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Analysis of the influence of internal pressure control to the total gas production in anaerobic digester

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Abstract

Production of bio-hydrogen from stale rice was conducted in an aerobic digester. It was applied 3 types of pressure control range to the digester, they are (0-3/3 %), (0-2/3 %), (0-1/3 %) of maximum pressure during the production of bio-hydrogen in mesophilic (35 ^{o}C) condition which is equal to (0-10 psi), (0-6 psi), (0-3 psi), and as small as possible pressure in the digester. This research shows that the optimum pressure control range to increase total gas production is (0-2/3 %) or (0-6 psi), with total production of 19 liters biogas.

Keywords: Bio-hydrogen; organic waste; anaerobic digester; mesophilic; pressure control;

1. Introduction

The process of hydrogen separation can be done through various processes, such as the process of steam reforming, water electrolysis, or biology. Hydrogen production by biological methods is more efficient in energy and more environmental friendly than other methods [1] [2]. One of biological hydrogen production methods is the anaerobic fermentation. Hydrogen can be produced by anaerobic bacteria from carbohydrate-rich substrate into organic acid, H_2 and CO_2 [3]. Three main stages of anaerobic fermentation in the anaerobic digester: (1) Hydrolysis; (2) Acidogenesis; (3) Methanogenesis [4]. The optimum hydrogen production can be obtained from acidogenesis phase. Some environmental conditions for anaerobic digester that affect bio-hydrogen production are pH, temperature, HRT, and partial pressure [5]. Increased pressure inside the digester is considered as a waste product and inhibits the metabolism of anaerobic bacteria [6], but by lowering the partial pressure of hydrogen can increase the production of hydrogen [5].

The purpose of this research is to utilize stale rice as a substrate to produce bio-hydrogen, with focus on the analysis of internal pressure control range to increase the production of hydrogen gas in a laboratory scale anaerobic digester. This research is a part of bio-hydrogen production research at Engineering Physics Department, Telkom University.

2. Materials and methods

2.1. Reactor design

The reactor used in this research is a type of anaerobic digester with a total volume of ± 11 liters. This reactor is made of stainless steel, it was designed so that the reactor can be used for temperature control and can withstand pressure of 11 to 14.5 psi. The reactor is composed of two layers of stainless pipes; there is a gap between the pipes that used as a chamber of heating fluid (water). Table 1 is a table that describes the dimensions of the reactor used in this study.

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Table 1. Dimension of anaerobic digester

Description	Dimension
Volume capacity	± 11 liters
Diameter of inner tube	25.4 cm
Diameter of outer tube	27.9 cm
Width of water heating gap	2 cm

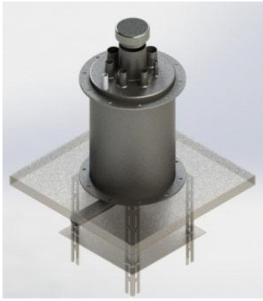

Fig. 1. Design of anaerobic digester.

2.1.1. Reactor Testing

Reactor was tested to determine the state of the reactor. This test should be done to ensure that the reactor can be used as an anaerobic environment for anaerobic facultative and anaerobic obligate bacteria alive. The testing is done by injecting pressurized air using a compressor into the reactor, after closing all channels of sensors and valves. The tests carried out in stages, ranging from the 8, 9, 10, 11, up to 14.5 psi. From the test results, when the reactor is pressurized to 14.5 psi reactor is safe and does not explode. But slowly after 2 hours the gas pressure inside the reactor started to fall, it indicates that there is a gas leak in the reactor. The leaks are at the gate of substrate disposal valve, gate of one-way valve of pH input, and gate of gas output solenoid valve. Similar things happened to the test reactor with pressurized air injection at 12 and 13 psi. Further is reactor testing at a pressure of gas 8, 9, 10 and 11 psi; at these four pressure points the reactor is able to maintain the gas pressure over 2 hours. Thus, it can be known that the maximum capacity of the reactor is 14.5 psi and 11 psi for maximum ability of the reactor to maintain gas pressure. Based on preliminary test, 10.4 psi was selected as a safe point of the reactor to maintain gas pressure. It shows that, the reactor is able to maintain 10.4 psi for 28 hours. Hence, during the bio-hydrogen production in this research, it was avoided to use the reactor until the maximum limit of the reactor (11 psi), and always under the gas pressure of 10.4 psi.

2.2. Pressure control design

In the production process of bio-hydrogen, generally it was given temperature and pH control to create optimum environmental conditions for anaerobic bacteria [7] [8] [9]. But in this research pH control is not applied to the system, because in pH control system the pH liquid must be injected into the reactor using pump, which is make sudden increase of internal pressure. This sudden increase is considered as a disturbance, because it creates unclear relationship between the increase of internal pressure digester and gas production of anaerobic bacteria. So the environmental control applied in this research is temperature control. Temperature is one of the most affecting factors in bio-hydrogen production [10]. The temperature control refers to a research that has been done by Pratiwi [11], but by re-adjusting the temperature set point to mesophilic range (35 ^{o}C). Two reasons for selecting mesophilic control due to: first, the anaerobic bacteria used in this research is the bacteria that has been found in stale rice or without any addition of thermophilic bacteria inoculum. Second, thermophilic experiment consumes more energy compared to a mesophilic experiment, and the different between yields in thermophilic and mesophilic is not always highly significant considering the difference in the amount of consumed energy [10]. While, to support the main purpose of this research, which is analyzing the optimum pressure control range, here is the design of the hardware and software or a program for pressure control and data acquisition.

2.2.1. Hardware

The design of the hardware to support this research is consist of the addition of solenoid valve, shut off the gas valve, and gas storage made of a balloon. During the production, the produced gas is stored in the reactor until internal pressure of the digester reaches the desired set point. Solenoid valve is required to regulate the volume of gas that comes out of the reactor, in order to control the internal pressure within the reactor, with the assistance of microcontroller and relay driver. Hardware design for pressure control system can be seen at figure 2.

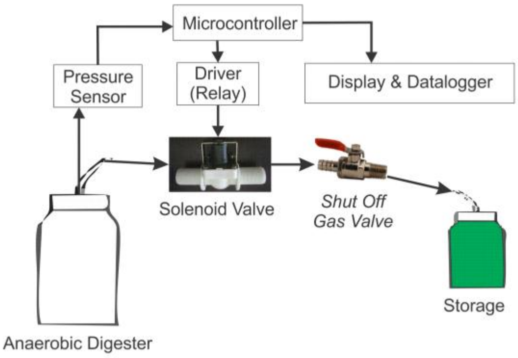

Fig. 2. Hardware design of pressure control system.

2.2.2. Software

Software or the program making is needed for solenoid valve control, and combine information of sensors, data logging, and display command. The data sampling of pressure and data acquisition of temperature control process performed within an interval of 1000ms. While the pressure control system takes different interval to open and close the solenoid valve automatically, so this research used two microcontrollers. One, for pressure and temperature data sampling, temperature control system, display command, and data logging. The other one to activate driver relay and solenoid valve, in order to control internal pressure digester as the desired set point.

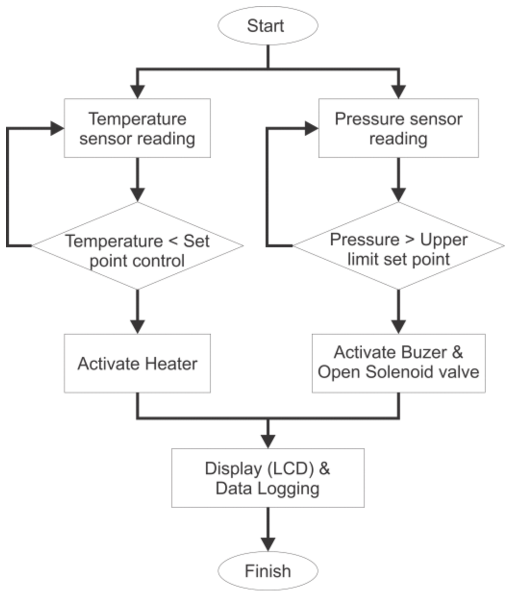

Fig. 3. Software block diagram.

2.2.3. Pressure control block diagram

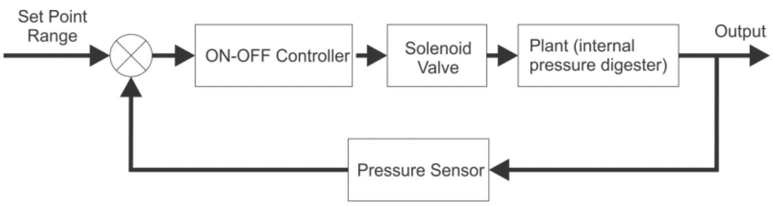

Fig. 4. Block diagram ON-OFF pressure control.

Previously, research about pressure control has been done by Rahmawan, the research showed that the performance of digester with on-off pressure control is better than the digester without control [12]. The pressure was controlled under the range of maximum pressure during the production and the defined pressure set point by Rahmawan. This research did the similar way to determined pressure control set point range, but by varying the control range into 3 ranges. The defined range are, 0-1/3 (30%), 0-2/3 (60%), and 0-3/3 (100%) of the maximum pressure during the mesophilic (35 ^{o}C) bio-hydrogen production with

HRT of 2 days. Based on the set point range that was determined in the controller, the controller will give instructions to the actuator (solenoid valves) to open and close automatically.

2.3. Substrate preparation

The substrate used in this research is organic waste such as rice which has been stale for 2 days, which is equal to the initial pH of 4-5. For the substrate preparation, the stale rice mixed with water, the ratio of stale rice and water is 1: 2 (rice: water in kg/kg). Total stale and water used for each study was 3.2 kg and 6.4 kg, and then the mixture of rice and water is blended for one minute. Next is the stage of substrate pre-heating in 30 minutes using an electric stove (600 watt). The purpose of substrate pre-heating is to enrich the hydrogen-producing microbial cultures, deactivate hydrogen-eating microorganisms, or as a selector of hydrogen-producing bacteria [13].

2.4. Analytical methods

From several studies mentioned by Balachandar et al. [5] there is the optimum hydrogen partial pressure depends on the temperature control used during the bio-hydrogen production. the production under the temperature of 60 ^{o}C was obtained 50 kPa as the optimum pressure [14], the optimum pressure for production under the temperature of 70 ^{o}C is 20 kPa [15], and from the research of Adams mentioned by Levin et al. [2], it was gained 2 kPa as the optimum pressure during the production under the temperature of 98 ^{o}C. So to find out the optimum pressure control range in this research, this research is comparing the total gas production under the three defined pressure control ranges and the production without pressure control. To control the internal pressure, the produced gas is stored in the reactor until its pressure reach the desired set point range. While, the production method of uncontrolled digester is by passing the produced gas continuously to the storage.

3. Result and discussion

3.1. Maximum pressure determination

The first experiment that was conducted is bio-hydrogen production under mesophilic (35 ^{o}C) control for 2 days, to determine the maximum pressure during the production. After the maximum pressure is known the production is stopped, then do the next experiment of bio-hydrogen production under mesophilic and pressure control. Figure 5 & 6 show the change of temperature and pressure inside the digester.

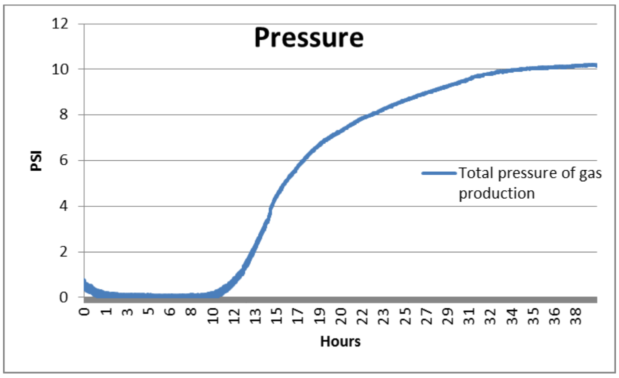

Fig. 5. Graphic of gas pressure change under mesophilic control.

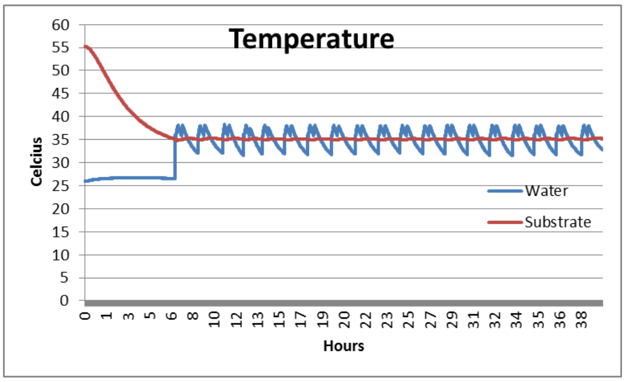

Fig. 6. Substrate and water temperature change.

After 10 hours, the pressure inside the digester is still constant at 0 psi. But starting from the10th to 38th hour the pressure began to increase, while the temperature inside the digester already constant at 35 ^{o}C. According to equation 1 & 2 of ideal gas equation [16]:

$$PV = nRT \quad (1)$$

$$P_T = \frac{RT}{V}(n_1 + n_2) \quad (2)$$

If the temperature and the volume is kept constant, then the change of the pressure are due to changes in the number of particles inside the digester. This shows the gas production activity by anaerobic bacteria inside the digester. Significant pressure changes inside the digester occurred between the 10-23rd hour, from 0 to 8 psi. 6 hours later (23-29th hour) the gas productivity began to decrease, there was only 1.26 psi pressure increase. 6 hours later (29-35th hour), there was only 0.74 psi pressure increase of 9.26 to 10 psi. 3 hours later the pressure change that occurred inside the digester is 0.21 psi, from 10 to 10.21 psi. This pressure change has been close to 0 psi and entered 2nd day of bio-hydrogen production, it can be concluded that the maximum pressure gas under mesophilic control at 35 ° C in anaerobic digester used in this study was 10.21 psi.

3.2. Hydrogen production

To know the optimum pressure control range to increase the total gas production produced by anaerobic bacteria, it was applied four different experiments: (1) Experiment 1 by controlling the gas pressure in the range of 0-10 psi; (2) Experiment 2 controlling the gas pressure in the range of 0-6 psi; (3) Experiment 3 by controlling the pressure in the range of 0-3 psi; and (4) Experiment 4 bio-hydrogen productions without pressure control. All this four experiments performed under mesophilic (35 ^{o}C) control. The principle of bio-hydrogen production with pressure control is by removing the excess pressure of the digester in the range of the desired pressure control range. According to the equation 2, by lowering the amount of gas in the digester, the partial pressures and the total pressure in the digester also decreased. By lowering the pressure inside the digester, it can increase the production of bio-hydrogen [5]. In experiment 1, 2 and 3, gas production is left in the digester, and the gas sampling for total volume measurement is done after the internal pressure reaches the desired control range. While on experiment 4, which is without pressure control, the produced gas is continuously passed to the storage.

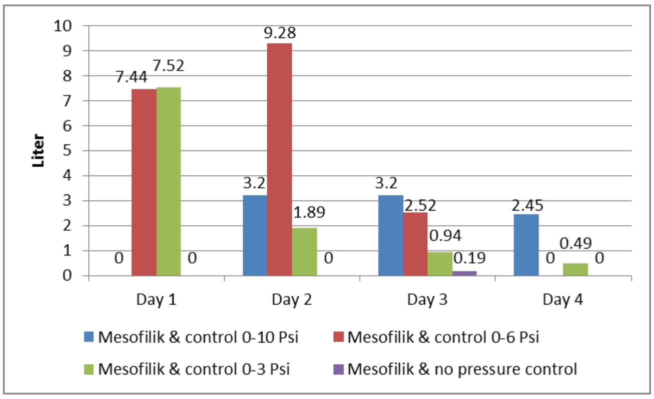

Fig. 7. Bio-hydrogen production based on the gas sampling time.

Figure 7 informed that the highest total volume of produced gas on the first day is obtained by experiment 3 (7.52 liters). On the second day, the highest total volume gas production was obtained by experiment 2 (9.28 liters). On the third day, the highest total volume of gas production is obtained by experiment 1 (3.2 liters). As a note, the third day is the last day of collecting gas production from experiment 4, because experiment 4 only reaches 0.19 liters even after the third day gas production. The third day is also the last day gas production of experiment 2, because after taking the produced gas of experiment 2 (2.52 liters) on the third day, there is no more gas production from experiment 2 on the fourth day. On the fourth day, gas production of experiment 1 stopped at 2.45 liters and experiment 3 stopped at 0.49 liters. Therefore, it can be concluded that the HRT of experiment 1& 3 is 3-4 days and the experiment 2 & 4 is 2-3 days.

Besides affecting HRT, bio-hydrogen production with pressure control also increases total volume of gas production. From figure 8 it is known that the optimum pressure control range to increase gas production is experiment 2 with control range 0-2/3 or 60% of the total pressure during bio-hydrogen production under mesophilic 35 °C control, which is equal to 0-6 psi. The total volume of gas produced by experiment 2 is 19.24 liters. And the minimum total volume of gas production is 0.19 liters from experiment 4.

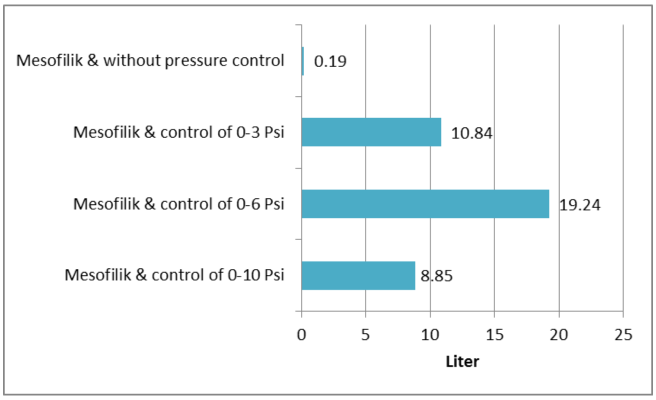

Fig. 8. Volume total of anaerobic digester produced gas.

4. Conclusion

Based on this research, it can be concluded that: first, the maximum pressure during bio-hydrogen production with mesophilic (35 ^{o}C) control in this research is 10.21 psi. Second, pressure control affects the total volume of produced gas and HRT of the system. The optimum pressure control range is 0-2/3 or 60% of maximum pressure, which is equal to 0-6 psi or 0-41.37 kPa, with total volume of 19.24 liters gas and HRT of 2-3 days.

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