB reactor influent distribution systems[7], a solids-gas separator (gas-solid separator)[27] and design jetting back effluent[32]. Mud dispersed due to the flow of biogas to the top, especially the reactor with a high organic load is large but can be detained by the separator on the top of UASB[7]. Pertiwiningrum *et al.*[33] reported that the biogas and methane generation showed an increase day after day until reached the maximum value and then decreased slowly day after day but biogas production was detected low in the reactor with mixing system during first week of the fermentation process. Jha *et al.*[35] reported that it happened due to high VFAs production, decrease in pH value and lack of methanogens.

Conversion of organic materials into biogas: The results of this study indicated that continuous phase had a higher average of biogas conversion than the batch phase. The average conversion of substrate into biogas was 0.28 mL biogas mL^{-1} sludge in batch phase and 2.51 mL biogas mL^{-1} sludge in the continuous phase (Table 5). The escalation of organic matter conversion started from the beginning of the continuous phase, where organic matter loading took place. The results also showed that organic matter loading and organic loading rate gave influence to the conversion of organic material into biogas (Fig. 2). Based on Pertiwiningrum *et al.*[33], the methane concentration (%) related to biogas production showed on day 14, 20, 25 and 30. The optimal methane production happened on day 30.

The accumulation of organic material in the reactor will increase the production of biogas. Organic-matter loading, organic-matter accumulation, sludge retention time and decomposition rate of organic matter by anaerobic bacteria are interrelated and influenced the volume of biogas production, biogas composition and reduction efficiency of organic material and solids.

Sedimentation (settling): Sedimentation will take place during the processing of waste using the upflow anaerobic sludge blanket reactor. This study also observed the sedimentation by measuring the height of the sediment through the observation window located on the wall of the digester. The solid precipitate began to build up on day 21 (the beginning of batch phase), an indication that the process of sedimentation continued during the batch phase. The sediment lied at the bottom of observation window (the height was 35 cm). It means that the top of the sediment at the end of the batch phase was 35 cm from the bottom of the digester. The height of the sediment during the batch phase could not be measured because it was still below the observation window.

The height of the sediment could be seen through the observation window on day 26 (Fig. 3). The sludge solid started to come out on day 29. It was the effluent of sludge sedimentation in the digester designed with UASB technology.

The results of the observations will become the basis of the digester's operation. This includes the approximate time

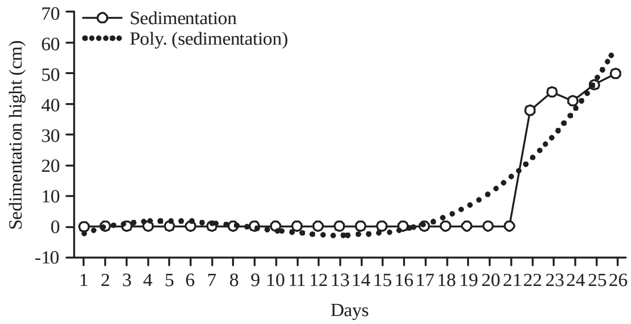

Fig. 3: Sedimentation of sludge in the UASB digester design research

Table 6: Draining time (blow up) of solid precipitate in UASB digester

Height allowed (cm)	Draining time (days)
37	22
40	23
45	25
50	26
70	50

that digester should be drained and cleaned from its sediment (blow down). If the height of the sediment allowed in the operating procedure is as high as 75% of the height of the digester based on the digester's volume (70 cm), the solid precipitate must be drained on the day between day 50 and day 52, on condition that the digester runs under the same conditions with this research (digester's volume, hydraulic retention time, organic loading rate and loading rate) (Table 6).

Raboni *et al.*[4] reported that the raw sewage proves "high strength" characteristics because of the high concentrations of BOD, COD and suspended solids. This condition, coupled with the high temperature, results in the achievement of average removal efficiencies in the UASB reactor as high as 74.0% for BOD, 71.1% for COD and 65.0% for suspended solids. These efficiency values are better than those that are typically obtained by a simple primary sedimentation step and may be related to both the anaerobic biological process occurring in the UASB and the mechanical filtration process taking place in the same biological bed.

CONCLUSION

The implementation of Upflow Anaerobic Sludge Blanket (UASB) design to process cow manure by handling to produce household-scale biogas had the advantages of upward flow, a gas-solid separator and the sedimentation process. The upflow and gas-solid separator has the roles to help remove and separate the biogas bubble from the sludge's solids and liquids and the highest methane content during production achieved in the continuous phase. The UASB technology can be applied efficiency and massively to manage livestock waste in household-scale in remote areas, especially in disadvantaged villages.

SIGNIFICANT STATEMENTS

- Biogas production began to increase at the beginning and during the continuous phase. Continuous phase had a higher average of biogas production than the batch phase
- The highest methane content from UASB technology during production in this study achieved the continuous phase
- The UASB technology can be applied efficiency and massively to manage livestock waste in household-scale in remote areas, especially in disadvantaged villages. The UASB technology also can be applied to industrial waste-water treatment

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