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Design and Performance of Ohmic-based Fermentor Model for Controlling Fermentation Process

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Design and Performance of Ohmic-based Fermentor Model for Controlling Fermentation Process

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Abstract. Traditional fermentation process usually takes a long time and hard to achieve and maintain the optimum temperatures condition. The controlled fermentation process can be done using a fermentor for conditioning the temperature at the beginning of the process as bacteria and yeast can develop optimally at certain temperatures. However, traditional heaters that utilize heat transfer by conduction and convection have not been able to homogenize the temperature of products so that the fermentation process is not well controlled. Heating technology that has great potential to produce fast and uniform heating is by using ohmic technology. This research aims to design and to conduct a test of ohmic-based fermentor model. Methods used in this study were a functional and structural analysis of fermentor design and performance test of the fermentor model. The test was conducted using two materials as the heated product (0.02 M NaCl solution as a liquid product and soybean as a non-liquid product) with three variations of voltage treatment (110, 165, and 220 V). Design of the ohmic-based fermentor model had been constructed and tested. Analysis of alternative methods, types, and ohmic fermentor material has been carried out as a reference in designing. Test results showed that the fermentor had been proven to be able to maintain, control, and monitor the temperature in the reactor in real-time. The energy efficiency achieved a high value of 81.96% up to 86.29%. The temperature distribution in the fermentor was also determined uniform for both liquid and non-liquid products, so it can be used for further fermentation test using various products.

1. Introduction

Fermentation is one of the bioprocess techniques that has been known for a long time in the world, and currently, it's widely used in the chemical and food industries [1], [2]. Fermentation has various functions such as techniques for affordable food preservation, improving food safety by eliminating natural toxic and unnecessary compounds, preventing the growth of microbes that cause disease and providing attractive taste and additional nutritional value to many products [3]. Most of the fermentation process was carried out using a batch system. According to Cinar *et al.* [2], although the batch process was easy to set up and operate, the modelling and controlling batch process are quite challenging. A minor change in working conditions may affect the quality and yield of the fermented product. One operating condition that affects the fermentation process is temperature [4]. Bacteria and yeast used for fermentation can grow optimally if appropriate conditions and temperatures can be achieved and be maintained.

The controlled fermentation process can be done using a fermentor. The purpose of using fermentor is conditioning the optimal temperature at the beginning of the process and maintain it. Widyotomo and Yusianto [5] developed and tested a fermentor using an electric heater with a water jacket heating system for coffee fermentation. It is reported that while the temperature is set to 40˚C, it cannot fulfil the specialty coffee standard due to contains browning beans (full sour). Browning beans can arise due to indications of the un-uniform distribution of temperature in the fermentor. It occurred when the heat transmitted by conduction so the coffee beans that exposed more heating causing brown beans. Furthermore, the use of fermentor with a water jacket heating system requires much water and also low energy efficiency.

Sakr and Liu [6] reported that heating technology that has great potential to produce rapid and uniform heating is using ohmic technology. Ohmic heating is a concept of product heating that uses the electrical resistance of the material itself to generate heat [6]. Ohmic heaters work by passing electrical current on the processed material/product. The effect that occurs is internal heat generation from the product. Electric conductivity (EC) is one of the important factors in the ohmic heating system. Previously published paper reported the electric conductivity of different materials, including fresh fruits such as apples, pineapples, pears, strawberries and peaches have electric conductivity ranges from 0.05 to 1.2 S/m, besides pure water has poor electric conductivity, and it is around 0.0055 mS/m [6]. The use of ohmic technology can reduce heating time up to 90% compared to conventional heating and save energy from 82 to 97% [7]. The energy efficiency used is close to 100%, and the temperature distribution is evenly distributed [8]. Currently, ohmic technology is used as a heating method for initial, pasteurization and sterilization of products such as milk, fruit juice and sausages [7], [9]–[11]. Recently the use of ohmic technology has also begun to be applied to the fermentation process as conducted by Risqan *et al.* [12] on cocoa products and Reta *et al.* [13] on arabica coffee products to reduce the acidity of coffee beans. However, the design parameters and considerations for developing ohmic based-fermentor have not been studied previously. Based on this, it is needed to be studied and design an ohmic-based controlled fermentor model that can be used for controlling and monitoring the temperature in the various fermentation process.

2. Materials and Methods

This study consisted of 3 research stages. Firstly, functional and structural analysis to design the ohmic-based controlled fermentor model. Secondly, building a model and a controlling unit based on the analysis. Thirdly, the performance test to determine the performance of the fermentor model that had been constructed.

At the functional and structural analysis stages, CAD software tool was used to produce the ohmic technology design drawings model. The fermentor and the controlling unit was constructed based on the design and consideration parameters from the analysis stage. Then the performance test was conducted using two materials (liquid and non-liquid products). The first material was 0.02 M NaCl solution (2 litres of water with additional NaCl of 2.4 g), the initial temperature was 27-28 °C and specific heat 4200 J/kg°C. The test was conducted using three variations of voltage treatment (110, 165, 220 V) or voltage gradient (2.2, 3.3, and 4.4 V/cm). The second material was using 2.5 kg of soybean, which was soaked into the water for 3 hours (moisture content was 61.26 ± 0.53 %). The specific heat of soybean was 2910 J/kg°C [14]. The test was conducted using optimum voltage which obtained in the first test using 0.02 M NaCl solution. The temperature was set to be maintained at 40°C as a reference of optimum fermentation condition. All the test used three replications. The performance test was carried out for testing the control system, the heat distribution in the reactor, and for obtaining the heating rate and power efficiency of the ohmic-based fermentor. In an evaluation of the performance of the process, energy efficiency needed to be calculated and evaluated using the following equation.

$$\eta = \frac{E_{out}}{E_{in}} \times 100\% \quad (1)$$

$$\eta = \frac{m \times c_p \times (Tf - Ti)}{\sum V \times I \times \Delta t} \times 100\% \quad (2)$$

Where, η is energy efficiency (%), m is mass of the product (kg), c_p is specific heat of product (kJ/kg°C), Tf is the final temperature (°C), Ti is the initial temperature (°C) dan Δt is heating time (s).

Measuring devices used for testing consists of temperature sensors in ohmic reactors, watt meters, and microcontroller integrated with the data logger for recording the temperature, time and electrical current during the process. Temperature sensors used were thermocouples, which set at three measurement points (left, center, right). Statistical analysis was used for testing the uniformity of temperature in 3 positions (left, center, right) using SPSS version 21. The space between thermocouples is 20 cm. The data logger was recording data with a measurement interval of three seconds. For analysis, samples of temperature data were obtained with a measurement interval of two minutes and the number of data about 20-40 data/thermocouple position.

3. Results and Discussion

3.1. Design of ohmic-based controlled fermentor

In the designing of the ohmic-based controlled fermentor, there are many considerations both in terms of function and structure of the fermentor. The role of each part of the fermentor was confirmed first through functional analysis then the fermentor structure was analyzed using structural analysis. Then it ends with analysis using the weighting index that refers to the digital logic method from Dieter and Schmidt [15] in two stages. Structural analysis commonly involves CAD (computer-aided design) software so that the design/model of the machine obtained before it was constructed. All functions needed to build ohmic-based controlled fermentor presented in table 1.

Table 1. The functional analysis of ohmic-based controlled fermentor.

Function	Stage one		Stage two		Total Weighted index
	Component and process	Weighting factor	Alternative of type and material	Weighting factor	
Placing the fermented materials	Reactor fermentor	0.13	PE	0.20	2.67%
			HDPE	0.10	1.33%
			LDPE	0.00	0.00%
			PP	0.40	5.33%
			PVC	0.30	4.00%
Transmitting the electric current	Electrodes	0.27	Titanium	0.17	4.44%
			Stainless steel	0.50	13.33%
			Aluminium	0.33	8.89%
			Graphite	0.00	0.00%
Processing materials in the reactor	Fermentation	0.20	Batch	1.00	20.00%
			Continuous	0.00	0.00%
Setting and controlling temperature	Microcontroller	0.07	Arduino	1.00	6.67%
			Raspberry pi	0.00	0.00%
Measuring temperature	Thermocouples	0.00	Type E	0.00	0.00%
			Type J	0.07	0.00%
			Type K	0.27	0.00%
			Type N	0.33	0.00%
			Type T	0.20	0.00%
			Type U	0.13	0.00%
Regulating voltage	Voltage regulator	0.33	AC Voltage	1.00	33.33%
			DC Voltage	0.00	0.00%
Total		**1.00**		**6.00**	**100%**

The reactor material used as a product container is not allowed to use materials that can transmit electricity such as iron metal, stainless steel, and so on due to the dangerous electricity transmission.

The ohmic reactor is highly recommended using plastic or something similar that cannot transmit electricity (isolator). For applications in food products, polypropylene (PP) plastic materials are very suitable. It can be seen in Table 1, which shows that the weighted index of PP material selection as a fermentation place is higher than the other available material. This type of plastic is the best choice of plastic material, especially for food places due to its excellent resistance to heat and electricity, resistant to chemicals and relatively inexpensive [16], [17]. However, for the fermentation experiment (especially the process with low temperature), it can be used alternative materials such as PE or PVC that more comfortable to find and also inexpensive. The dimensions of the fermentor were designed using materials with 4 inches of diameter and 50 cm length (maximum capacity is 4 litres).

Another critical factor in the designing of an ohmic-based fermentor is the electrode. Electrodes is generally chosen based on price and quality (resistance and durability), which might affect the efficiency of the ohmic heater. Low carbon electrodes commonly used when product quality is not the priority such as waste treatment, while metals such as stainless steel were better to apply for the application of food products and something similar [11]. The results of the selection using the digital logic method (table 1) also show that the stainless steel material is more suitable than the others. In terms of temperature monitoring, Zell *et al.* [18] have tested a thermocouple probe to monitor temperature changes in the reactor during the heating process. Zell *et al.* [18] also reported that there should be at least three measurement points the most satisfying for ohmic heating applications. Meanwhile, the thermocouple used was K type because it's the most common thermocouple used for many purposes, inexpensive and excellent resistant of corrosion [19]. Furthermore, the batch type was chosen due to the setup and operation, which easier than using continuous type. Process performance can be improved by evaluating the results of a batch system that was running before [2]. Besides, the fermentation process is most suitable for using a batch type due to time requirement, which generally takes a long time.

Temperature monitoring devices based on the results of the selection of components and processes have the second lowest index based on stage 1. It shows that the device can be widely considered with alternative methods and types to be used. Therefore the microcontroller used was Arduino due to more straightforward and easier to use. The parameters which controlled was only temperature, so it was sufficient to choose microcontroller Arduino UNO. Based on the results of functional design analysis, it was continued to the structural analysis using CAD software. The ohmic-based controlled fermentor design, the fermentor model that has been constructed, and the controlling unit were shown in figure 1, figure 2, and figure 3, respectively.

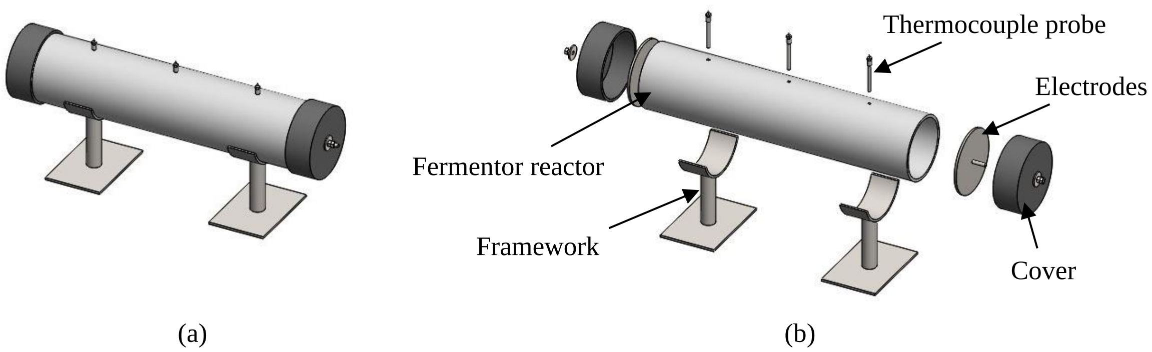

Figure 1. Design of ohmic-based fermentor: (a) isometric view; (b) exploded view

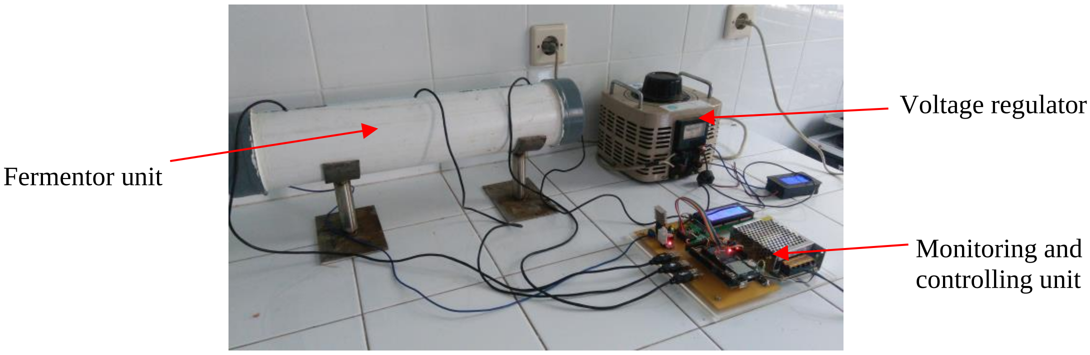

Figure 2. Ohmic-based controlled fermentor model construction

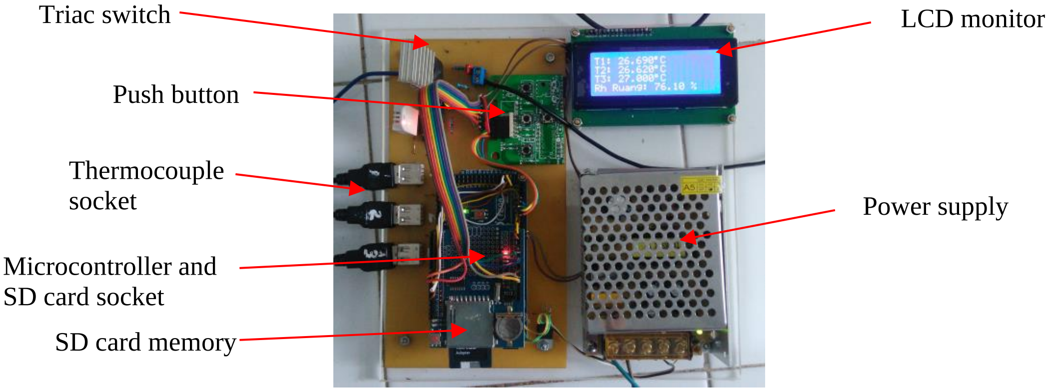

Figure 3. Controlling unit of ohmic-based fermentor

The temperature setpoint can be determined using the available buttons, and the setpoint value can be seen on the LCD monitor. After the process begins, the LCD monitor in real-time displays temperature data in the reactor and also stored the data in the SD card memory with an interval of 3 seconds. The microcontroller was able to control the temperature according to the setpoint and maintain it relatively stable. If the temperature exceeds the setpoint, the electricity will be cut off by microcontroller, and when it was less than the setpoint, the electric current will flow to the fermentor.

3.2. The Performance Test Result of Ohmic-Based Controlled Fermentor Model

Table 2 presented the performance test results of the ohmic-based fermentor using 0.02 M NaCl solution as a heated product, and the observing effects of temperature changed in the fermentor reactor were shown in figure 4. It was shown that the control system has been able to monitor and control the temperature become stable at 40°C during the process of all trial. The developed device could measure the temperature of the product with an error of less than 1°C.

Table 2. Performance of ohmic-based controlled fermentor

Voltage (V)	Heating rate (°C/hour)	Electric current (A)	Power (W)	Efficiency (%)
110	5.49	0.203	22.34	59.24
165	21.42	0.355	58.60	85.19
220	34.44	0.446	98.05	81.96

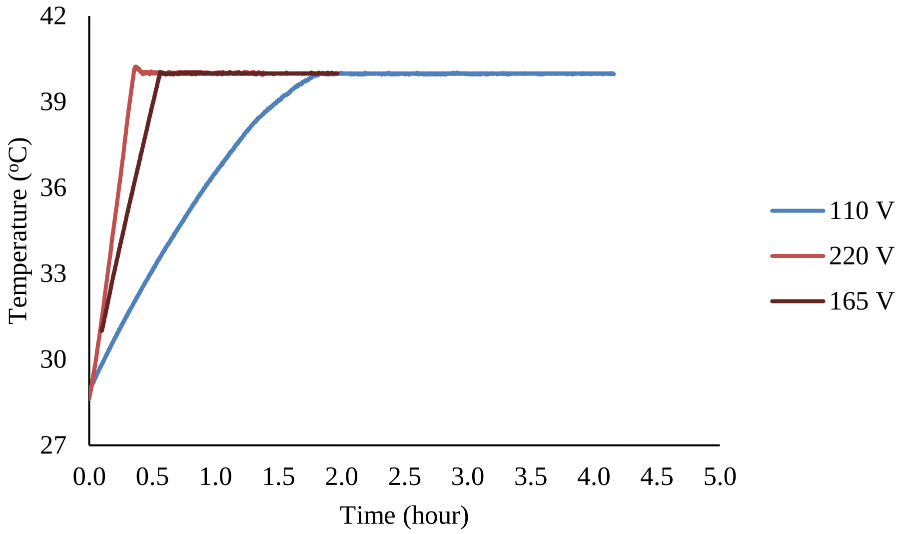

Figure 4. Temperature changed during the heating process

The heating rate of the three voltage treatments shows there was a difference between one and another. It was shown that the increase in voltage could increase the heating rate and electric current linearly (figure 5), and directly increased power. This phenomenon occurred due to higher voltage changed the movement of electrons become faster as the value of electric current, which also getting higher. Meanwhile, in terms of energy efficiency, the results showed that the highest efficiency was obtained at 165 V of voltage (3.3 V/cm of voltage gradient). It was occurred due to the heating rate changed which not proportional. The increasing voltage from 110 to 165 increase the heating rate of 16°C, but increasing the voltage from 165 to 220 only increase 13°C. Based on these observations, the fermentor was highly recommended using a voltage of 165 V (3.3 V/cm) due to its efficiency and the power requirement which lower than 220 V, so it would be excellent and suitable for fermentation, which needed a long process. The process which needed rapid heating, such as pasteurisation was recommended using a higher voltage or even higher than 220 V. The efficiency value of test results has not been able to reach 100% due to heat absorption occurred from the product to the reactor fermentor, which did not use insulation yet.

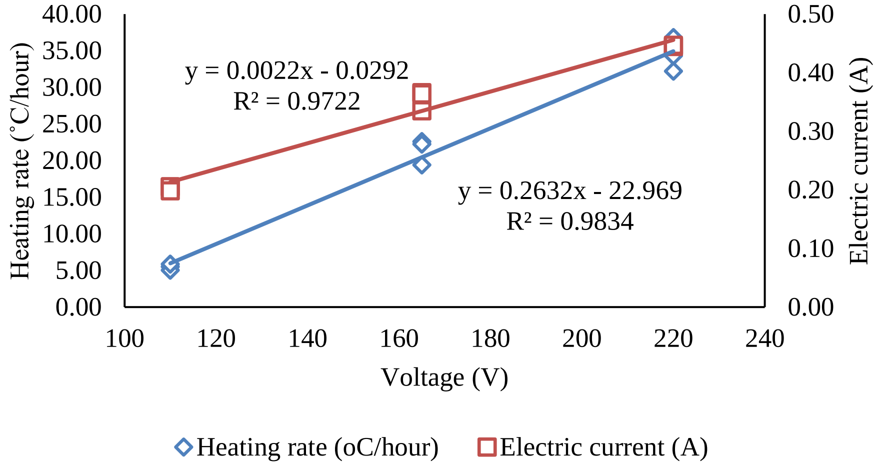

Figure 5. The effect of voltage on the heating rate and electric current of 0.02 M NaCl solution

The heat distribution in reactor fermentor had a high uniformity level with a p-value of ANOVA test > 0.05 for all analyses (not significantly different between the left, center and right positions). It means that ohmic heating claims have a high uniformity of temperature distribution have been proven, as reported by Kong *et al.* [20]. Moreover, it's also been revealed not only on the liquid products but also on non-liquid products. Based on the results, the ohmic-based controlled fermentor design has been proven to be able to maintain, control and monitor the temperature condition in the reactor in real-time, and has a high uniformity of temperature distribution so that it can be used for further fermentation testing using various products.

The test using soybean material was carried out after obtaining the optimum voltage of 165 V (3.3 V/cm) in the first test using 0.02 M NaCl solution. The purpose of the test using soybeans was to investigate the application of ohmic-based fermentor to non-liquid products and to observe the heating behaviour and temperature distribution that occurs during the process. Table 3 showed the test results of soybean materials. The heating rate obtained was 12.61°C/hour, the electric current was 0.18 A and power was 29.81 W. Those values are lower than using 0.02 M NaCl solution at the same voltage (165 V), this means that the electric conductivity of soybean (moisture content 61.26%) is lower than the electrical conductivity of 0.02 M NaCl solution. Electrical conductivity (σ) is a unit that indicates how well a material transmits electric current movements. Meanwhile, the efficiency is 86.29%, relatively the same as the test using 0.02 M NaCl solution. Besides, based on the temperature uniformity test, it was proven that the temperature distribution between the left, center and right positions was uniform after ANOVA test at the 0.05 significance level (there were no significant temperature differences between all position). Based on this test, the ohmic applications could be used for non-liquid materials (in this case was using soaked soybeans), and it has the potential to be applied in the process of making tempeh product (a fermented food from Indonesia, based initially on soybeans). Another potential is tremendous to be applied to other bean products such as coffee, cocoa and other products (especially wet products or high moisture content products). Temperature conditioning at the beginning of the process may have an accelerating effect on fermentation as bacteria and yeast can develop optimally at certain temperatures (35-40°C).

Table 3. Performance of ohmic-based controlled fermentor using soybean product

Parameter	Value
Heating rate (°C/hour)	12.61
Electric current (A)	0.18
Power (W)	29.81
Efficiency (%)	86.29

4. Conclusion

The ohmic-based fermentor model has been successfully developed and tested. The fermentor controlling unit has been proven to be able to maintain, control and monitor the temperature condition in the reactor in real-time. The energy efficiency achieved the value of 81.96% up to 86.29%. The ohmic-based fermentor was able to produce a high uniformity of temperature distribution both for liquid and non-liquid products (especially wet products or high moisture content products), so it can be used for further fermentation test using various products. More in-depth studies related to the phenomena and reactions occur during fermentation using ohmic heating need to be conducted, especially on products that commonly involve fermentation processes such as tempeh, cocoa, coffee, modified cassava flour, yoghurt and others.

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