Design and Construction a Temperature and Humidity Control System for Soybean Fermentation Process Based on Internet of Things for Optimizing Tempe Production Time

By

Putri Yeni Aisyah
Program Studi Rekayasa Teknologi Instrumentasi, Institut Teknologi Sepuluh Nopember
Email: putri.yeni@its.ac.id

Trisna Anugrah Syahputra
Program Studi Rekayasa Teknologi Instrumentasi, Institut Teknologi Sepuluh Nopember

Abstract

In the conventional tempe-making process, the soybean fermentation process is carried out by spreading the wrapped soybeans in the open, in this case the temperature and humidity that affect the growth of molds are not measurable. Therefore, it is necessary to design a device to control temperature and humidity in the soybean fermentation process with the integration of mass sensors and internet modules in it. The mass sensor and IoT are intended so that the tool can warn users that soybeans are indicated to be fermented and can be controlled remotely through the Blynk application on a smartphone. The temperature and humidity control system is designed to work using an on-off control mode with a temperature range between 30°C - 35°C. The temperature sensor used is a DHT22 module which can also measure humidity. For mass sensors, a load cell module is used to measure changes in soybean mass as an indicator that soybeans have been fermented. The controller used is the Arduino Uno module as the main controller and the ESP32 module as the IoT controller. The actuator consists of two incandescent lamps placed above and below the soybean. From the soybean fermentation test that has been carried out, the soybean fermentation time using a tool is faster than the conventional fermentation time. Fermentation on 250 grams of soybeans using a tool is 11.4 hours faster than conventional fermentation, on 500 grams of soybeans it is 7.7 hours faster, and on 750 grams of soybeans it is 2.1 hours faster. For changes in soybean mass, the three variations showed a reduction in the mass of fermented soybeans. The mass of fermented soybeans is reduced by about 3% – 7.6% from the initial mass.

Keywords— Control System, IoT, Mass Change, Soybean Fermentation, Temperature and Humidity

Introduction

Tempe is a typical Indonesian food that is popular and widely consumed [1].. The high nutritional content of tempeh and affordable prices make Indonesian people often consume tempe every day [2]. According to data from Badan Pusat Statistik Nasional in 2020, the average consumption of tempeh per capita of the Indonesian people is 0.48 kg per month. This amount is higher than the consumption of tofu, beef, chicken, and mujair. Lots of people take advantage of this opportunity by producing or selling tempeh. Tempe is a food made from fermented soybeans with the help of *Rhizopus* sp. [3]. The fermentation process is an important step in the process of tempe making because it will determine the tempe quality [4] [5]. The main factors that affect the soybean fermentation process are the temperature and humidity that need to be maintained so that the fungus or mold can grow optimally [6]. In the conventional tempe-making process, the fermentation process is carried out by spreading the wrapped soybeans in the open [7], in this case the temperature and humidity that affect the growth of molds are not measurable [8]. In uncertain weather conditions, changes in temperature and humidity in the fermentation chamber fluctuate in a wide range and are difficult to predict [9]. Erratic conditions of temperature and humidity due to weather can have a bad impact on tempeh production [10]. This can affect the quality of tempe, for producers it has the potential to experience failure in tempe production [11]. Based on these conditions, the solution is to replace the conventional method (manual) to automatic so that the soybean fermentation process becomes easier and more practical with better results.

So that the temperature and humidity in the fermentation process remain stable at optimal conditions between 30 - 35 °C and 60 - 70 %RH [12], it is necessary to develop a temperature and humidity control device for the soybean fermentation process. The device functions to control the temperature and humidity in the soybean fermentation chamber automatically [13]. Controlling temperature and humidity will optimize the soybean fermentation process so that the production process is maximized. In previous studies, automatic temperature and humidity control systems in the soybean fermentation process have been widely used. In previous research, a temperature and humidity control device for the tempe hardening process was designed using the DHT11 sensor module as a measuring device, an incandescent lamp and a humidifier as an actuator [14]. This study uses a control method based on Proportional Integral Derivativ without direct integration with the internet so that users must monitor the handling process directly. In another study, a temperature and humidity control system was carried out in the tempe hardening process, but there was no time setting for tempe hardening for different masses [15].

From the literature study that has been carried out, it is necessary to design or develop a device from previous research that can be used to control temperature and humidity in the soybean fermentation process with the integration of mass sensors and internet modules in it. Therefore, in this study, a design of a temperature and humidity control system for the Internet of Things-based soybean fermentation process was made to optimize the tempeh production time. The design of the tool in this study has three main components: measuring instruments, controllers, and actuators. The DHT22 sensor module functions as a temperature and humidity measurement tool in the fermentation chamber, and the load cell sensor functions as a tempeh mass measurement tool. The sensor reading results will be sent to the controller, the Arduino Uno microcontroller module with on-off control mode, to be processed and compared with a predetermined set point. The error value generated by the controller is used to control the incandescent lamp actuator. The fermentation process can be monitored and controlled using the Blynk application on a smartphone with an internet connection.

The purpose of this study is to design a temperature and humidity control system in the soybean fermentation process based on the Internet of Things. The output target resulting from this research is a prototype of a temperature and humidity control system. With the addition of IoT in this tool, it is hoped that it will make it easier for users to control the temperature and humidity in the soybean fermentation process. With stable temperature and humidity conditions, the soybean fermentation process will be faster and the tempeh production process will take place optimally.

Methodology

A. System and Tool Design

Before the manufacture of a temperature and humidity control system in the IoT-based soybean fermentation process is carried out, a system and tool design is needed to provide a clear picture of the tool to be made. The design carried out includes: system design, hardware, and software.The temperature and humidity control system in this study is a closed loop control system.

There are three main components to a closed-loop control system: measuring instrument, controller, and actuator [16]. The DHT22 sensor module functions as a temperature and humidity measurement tool in the fermentation chamber. The sensor reading results will be sent to the controller, the Arduino Uno module with the on-off method, to be processed and compared with a predetermined set point. The error value generated by the controller will be used to drive the incandescent lamp actuator. The power source for the tool components comes from 220-240 volt AC PLN electricity which is used as input to the 5 volt DC power supply. The power supply will supply voltage and electric current to components that require a DC voltage source, such as: Arduino Uno, ESP32, LCD, DHT22, load cells, and relays. The design of the temperature and humidity control system in this study can be seen in Figure 1.

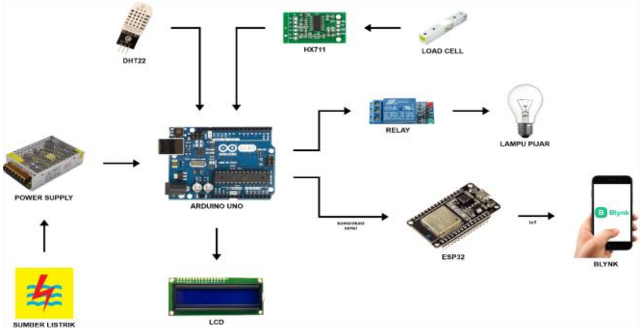


Figure 1. *Temperature and humidity control system design*

The use of the ESP32 microcontroller, which is integrated with the Wi-Fi module in the temperature and humidity control system, aims to allow the system to be monitored and controlled remotely via a smartphone. ESP32 and smartphone will send data to each other via the internet [17]. The IoT software used on the user's smartphone is the Blynk application which functions as an HMI (Human Machine Interface) as well as a server for data transmission [18]. The data received by the ESP32 from the Arduino Uno will be sent to the server and displayed on the Blynk application page [19]. On the other hand, the user can execute a command to turn off the actuator in the form of a relay via the Blynk application and send it to the ESP32 for action on the actuator. In the application interface, the data displayed include: mass of fermented soybeans, temperature and humidity of the fermentation chamber, actuator conditions, and fermentation time. The IoT concept in this study can be seen in Figure 2.

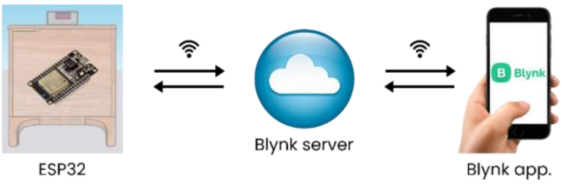


Figure 2. *IoT concept of temperature and humidity control system*

Hardware design in this research consists of mechanical design of tools and wiring on components (electrical). The tool mechanical design can be seen in Figure 3.

Figure 3. *Tool mechanical design exterior*

The mechanical design of the tool is in the form of a cube-shaped box with dimensions of 50 cm long, 50 cm wide, and 60 cm high. The box material used is plywood coated with anti-moisture, heat, and termite paint. At the top of the outer box, there is a panel box as a place for the power supply, microcontroller, and other necessary components. Inside, there are two incandescent lamps placed above and below the soybeans so that the heat generated is evenly distributed throughout the fermentation chamber. There is a DHT22 sensor that is placed in the fermentation chamber as a temperature and humidity measurement [20] instrument and a load cell sensor that is installed under the soybean container to measure the mass of fermented soybeans [21].

The next hardware design is the tool wiring design. After determining the components to be used, the components will be assembled using cables. Wiring design to facilitate cable installation during tool making. The design of the component wiring in this study uses the fritzing application. The component wiring sketch can be seen in Figure 5.

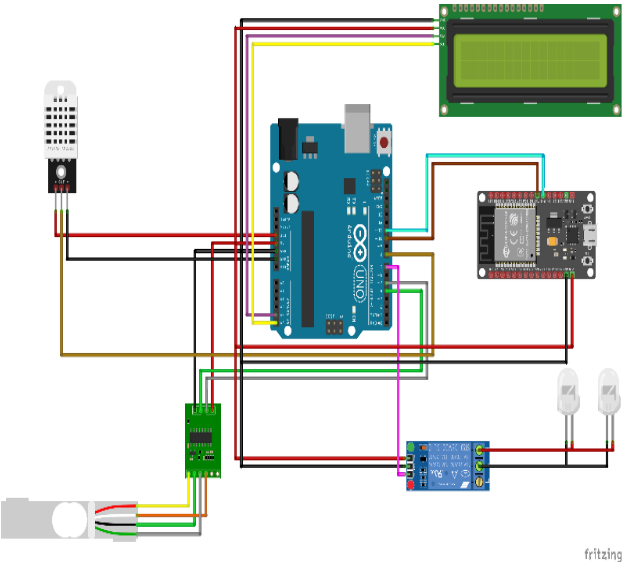
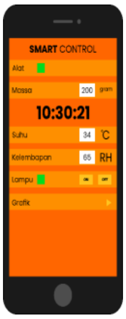


Figure 4. *Component wiring*

When the temperature and humidity control system is working, the load cell and DHT22 sensors will start working. The DHT22 sensor functions to regulate the temperature in the fermentation chamber to match a predetermined set point, while the load cell sensor functions to detect the ripeness of tempeh by measuring the increase in soybean mass. If the soybean mass increases by 1.4% - 1.8% from the initial mass [22], then ESP32 will send a notification signal to the smartphone to alert the user that the soybean is indicated as fermented. Data on temperature, humidity, and soybean mass during fermentation will be displayed on a smartphone for monitoring.

The next software design is the HMI design on the Blynk application. In the application interface, users can view data, including: mass of fermented soybeans, temperature and humidity of the fermentation chamber, actuator conditions, and fermentation time. Users can turn off the actuator through the application to regulate the fermentation process on the device. The design of the Blynk HMI application can be seen in Figure 5.



Massa 200 gram
10:30:21
Suhu 34 °C
Kelembapan 65 RH

Figure 5. *Blynk app HMI design*

Results And Discussion

B. DHT22 Sensor Validation Test Results with UT333S

In this validation, a variation of temperature and humidity values was tested, with each variation the same temperature and humidity measurement values were taken three times. The initial step of validation is to prepare the equipment to be used: sensor module DHT22, UT333S, and dimmer. First, the dimmer is connected to the lamp and the rotation range is determined using a multimeter. For the first variation, the dimmer rotation is set at 0% or 36 volts AC. After the dimmer is turned, the appliance is left for five minutes to allow the temperature and humidity inside the appliance to adjust to the lamp heat. After five minutes, the readings of the temperature and humidity values from the DHT22 and UT333S sensors were recorded as the first data collection for the first variation. For the second data collection, an interval of one minute is given from the first data collection, then the reading of the temperature and humidity values from the DHT22 and UT333S sensors is recorded again and the same for the third data. For the second variation, the steps used are the same as the first variation but with a dimmer rotation of 25% or 84 volts AC. The same steps are carried out for each variation up to the fifth variation, dimmer rotation of 100% or 228 volts AC. After obtaining all the validation data, the accuracy value is calculated to determine the feasibility of the sensor. After validation, the data obtained from the validation results and calculation of the accuracy of the DHT22 sensor, the temperature value as in Table 1 and the graph in Figure 6 and the humidity value in Table 2 and the graph in Figure 7.

Table 1. *The results of the DHT22 temperature value sensor validation*

Dimmer	UT333S (℃)	DHT22 (℃)	Corr. /Error	Error (%)	Accuracy (%)
0% (36 VAC)	25.9	26.6	0.7	2.7	97.3
	26.1	26.8	0.7	2.7	97.3
	26.2	26.9	0.7	2.7	97.3
25% (84 VAC)	27.0	27.6	0.6	2.2	97.8
	27.2	27.8	0.6	2.2	97.8
	27.3	27.9	0.6	2.2	97.8
50% (132 VAC)	28.7	29.2	0.5	1.7	98.3
	29.0	29.5	0.5	1.7	98.3
	29.2	29.6	0.4	1.4	98.6
75% (180 VAC)	31.1	31.2	0.1	0.3	99.7
	31.4	31.6	0.2	0.6	99.4
	31.8	31.9	0.1	0.3	99.7
100% (228 VAC)	33.8	33.6	0.2	0.6	99.4
	34.4	34.1	0.3	0.9	99.1
	34.8	34.4	0.4	1.1	98.9
Average			0.4	1.6	98.4

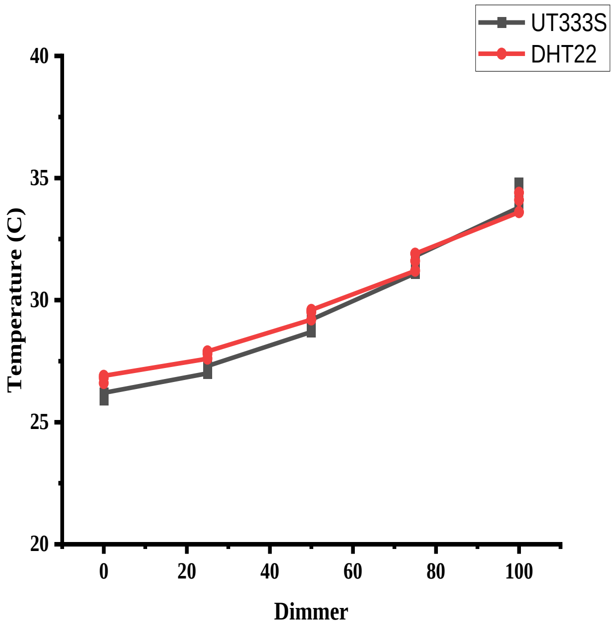


Figure 6. *The graph of the DHT22 temperature value sensor validation*

Table 2. *The results of the DHT22 humidity value sensor validation*

Dimmer	UT333S (%RH)	DHT22 (%RH)	Corr. /Error	Error (%)	Accuracy (%)
0% (36 VAC)	61.4	60.3	1.1	1.8	98.2
	61.0	59.9	1.1	1.8	98.2
	60.7	59.8	0.9	1.5	98.5
25% (84 VAC)	59.8	58.0	1.8	3.0	97.0
	59.6	57.9	1.7	2.9	97.1
	59.4	58.0	1.4	2.4	97.6
50% (132 VAC)	58.5	57.6	0.9	1.5	98.5
	58.3	57.5	0.8	1.4	98.6
	58.0	57.4	0.6	1.0	99.0
75% (180 VAC)	57.2	56.3	0.9	1.6	98.4
	57.1	56.7	0.4	0.7	99.3
	56.8	56.7	0.1	0.2	99.8
100% (228 VAC)	55.8	55.6	0.2	0.4	99.6
	55.4	55.5	0.1	0.2	99.8
	55.2	55.6	0.4	0.7	99.3
Average			0.83	1.40	98.60

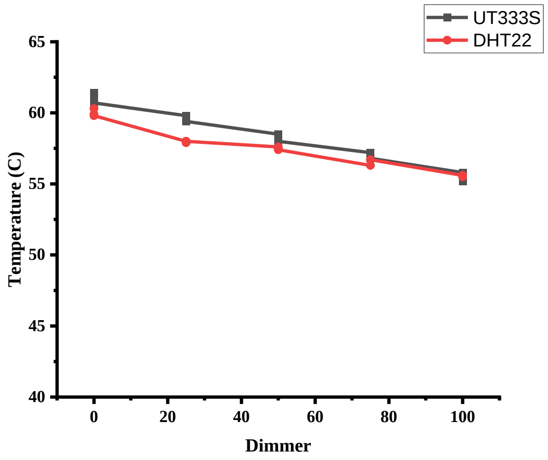


Figure 7. *The graph of the DHT22 humidity value sensor validation*

From the results of the validation of the DHT22 sensor with UT333S, it can be seen that the measured temperature value has an average error of 1.6% and an average accuracy of 98.4%, and the humidity value has an average error of 1.4%. and an average accuracy of 98.6%. From the static characteristics [23] obtained, it can be ascertained that the DHT22 sensor is feasible to use and can be applied.

C. Load Cell Sensor Validation Test Results with Digital Scale

The mass value variation was tested, with each variation the same mass measurement value was taken three times. The first step for validation is to prepare the equipment to be used: load cell sensor, Digital Scale, and lead [24]. The first variation was tested using 100 grams of lead. The lead is placed on the Digital Scale and left for a while until the reading stabilizes. After stabilizing, the results of the Digital Scale reading are recorded in Microsoft Excel as the first data retrieval in the first variation. The second and third data collection is the same as the first data collection. For the second variation, the steps used are the same as the first variation but with 200 grams of lead. The same steps were carried out for each variation up to the fifth variation, lead with a mass of 500 grams. After obtaining all the validation data, the accuracy value is calculated to determine the feasibility of the sensor. The data from the validation results and the calculation of the load cell sensor accuracy are as shown in Table 3 and the graph in Figure 8.

Table 3. *Load cell validation results*

Lead	Digital Scale (grams)	Load Cell (grams)	Corr. /Error	Error (%)	Accuracy (%)
1 (100 grams)	99.50	99.65	0.15	0.15	99.85
	99.70	99.75	0.05	0.05	99.95
	100.00	99.73	0.27	0.27	99.73
2 (200 grams)	199.50	199.75	0.25	0.13	99.87
	199.50	199.80	0.30	0.15	99.85
	199.50	200.02	0.52	0.26	99.74
3 (300 grams)	299.20	299.80	0.60	0.20	99.80
	299.50	299.72	0.22	0.07	99.93
	299.10	299.83	0.73	0.24	99.76
4 (400 grams)	399.00	400.10	1.10	0.28	99.72
	398.90	400.05	1.15	0.29	99.71
	398.90	400.00	1.10	0.28	99.72
5 (500 grams)	498.50	496.60	1.90	0.38	99.62
	498.70	496.75	1.95	0.39	99.61
	498.70	496.48	2.22	0.45	99.55
Average			0.83	0.24	99.76

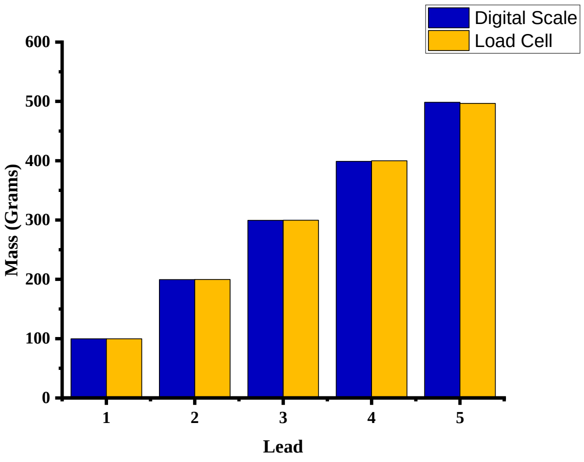


Figure 8. *The graph of load cell validation result*

From the validation results of the load cell sensor with Digital Scale, it can be seen that the measured mass value has an average error of 0.24% and an average accuracy of 99.76%. From the static characteristics obtained, it can be ascertained that the load cell sensor is feasible to use and can be applied.

D. On-Off Control System Test

The control system test is intended to determine the performance of the on-off control mode that has been embedded in the main controller, Arduino Uno. The test is carried out by running the tool for 60 minutes and recording the results of the temperature and humidity values every minute. From the 60 temperature value data obtained, the response graph is obtained as shown in Figure 9.

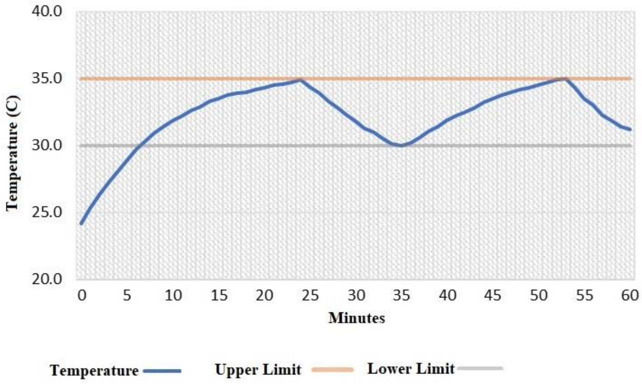


Figure 9. *Graph of temperature response on on-off control system*

At the beginning of running, the temperature in the fermentation chamber was 24.2°C. Due to the heat of the incandescent lamp, the temperature rises slowly until it reaches 35°C. The time required for the tool to reach 35°C is 25 minutes from the start of running and 18 minutes from 30°C. At 35.1°C, the light turns off and the temperature drops slowly until it reaches 30°C. The time it takes the tool to reach 30°C from 35°C is 11 minutes. At 29.9°C, the light comes back on until it reaches 35°C. The time it takes the tool to reach 35°C from 30°C is 18 minutes. The temperature in the fermentation chamber will continuously rise and fall between 30°C - 35°C until the tempeh is fully fermented. From the temperature response data, it can be stated that the on-off control system on the tool is running well. For humidity value data, a response graph is obtained as shown in Figure 10.

Figure 10. *Humidity response graph on on-off control system*

Temperature and humidity are related variables. The two variables are opposite each other if the temperature value is high then the humidity is low and vice versa. This can be seen in the humidity response graph which tends to be in the opposite direction to the temperature response graph.

E. Soybean Fermentation Data Collection

The data collection in this study was based on the results of the soybean fermentation test that had been carried out. There were three soybeans with different masses which were tested for the fermentation process. The purpose of mass variation was to determine the effect of each mass of soybean on fermentation time. Other data that will be taken is the change in soybean mass before and after fermentation. Data collection on mass change aims to directly prove the theory that fermented soybeans will increase in mass by 1.4% - 1.6% based on the reference of previous studies. The first step for collecting this data is to prepare soybeans to be fermented. There are three variations of fermented soybean mass: 250, 500 and 750 grams. Each variation of soybean mass required two kinds to be fermented with and without tools. Prior to the fermentation test, measure the initial mass of each soybean. The fermentation test was carried out by placing one of the soybeans in the open and the other soybeans being placed on the tool. Along with turning on the tool, also turn on the timer to calculate the fermentation time. Soybeans are left to ferment completely. After the soybeans are completely fermented, measure the final mass of the soybeans and record the fermentation time. After fermenting, tempeh was then analyzed for fermentation time and changes in mass that occurred. The results of the soybean fermentation test can be seen in Tables 4 and 5 and the graphs in Figures 11 and 12.

Table 4. *Results of conventional soybean fermentation test*

Test	Time (hours)	Conventional Fermentation		
		Initial Mass (grams)	**Final Mass (grams)**	**Mass Change (%)**
250 gr	34:25:19	246,51	234,83	-4.74
500 gr	34:28:16	498,53	483,75	-2.96
750 gr	32:13:20	735.01	712.85	-3.01

Table 5. *Results of soybean fermentation test using tools*

Test	Time (hours)	Fermentation using tools		
		Initial Mass (grams)	**Final Mass (grams)**	**Mass Change (%)**
250 gr	22:58:20	245,52	230,85	-5.98
500 gr	26:48:33	506,56	481,30	-4.99
750 gr	30:04:37	712.10	657.38	-7.68

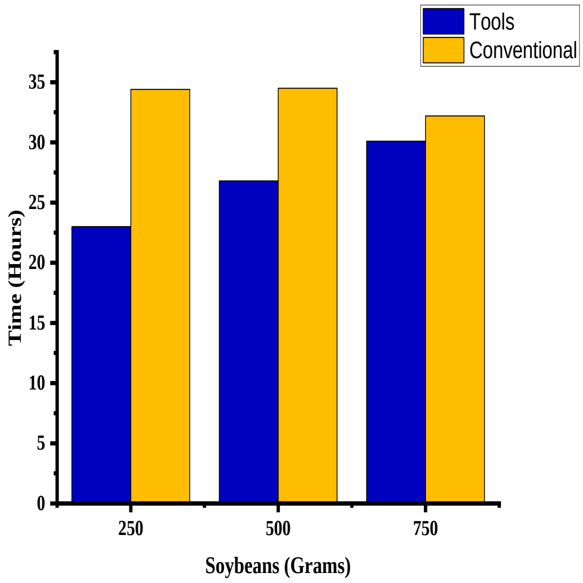


Figure 11. *Soybean fermentation time comparison chart*

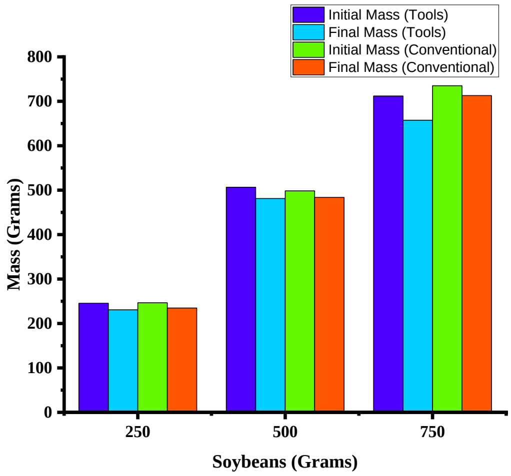


Figure 12. *Soybean mass change comparison chart*

From Table 4 and Figure 11, it can be seen that the soybean fermentation time with the tool is faster than conventional fermentation. This is because the temperature in the fermentation chamber is more stable when compared to the temperature of the fermentation chamber without tools. Stable temperature causes mold growth and fermentation time to be faster. Fermentation of 250 grams of soybeans using a tool is 11.4 hours faster than conventional fermentation, 500 grams of soybeans is 7.7 hours faster, and for 750 grams of soybeans it is 2.1 hours faster. From these data, it can be seen that the more mass of fermented soybeans, the time difference between fermentation using tools and conventional fermentation tends to decrease. Temporary analysis, this is due to the wrong way of packaging soybeans so that fermenting soybeans using a tool takes longer. For mass changes, from Table 5 and Figure 12, the three tests showed a reduction from the initial mass of soybeans to fermented. The mass of fermented soybeans is reduced by about 3% – 7.6% of the initial mass. After being analyzed, the reduction in soybean mass after fermentation was the result of the yeast application in the water which resulted in very high water content in the soybean mass before fermentation.

Conclusion And Suggestions

From the research that has been done, it is concluded that the validation process produces good accuracy. Each DHT22 sensor and load cell has an accuracy of 98.4% for temperature values, 98.6% for humidity values, and 99.76% for mass values. From the static characteristics obtained, it can be ascertained that the DHT22 sensor readings and the load cells used are accurate. The control system response test that has been carried out, the on-off control system used can maintain the heating room temperature between 30℃ - 35℃. Fermentation time using a tool is faster than conventional fermentation time. Fermentation of 250 grams of soybeans using a machine is 11.4 hours faster than conventional fermentation, 500 grams of soybeans Fermentation of 250 grams of soybeans using a machine is 11.4 hours faster than conventional fermentation, 500 grams of soybeans are 7.7 hours faster, and 750 grams of soybeans are 2.1 hours faster. From these data, it can be seen that the more mass of fermented soybeans, the time difference between fermentation using tools and conventional fermentation tends to decrease. This is due to the wrong way of packaging soybeans so that fermenting soybeans using a tool takes longer. The three mass variations showed a reduction from the initial to fermented soybean mass. The mass of fermented soybeans was reduced by about 3% – 7.6% of the initial mass. The reduction in soybean mass after fermentation is the result of the yeast process in the water which results in very high water content in the soybean mass before fermentation.

The suggestion for this research is the use of mass sensors as an indicator of fermented soybeans is less effective due to changes in soybean mass that fluctuate so that users still need to monitor the condition of soybeans. The use of image processing is considered more suitable for the use of a remote control system for soybean fermentation.

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