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Real-Time Monitoring System for Temperature, Humidity, and pH for Composting Process

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ABSTRACT

Straw is an organic material that has the potential to be used as a basic material for making compost. Rice straw rich in cellulose and lignin, requires a long composting process. The use of IoT as a compost monitoring system is needed to predict the level of compost maturity to meet standards. The aim of this study is to design a composter that is integrated with the development of a monitoring system to obtain data on temperature, humidity, and pH distribution in real time as reference to determine the maturity of straw compost. The monitoring system used based on an ESP32 which was connected to DHT22 sensors, DS18B20, soil moisture sensor V1.2, and soil pH sensor. Data collected from these sensors was transmitted and visualized through the Antares website. The temperature of the composter reached its peak on the 7th day with a value of 56.7°C. The temperature of the compost material reached its highest peak on the 7th day with a value of 42.75°C. The pH value is in the range of 5.5 – 7.4 from the beginning to the end of composting. C/N ratio of compost is 18.13 and is in accordance with SNI 19-7030-2004. Monitoring was conducted for 35 days, in accordance with the estimated compost maturity.

1. INTRODUCTION

Straw is a by-product of agricultural in the form of stalks and stems of cereal crops, after the seeds are separated (Widiyono *et al*., 2021). Generally, straw is used as animal feed but the rest is thrown away or burned so that it can pollute the air. The lack of information about straw recycling is a factor that causes the crowd of farmers who burn straw. Straw used for animal feed is 39%, straw is used for fertilizer by 36%, and 7% is used for industrial materials (Rhofita, 2016). Utilization of straw as fertilizer is able to increase soil fertility and organic fertilizer is obtained through the composting process.

Rice straw contains high of cellulose, lignin, and a C/N ratio and thereby require additional organic matter so that the straw can decompose quickly. The addition of other organic matter, such as chicken manure with high nitrogen (N), can accelerate the decomposition process and reduce the C/N ratio. Composting by mixing straw and chicken manure is a commonly used method in processing organic waste into high-value organic fertilizer.

The problem that often occurs in making compost is the imperfect maturity level of fertilizer. The Internet of Things (IoT) is a concept can exchange various sources of information and interact with objects around us through an internet connection that can be monitored remotely without manually check. Through the use of sensors and wireless networks, IoT-based monitoring systems can provide real-time information about environmental conditions that affect the composting process. The application of IoT is expected to be able to assist farmers or compost managers in monitoring the distribution of temperature, humidity, and pH to determine the composting phase and actions to be taken when composting activities do not match the predetermined set point values.

Based on research about monitoring composting process, IoT-based temperature and humidity monitoring system was designed in the process of making solid organic fertilizer, using ESP8266 microcontrollers, DS18B20 sensors, and soil moisture sensors (Amin *et al*., 2021). Another research on temperature and humidity monitoring with the type of microcontroller used, Wemos D1 mini and equipped with two types of sensors, DHT-22 sensor and pH sensor (Hardyanti & Utomo, 2019). The two research focus on prototype of monitoring composting with organic waste in the surrounding environment. Rice straw with a higher cellulose certainly requires a longer composting time. Therefore, this research is purposed to develop a monitoring system for the rice straw composting process with the measurement of temperature, humidity, and pH parameters using an ESP32, DHT 22 sensor, soil moisture sensor, and pH sensor connected to the Antares IoT platform. The implementation of the monitoring system is expected to provide comprehensive information about the composting process, enabling precise estimation of the compost maturity.

2. MATERIALS AND METHODS

The tools and materials for this research are categorized into monitoring systems and composting materials. The monitoring system consisted to laptop, NodeMCU ESP32, DHT 22 sensor, DS18B20, soil pH sensor, soil moisture V1.2, power supply, leads, relay, jumper cables, box panel, and a breadboard. The monitoring system was installed on composter with dimensions of 50 cm x 43 cm, which has been equipped with an aeration duct from PVC pipes. Whereas basic compost materials were rice straw that has been chopped into 2 cm lengths, laying hen manure, and an EM4 activator.

This research was carried out in several stages as follows: designing the composter, assembling the monitoring systems, programming and connecting the monitoring system to the composter, observing the results of monitoring system test, and performing data analysis. These stages also involved calibrating each sensor against a standard measuring instrument.

2.1. Feedstocks

The composter can hold 6.5 kg of compost raw material. Based on research, the best mixture for making rice straw compost and chicken manure is with a ratio of 3:4 based on weight (Krisnawan *et al*., 2018).

Table 1. Proportion of compost materials

Material Compost	Proportion	Weight
Rice straw	43%	2.8 kg
Laying hen manure	57%	3.7 kg
Total	**100%**	**6.5 kg**

2.2. Composter Design

The composter used had diameter of 50 cm with a capacity of 60 liters, and was made of polypropylene plastic material. The side of the composter is perforated with 5 holes, 4 of which served as connection for the aeration duct and 1 hole was used for connecting the faucet. An aeration duct made of 3/4-inch PVC pipe was arranged diagonally, intersecting inside the composter. The spacing for the installation of aeration duct was 20 cm. Each end of the aeration pipe was capped with a pipe that had 4 holes, each with a diameter 1 cm. Aeration duct in the composter was designed to maximize the oxygen supply during the composting process. Design of composter is shown in Figure 1.

There are 6 sensors utilized, which have been programmed to transmit sensor readings in real time. The sensors were installed on the surface and at the base of the composter. Four sensors were deployed on the compost surface, comprising the DHT22, DS18B20, soil moisture sensor, and pH sensor. In contrast, two types of sensors were positioned at the base of the composter, directly beneath the second aeration channel as shown in Figure 2. The DHT22 sensor will monitor changes in temperature and humidity within the composting chamber. The Soil Moisture Sensor V1.2 will measure soil moisture levels. The DS18B20 sensor will detect temperature changes in the compost. The soil pH sensor will measure variations in acidity (pH) throughout the composting process.

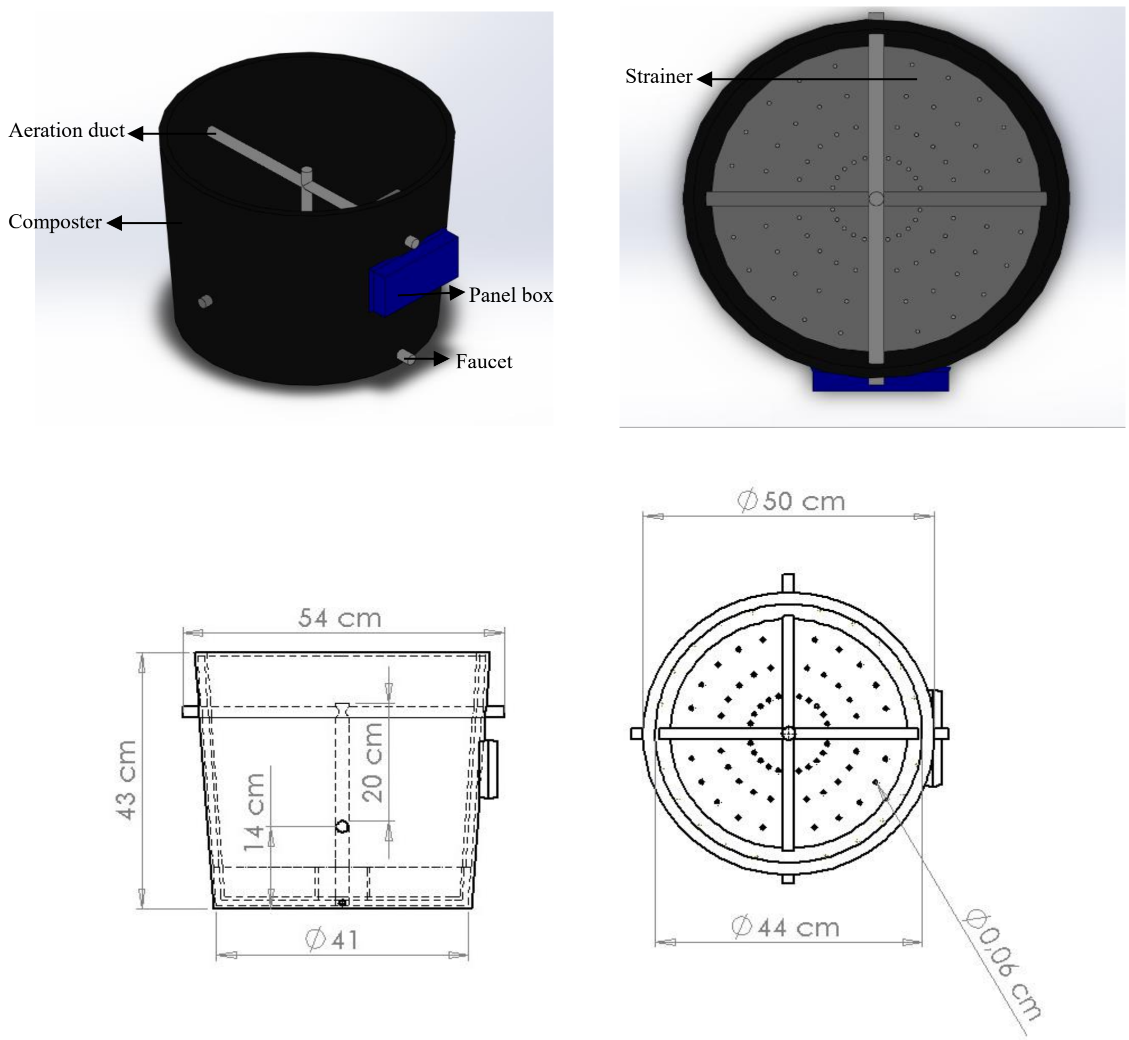


Figure 1. Installation of composter

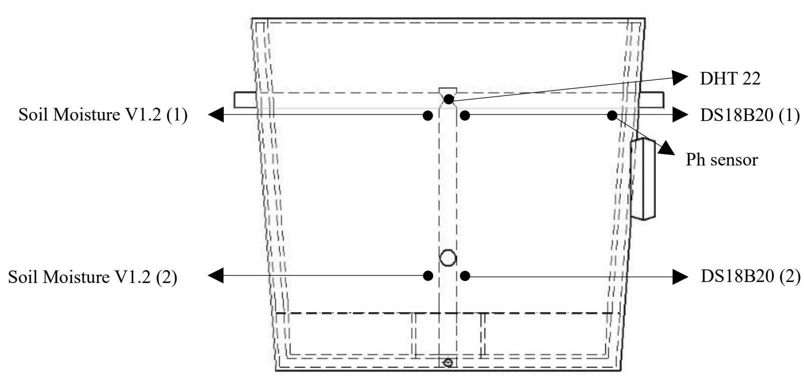


Figure 2. Sensor position on composting chamber

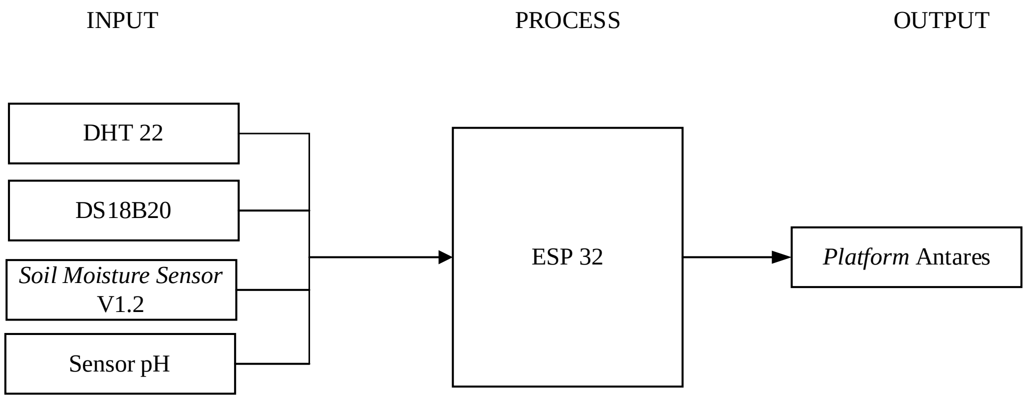


Figure 1. Monitoring system diagrams

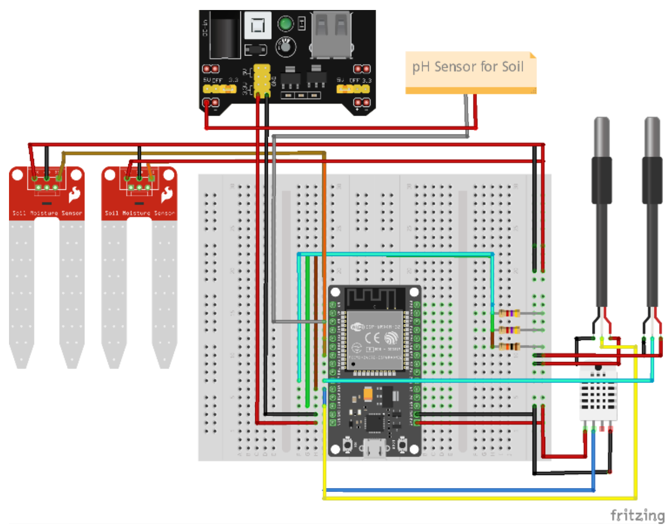


Figure 4. Schematic diagram of sensors

The monitoring system sending data for 23 hours per day. In figure 3, monitoring system is divided into three parts, input, process and output. Input is obtained from the results of condition readings by the DHT22 sensor in the form of temperature and humidity values and pH sensors. The process stage takes place on the ESP32 microcontroller which will process the input from the sensor into a signal that will be sent to the smartphone. The output stage is in the form of data output that has been processed from the microcontroller and received by the web server as a result of reading the sensor in real time.

Based on Figure 4, there are six sensors programmed into the ESP32, three of which require additional resistors in the circuit: the DHT22 and two DS18B20 sensors (I and II). The power source is a 5V supply from an AC current. The ESP32, connected to Antares, transmits real-time data to provide information on the composting process.

3. RESULTS AND DISCUSSION

3.1. Temperature and Humidity of Composting Chamber

Temperature observing was carried out from the beginning process of composting to the maturation compost, which was for 39 days. Temperature of composting chamber is earned from DHT22 sensor, whereas temperature of compost is earned from DS18B20 sensor. In Figure 5a, the changes in temperature values in the composting chamber are shown. The maximum temperature value is reached on day 7, indicated by the red dot Z the graph. The temperature of the composting chamber is more volatile with the same pattern of increase every day. An increase in temperature until it reaches the highest value indicates that the compost is in the thermophilic phase. Composting that has passed the thermophilic phase will pass through the mesophilic phase with lower and stable temperature conditions.

Temperature value of composting chamber in the range of 25.9–56.7°C. The red line on the graph shows the maximum and minimum values daily temperature of composting chamber. Temperature of composting chamber began to increase at 12.00 and continued until it reached the peak daily temperature. Composting chamber enters the cooling and heat release stage from 18.00 to 04.00 the next day. This is shown by the graph which tends to be stable in that time range. One of factor that affects the temperature distribution of the composting chamber is the ambient temperature around the composter.

The humidity of the composting chamber is affected by the amount of water vapor released into the environment after the compost passes through the temperature rise phase. Composting chamber humidity data is obtained from the DHT22 sensor. Based on the observation results (Figure 5b), the highest humidity value in the composting chamber was obtained which was 99.1%. This condition is caused by water vapor that is formed due to the heat caused by the composting process that takes place. Cycle humidity of the composting chamber is almost same in every day, where the lowest room humidity value lasts from early morning to morning. By noon, the humidity will decrease as the temperature increases and at night the humidity of the room will increase again.

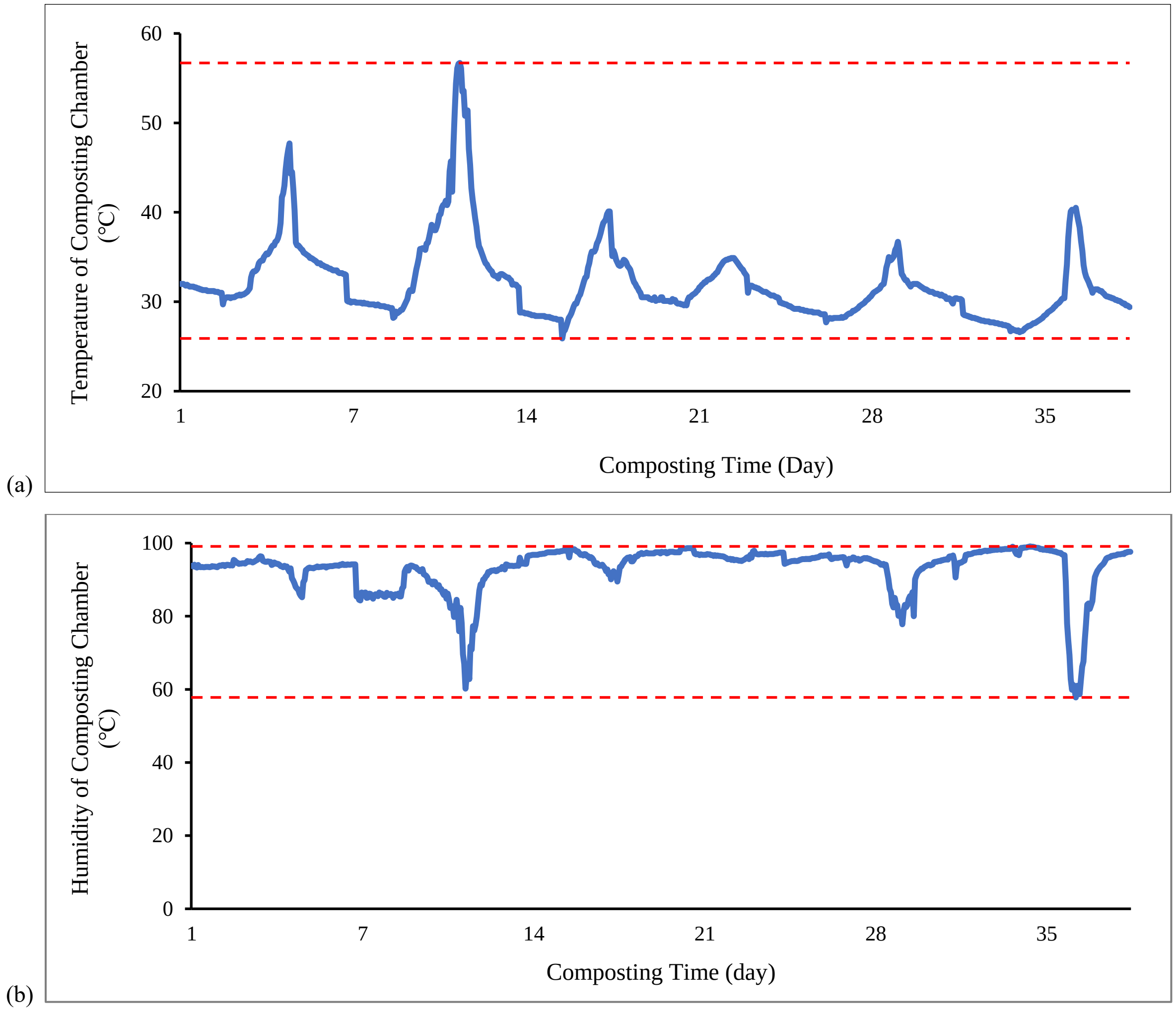


Figure 5. Temperature (a) and humidity (b) of the composting chamber

Humidity of composting chamber is in value range of 57.8% - 99.1%. The red lines on the graph show the maximum and minimum values of daily humidity. The distribution of the humidity value of the composting chamber is greatly influenced by the increase in temperature during the composting process. Based on Figure 6, it can be seen that the decrease in humidity value is directly proportional to the increase in temperature. The downward trend in the humidity value of the composting room began at 14.00 and increased again when the composting process entered the cooling stage.

3.2. Temperature and Humidity of Compost

Temperature of the compost (compost matter) earned from the sensor DS18B20 observed in two sensor positions, 1st sensor placed 34 cm from the base of the composter and 2nd sensor placed 14 cm from the base of the composter (Figure 6). There is a not very significant temperature difference between sensor 1 and sensor 2. Temperature at sensor 2 tends to be lower than sensor 1, the water content at the base of the composter is more dominant, which causes the temperature to be more stable. The compost temperature reached its highest value on 7th day with 42.7°C.

Temperature observation during the composting process has a downward trend with a long time of composting. In Figure 7, it can be seen that the highest composting temperature is on day 7, meaning that thermophilic bacteria play an active role in this phase and are directly proportional to the temperature increase to more than 40°C (Nghi *et al*., 2020). The composting temperature that has reached its peak, will experience a decrease in temperature caused by heat when the composting process moves more to the environment (Budiarta *et al*., 2017). The trend of composting temperature that tends to be stable indicates that the degradation process of organic matter by microorganisms has been completed so that the compost enters the maturity stage (Sugito & Ratnawati, 2020). Based on the values obtained, the temperature of the composter chamber is higher than the temperature of the compost material because the heat release carried out during fermentation will evaporate into the air, so that the heat will produce moisture on the composter cover which can affect the humidity of the composter room.

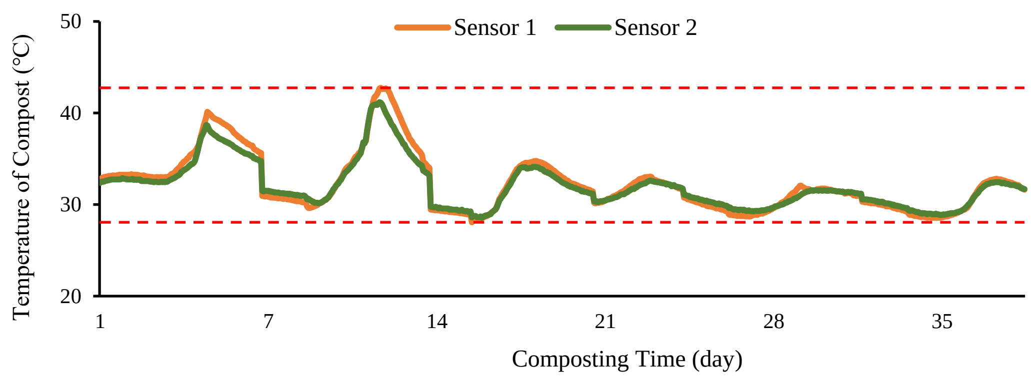


Figure 6. Temperature of compost

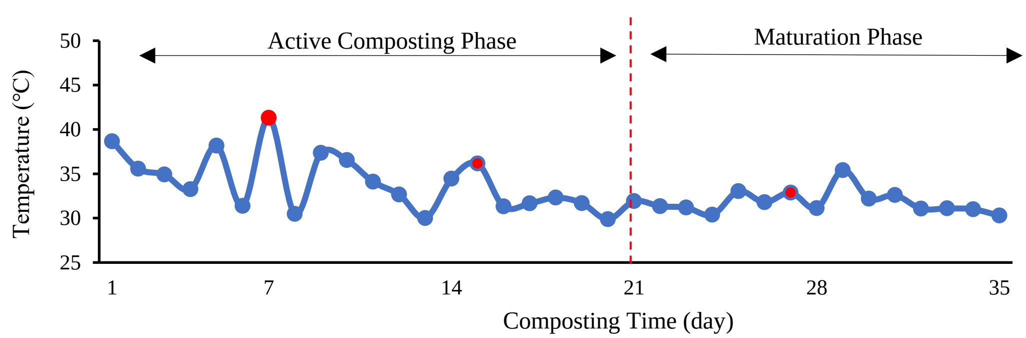


Figure 7. Composting phase with temperature parameters. (Red points show reversal time)

Temperature analysis during composting provides insights into the phases of the composting process. There are two primary phases: the active composting phase, marked by a rise and subsequent drop in temperature, and the ripening phase, characterized by a stable temperature graph (Zaman & Priyambada, 2007). The active phase, lasting until the 21st day, is defined by temperatures exceeding 40°C due to intense microbial activity during decomposition. After this period, temperatures steadily decline and eventually stabilize, indicating reduced decomposition activity and the transition to the ripening phase.

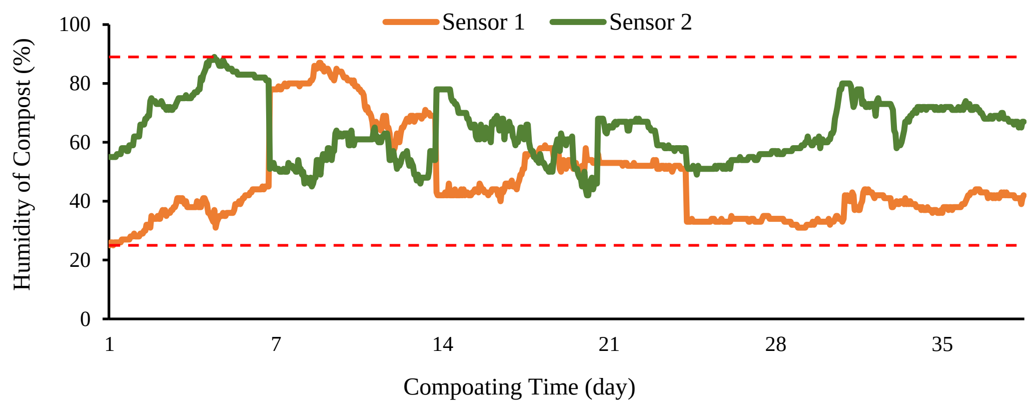


Figure 8. Humidity of compost

Compost humidity is influenced by the spraying of solution during compost accumulation and the moisture retained in the compost layer due to heat. Compost moisture data was obtained from soil moisture sensors. Humidity data, obtained from soil moisture sensors, shows varying values that decrease over time. Excessive dryness can inhibit microbial activity during composting (Budiarta *et al*., 2017). If the humidity drops below 40%, EM4 solution is sprayed to restore it to 70%–80%. During a composting cycle, the solution is sprayed three times: on the 7th, 28th, and 36th days such as the red dot in Figure 8.

Based on the compost humidity distribution graph (Figure 8), the humidity at sensor 2 tends to have a higher humidity value than sensor 1 on the surface of the compost. In the bottom layer of compost, more water vapor is formed during the composting process than water vapor released into the environment (Budiarta *et al*., 2017). The decrease in the humidity value of compost can be caused by the degradation of organic matter by microorganisms until it is close to a stable humidity value (Muliarta *et al*., 2019).

3.3. pH Value

The pH value during the composting process varies in the range of 4.9 – 8.3 (Zakarya *et al*., 2018). Initial condition of acidic compost is due to the activity of decomposing microorganisms that produce organic acidic acid. Compost will be close to neutral until the compost is mature and ready for harvest. The increase in the pH of the compost occurs due to the activity of microorganisms that decompose nitrogen into ammonia.

Based on the data obtained (Figure 9), the composting process starts with a pH that is in a fairly low range, with a value of 5.5. In the early stages of composting, the pH of the compost is in an acidic condition due to the formation of organic acids (Muliarta *et al*., 2019). A gradual increase in pH occurs until the 21st day with a pH range of 5.9 – 6.8. An increase in pH can be caused by the decomposition of organic matter and the formation of ammonia (Zakarya *et al*., 2018). The compost was in neutral condition on the 35th day with a pH value of 7.4. Based on SNI 19-7030-2004, the final pH value for each compost is in the range of 6.8 – 7.49, meaning that the pH of the compost when ripe is in accordance with the standard. Straw compost, which is humic in nature, can bind hydrogen to a slight increase in soil pH (Harahap *et al*., 2020). However, if the compost pH is too acidic, it can inhibit nutrient absorption by plants and transform micronutrients into toxic substances for plants.

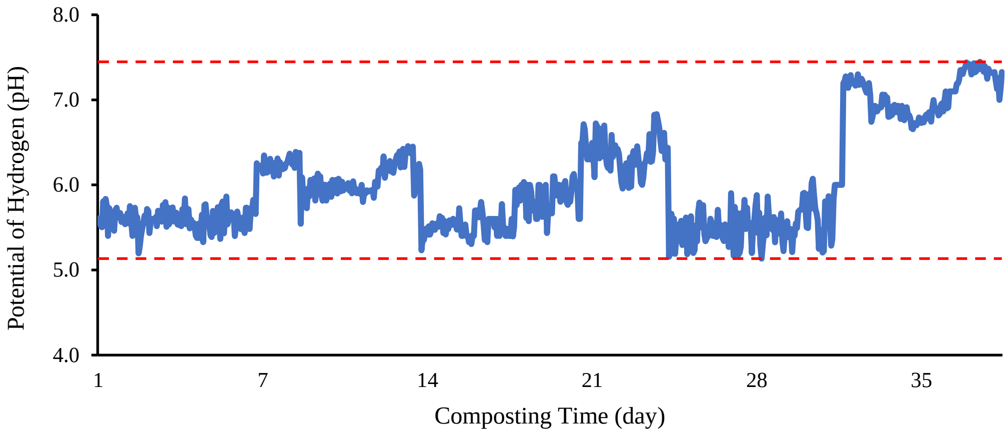


Figure 9. Changes of pH during composting process

3.4. Reversal Time

Compost reversal or turning aims to mix the compost base as well as maintain the moisture of the compost. The decisive condition for compost reversal is when the compost enters the thermophilic phase or when the temperature on the composter is high enough. During the composting process, there are 3 times of compost reversal, including 7th day, 15th day, and 27th day. The reversal is carried manually by moving the bottom layer of the compost to the surface of the composter. This aims to release the heat in the compost pile, flatten the weathering process of the material, and maintain the moisture of the compost (Irianti & Suyanto, 2016).

3.5. Color of Compost

Color is one of the important parameters in determining compost maturity. Based on observations, the color of the straw compost does not change significantly over a short period. The straw will continue to change color until the compost is fully mature, which is indicated when the straw fibers have decomposed completely and the compost has turned dark brown to black. Table 2 illustrates the color changes in the compost for each week. After 21st day, compost enters the maturation phase, during which the composting process stabilizes and microbial activity diminishes. The compost is yellow for the first 14 days with a slight reddish tinge. On the 21st to 28th day, the compost begins to brown. There is no significant color change during the maturation phase between 22nd to 28th day, however the degradation of the material is quite evident. The compost starts to be dark brown on the 35th day until blackish-brown when the compost matures. The activity of bacteria and fungi during the composting process causes a gradual change in the color of the compost (Hidayati & Agustina, 2019).

3.6. Aroma of Compost

Changes in aroma during the composting process indicate that decomposition activity is underway. Composting straws does not produce a foul smell or stinging aroma (Table 3). The addition of chicken manure as a raw material also does not affect the aroma of the compost. The moisture of the compost also affects the aroma of the compost. A sensory test of compost aroma was carried out based on 4 variations of references, including very stinging aroma, quite stinging, less stinging, and earthy odor (Almastin & Asngad, 2020). The first 10 days, the compost has a less stinging aroma that is dominant in the smell of straw litter and smells sour. From the 11th to the 29th day, the smell of compost tends be faint and begins to smell of soil. Compost already smells of soil/humus on the 30th day.

3.7. Texture

Straw has a rough texture because it has a low moisture content. The activity of microorganisms during the decomposition process causes a decrease in fibers in the straw so that it is easier to break down (Rani *et al*., 2011). Type of activator and straw compost mixture greatly affects the change in texture in the resulting compost.

Table 2. Description of compost color changes based on Munsel Soil Color Charts (Munsell, 2024)

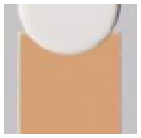
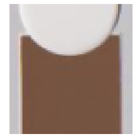
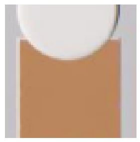
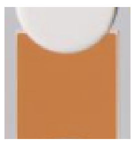
Color	Indicator	Details	Color	Indicator	Details
	 **7.5 YR 7/6**	1st day: Reddish yellow		 **7.5 YR 4/3**	28th day: Brown
	 **7.5 YR 6/6**	7th day: Reddish yellow		 **7.5 YR 3/4**	35th day: Dark brown
	 **7.5 YR 6/8**	14th day: Reddish yellow		 **7.5 YR 2.5/3**	Harvest day: Very dark brown
	 **7.5 YR 5/3**	21st day: Brown			

Table 3. Alteration of compost aroma and texture

Composting Time	Aroma	Texture
1st day	Less stingy	Very rough
7th day	Less stingy	Very rough
14th day	Less stingy	Rough
21st day	Less stingy	Rough
28th day	Less stingy	Slightly smooth
35th day	Smelling of earth	Smooth

3.8. Composting Rate

Shrinkage of compost weight is caused by the use of carbon for respiration and the formation of microbial cells (Wardana *et al*., 2022). The decrease in the moisture content of the material also leads to the shrinkage of the compost weight as water is required by microorganisms for decomposition activities. Based on the calculation results, a composting rate of 61.53 grams/day was obtained. The composting rate will be faster in the mesophilic to thermophilic phase. Meanwhile, in the cooling phase, the composting rate will decrease along with the decrease in microorganism activity until the compost matures.

3.9. C/N Ratio

Another factor that affects the composting rate is the C/N ratio. Based on the results of compost sample testing that has been carried out at the Padang Standardization and Industrial Services Center (BSPJI), the results of the test were obtained with a C-organic content of 17,59% and a nitrogen content of 0.97%. The C-organic content of the compost meets the SNI 7763:2018 standard, with a minimum requirement of 15% (BSN, 2018). Nitrogen test results also comply with the SNI 197030:2004, with a minimum value of 0.40% (BSN, 2004). The N content in compost is influenced by the raw materials and composting activities. The C/N ratio of straw compost and chicken manure in this study was 18.13. The final C/N ratio of the compost meets the SNI 197030:2004 standard (C/N Ratio = 10-20) and the SNI 7763:2018 standard (max. 25). A high C/N ratio reduce the nitrogen availibility for protein synthesis, while a low C/N ratio will inhibits bacterial assimilation (Utomo & Nurdiana, 2018).

3.10. Compost Yield

The weight shrinkage of materials at the beginning and end of the process is part of the degradation process of organic matter. The percentage of the final weight of the resulting compost is called the yield value. Based on the calculation results, the compost yield value was obtained at 63.07%. The yield obtained from straw composting ranges from 50% - 70% (Krisnawan *et al*., 2018). This condition shows the composting process is underway effectively.

4. CONCLUSION

The composter system was constructed using a chamber with diameter 50 cm, featuring a diagonal parallel duct made of ¾-inch PVC pipe with 0.5 cm diameter aeration holes. The final compost temperature reached a stable phase at 31.5°C, with a humidity content of 48%, and pH of 7.4 at harvest. The final C/N ratio of the compost was 18.13 and meeting the SNI 19-7030-2004. The application of this monitoring system provides real-time information on the composting process, allowing for adjustments such as reversal the compost or adding moisture, as well as predicting when the compost will be ready for harvest. Further development of straw mixtures and activators is recommended to accelerate the composting process. The use of aeration ducts is not recommended for straw composting, as the heat released into the environment prevents the compost from reaching its optimal temperature.

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