Design of temperature control system in extraction process based on Microwave Assisted Hydrodistillation (MAHD) method

B D Argo1,2, B Hermanto1, D W Indriani1, F A Amaliyah1
1 Faculty of Agricultural Technology, Brawijaya University, Jl Veteran Malang, Indonesia
2 Corresponding author, Email : Dwiargo@ub.ac.id

Abstract. Research on temperature control in microwave assisted hydrodistillation has been carry out and it has become special topic in this article. According to data from the Ministry of Trade of the Republic of Indonesia in 2014, 40 of 70 essential oil-producing plants in the world can be produced in Indonesia. However, almost all essential oil produced in Indonesia have a low quality. This is caused by many factors, one of them is the lack of downstream processes. Some of the essential oils produced do not meet international standards. A common method to produce essential oils is conventional distillation which is not efficient and need a high consumption of energy. In order to reduce extraction time, increase extraction yields and minimize production costs, several new approaches have been taken such as MAE (Microwave Assisted Extraction). In this study, we developed a MAHD method with controlled temperatures. Extracted material was placed in the container given microwave exposure and the temperature was controlled. The purpose of the research is to develop extraction methods in order to improve the quality of essential oils produced in Indonesia. The results of apparatus performance are: a) capable to control the temperature with a range of errors ±1°C, b) to be able to produce the essential oils (Zingiber officinale) greater than other methods, namely, 1.71% and c) to be able to has energy effectiveness of 90.29%

I. Introduction
Essential oils are natural extracts from certain types of plants, derived from leaves, flowers, wood, seeds and even flower buds. Their extracts are formed by combination of diverse and complex volatile mixtures of chemical compounds. According to data from the Republic of Indonesia's Ministry of Trade in 2014 out of 70 plants producing essential oils in the world, around 40 types of them can be good cultivated in Indonesia. The export value of essential oils is one of the main sources of foreign exchange for Indonesia. In the list of 10 potential commodities from the Ministry of Trade, exports of essential oils and fragrance cosmetics were around 580 million USD to 637 million USD during the period 2011 to 2015. The types of essential oils exported are cinnamon oil, sandalwood oil, kemukus oil, patchouli oil, cananga oil, nutmeg oil, clove oil, eucalyptus oil. Around 20 of them are potential oils that have developed in international market and have a high economic value.

However, almost all essential oils produced in Indonesia have a low quality. Fair selling price cannot determine for the essential oil produced. This is caused by so many factors, one of them is the lack of downstream process in Indonesia. Some of the essential oils produced do not meet international standards and fail to compete in the world market. The quality characteristic that has not been fulfilled for essential oils from Indonesia is optical rotation which is still positive (+), while international requirements the optical rotation must be negative (-). The most common method used to separate essential oils is conventional distillation, maceration and steam distillation. It is proved by a
number of studies that the quality of essential oil produces mainly influenced by their extraction process. In contrast, these common methods can induce thermal degradation, hydrolysis and water solubilization of some fragrance constituents. The high energy consumption needed to heat the oil making it less economical.

However, in order to reduce the extraction time, increase the extraction yield and minimize production costs, several new approaches have been carried out such as MAE (Microwave Assisted Extraction), supercritical fluid extraction and UAE (Ultrasound Assisted Extraction). As already reported, research by (Purwanto, 2010) which states that the quality of essential oils from the MAE method has higher zingerberin levels so that the quality is better. In an attempt to take advantage of microwave heating with the conventional hydrodistillation, microwave-assisted hydrodistillation (MAHD) was then developed and used for the extraction of essential oils. MAHD (Microwave Assisted Hydrodistillation) is a method development in which the temperature used in the process can be controlled properly. The impact can reduce the risk of damage to the material and increase the effectiveness in cell breakdown using microwaves in the extraction process. Based on this background, this study aims to examine the structural design both in functional and structural, as well as the performance of the tools produced. In addition, this research also explains about increasing productivity when compared with existing methods.

2. Materials and Methods

2.1. Materials and Tools

The materials used in this research are ginger and aquades. The tools used to make prototype are microwave oven Electrolux type EMM2308X, type K thermocouple, boiling flask size 1000 ml, graham condenser DURAN, thermostat OMRON, Erlenmeyer flask size 250 ml, water pump, PTFE, OMRON relay, and transparent hose size 26 mm.

2.2. Design Tool Plan

2.2.1 Functional Design. The tool made in this research was a combination of hydrodistillation and radiation methods using microwaves to increase the effectiveness of the extraction process and speed up the processing time. This tool worked by heating material which was mixed with water. By using microwave radiation, it produced steam which then was condensed. The result of this process was essential oil.

In functional design, the distillation equipment was made from the modification of kitchen microwave with certain specifications which has been explained, and also with the addition of a controller to the temperature setting. On the inside of the microwave, there were several parts, such as the glass door to remove and insert material, the glass tray to put the materials, and setting buttons to operate the microwave.

The main components were as follows:

a) Microwave used for a place to heat the materials and a place to put the boiling flask and thermocouple sensor.

b) Hydrodistillation unit, as a component used in the hydrodistillation process, consisted of boiling flasks, condensers, connectors and funnels.

c) Relay as regulator of the flow of electric current which went to the magnetron; as controller of the On/Off mechanism on the magnetron as actuator.

d) Thermocouple as a thermometer for the material, in which later became the input of the thermostat for the On/Off process during the control. Temperature measured was limited under 100°C.

e) Thermostat as a regulator component for On/Off mechanism.
2.2.2 Structural Design. The microwave oven used had dimensions of 54.7 x 32.8 x 38.8 cm. The heating room of the oven was 26 cm long, 18 cm wide and 13 cm high. The main frame of the microwave was made of iron plates whose walls were coated with heat retaining material. The heat produced was derived from micro wires emitted which made the solution in the boiling flask evaporated and produced essential oil. The design of this tool was a modification of the microwave by perforating the top of the microwave so that the glass cylinder could pass through, then the water vapor would be cooled by the condenser. The final result obtained the essential oil. The circuit of the device contained several main components, such as microwave oven, boiling flask, thermocouple as the temperature control unit, Erlenmeyer flask, condenser and microwave setting button. Thermocouple functioned to cut off the heat flow. When the temperature in the boiling flask reached set points (a specified temperature limits) of 50, 60, 70 and 80°C. If the temperature dropped to the minimum limit, the relay would reconnect the electrical current.

![Diagram of tool design](image)

Explanation:
1. Condenser, 2. Microwave, 3. Temperature 4. Control Box, 5. Erlenmeyer Flask and 6. Boiling Flask Sensor

**Figure 1.** Design of the tools

2.2.3. Tool Design Procedures
a. Tool making process
The main material used in this process was microwave. The other components were control box, distillation units and sensors. The first step that had to be done was making a hole in the top of the microwave as a place to connect the boiling flask and the condenser outside the microwave. The second steps were installing the temperature control unit, then installing components such as relays, jumper wires, and also connecting those components with thermostats and temperature sensors. The temperature control unit was connected to the components and united in one place which was on the side of the microwave using a box made of acrylic material with a dark color. The design of the acrylic box was also completed with a hinge which could be opened and closed to make maintenance process easier. The last step was calibrating or checking the components which had been installed.

b. Distillation Process
In the distillation process, there were several stages, which were preparing the materials, dissolving the powder produced from the drying with water in a certain ratio, then placing it to the boiling flask. The next step was installing and checking the hydrodistillation device. The next step was connecting the switch to the electrical power source, setting the temperature between 50 degrees Celsius to 100 degrees in the control box and the power in the setting button of the microwave (in this study used 600 watts of power) based on the previous studies. The distillation process was conducted until all the material evaporated, then the machine was turned. The remaining solution in the boiling flask was taken to measure the data qualitatively and quantitatively. After that, the temperature control unit and
the microwave were turned off. The remaining distillation resulted from the boiling flask could be taken.

3. Results and Discussion

3.1 Tool Design Results

3.1.1 Results of Structural and Functional Design
The design of the MAHD tool was made with dimensions of 95 x 45 x 29.25 cm. The dimensions of the microwave used were 48.5 x 37 x 29.25 cm. The results of the design of MAHD were explained below.

![Figure 2. Tool Design Results](image)

To support the performance of the tool, several components were added. MAHD prototype was made from microwave typed Electrolux with the specifications as stated. The microwave was equipped with a setting button to adjust the processing time and power used, a front cover which was made of transparent glass that could be penetrated by light. The control box which contained power button, LCD, and thermostat was placed at the side of the microwave. The material used to make the box was dark acrylic size 3 mm. There were hinges and hooks at the front of the box, in case it was needed to open the box for maintenance.

![Figure 3. Control Box](image)

1. On/Off button, 2. LCD and 3. Thermostat

The control box contained components used for temperature control system, such as thermostat, On/Off buttons, LCD, and jumper cables to be connected to the microwave. The thermostat specifications used was Omron type E5CC-RX2ASM-800. The thermostat was chosen based on the control system requirements. This type of thermostat was used as the On/Off control during the distillation process. The display on the thermostat was used to view the temperature setting and the actual temperature shown in figure 4.
Figure 4. Thermostat

The main feature of the thermostat was the display of PV (Present Value) which functioned for displaying the actual temperature value provided by a thermocouple sensor, and also the display of SV (Setting Value). SV was the temperature value that was set. This temperature value could be changed as needed. The last feature was the setting button that functioned to regulate by raising and lowering the SV temperature. When the distillation process took place, the setting point was set according to the expected temperature, while the actual temperature value on the boiling flask measured by the thermocouple was raised as the present value. The difference of the temperature value of PV and SV became the input for the relay in making decision for the On/Off mechanism.

3.1.2 Results of Control System Design
In addition to structural and functional design, there was an electrical system design as a measure of the success of the automatic control system that had been carried out. The electrical system was composed of the components which were mentioned earlier to form a function on the On/Off control mechanism. The following are the results of the electrical system design on temperature control shown in figure 5.

Figure 5. Control system series

The picture above is a series of control systems that had been made for controlling the temperature with on/off system. Temperature control system components consist of 1). Relay, 2). Thermostat, 3). Digital multimeter, 4). On/off button, 5). Thermocouple, 6). Acrylic box and 7). Jumper cable.

The automatic control system was equipped with a digital multimeter to allow users to read data about the current strength, frequency power, and power of the prototype. Relay was used to disconnect or connect the electric current to the magnetron thus the temperature in the heating room remained stable. The relay was connected to a thermostat in which when the distillation was conducted, the sensor read the temperature value of the water in the boiling flask, and would send a digital signal when the temperature reached the setting point. Then, the magnetron would turn off and on again when the temperature reached the minimum point. Below is the scheme of the automatic temperature control system on the MAHD prototype shown in figure 6.
3.1.3 Results of System Test

1. Relay Automation Test

MAHD is a tool that uses an automation system for its temperature settings. The automation setting on the system used a relay to disconnect and connect the electric current and was connected to the thermostat as a data input controller to be the output to the relay. With ON/OFF control, hysteresis was used to stabilize the operation during the switch between ON and OFF. The functions of output control (heating) and (cooling) control output were set in Hysteresis. In other words, Hysteresis was a temperature band created between ON and OFF condition (Source: Manual Books Omron E5CC). For example, if the Temperature Controller with a temperature range of 0 to 400°C had a hysteresis of 0.2%, D would be 0.8°C. If the set point was 100°C, the output would be OFF on the process value of 100°C and would be ON at a process value of 99.2°C. Block diagram of control output shown in figure 7.

Table 1. Relay Test Results for 50°C set point

| No | Temperature (°C) | Condition |
|----|-----------------|-----------|
| 1. | ≥ 50°C          | Off       |
| 2. | 1°C - 48°C      | On        |
| 3. | < 49°C          | On        |

3.1.4 Results of On/off Control System Test

The control system test was for determining the success of the components on the prototype which was the control unit to maintain the temperature in accordance with the expected result. The following is a graph obtained from experiments conducted for approximately 10 minutes and the changes of the temperature was recorded every 5 seconds.
The distillation process was conducted by using an On/Off control mechanism at 1°C intervals. It meant that if the set point was 60°C, the maximum temperature reached was 61°C and the minimum temperature was 59°C. The data that had been taken was presented in graphical form using Microsoft Excel software as shown in Figure 8. Based on the data, at 60°C, the maximum temperature during the process was 61°C and the initial temperature was 28°C. The time required to reach a stable or steady-state temperature condition was 190 seconds, and the average temperature during the steady-state process was 59.39°C. Whereas, at 70°C, the maximum temperature during the process was 71°C, and the initial temperature was 30°C. The time needed to reach a steady state condition was 250 seconds, and the average temperature during the steady state process was 69.41°C. Based on the data that had been obtained, it could be concluded that the prototype could control the temperature with error intervals during steady state conditions of 1°C. At 50°C and 80°C, the time needed to reach steady-state conditions was 155 seconds and 410 seconds respectively.

From the results above, it could be concluded that for higher temperature of the setting point needs longer time to reach the stable temperature condition and it could be seen in figure 9:

Figure 8. Graph of Temperature Change to the Time during 50 °C, 60 °C, 70 °C, and 80 °C

(a) Graphs with linear equations
Based on the graph that had been made, a linear equation showed that the equation of \( y = ax + b \) could be used as a help in determining the rising temperature as function of time (second). In this case, the \( x \) value was the time at the setting point, and the \( y \) value was the temperature. Here is the equations obtained from the data plot which had been done.

\[
y = 0.1501x + 27,123
\]  
(1)

Explanation:
- \( y \) = Temperature setting point
- \( x \) = Time (rising time) needed to reach the setting point temperature.

### 3.1.5 Comparison of the MAHD Method with the Conventional Method

Hydrodistillation using MAHD offered many advantages compared to conventional method. One of the advantages was the effectiveness in breaking down the cells in the material so that the contents in the material could be extracted more easily. It was proved by the yield in which its value using the MAHD method was different compared to the conventional hydrodistillation method that used microwave pretreatment before the process. Figure 10 shows the comparison chart between the two methods.

**Figure 9.** (a) and (b) Graph of required time to reach

**Figure 10.** Comparison of the yield between (1) MAHD and (2) conventional method
Based on the graph, it could be concluded that distillation using MAHD was more efficient in producing essential oils because it produced more yield. The first data was yield of the best treatment at a ratio of ginger powder of 40 grams: 320 ml of water and 600 watts of power. It produced oil yields with a mass of 0.68 grams, so the yield was 1.71 %. The second data was a study conducted by Pahalati (2018). Treatment with the best yield was pretreatment using power of 100 watts for 2 minutes with a sample of 100 grams and water of 1200 ml. Its rendement was 1.36 % yield. These showed that the MAHD method offered advantages compared to the conventional methods even though it used a pretreatment using a microwave. It was also proved by Golmakani (2007) in which distillation using MAHD caused rapid damage to cell walls thus higher extraction efficiency was obtained in a shorter time, and significantly lower energy consumption.

4. Conclusion
Based on the research which had been conducted, it can be concluded that:

a) This research has produced a design of On/Off temperature control system using a thermostat based on Microwave Assisted Hydrodistillation method.

b) The results of the On/Of control test sample conducted at the 60°C and 70°C setting points showed that the average temperature during the process (steady-state) was 59.39°C at 60°C and 69.41°C at 70°C.

c) Comparison of yields between conventional methods with microwave pretreatment showed a difference in which the value of yield using prototype was 1.71%, higher than the conventional method which was 1.36%.

5. References
[1] Indonesian Ministry of Trade 2014 “Market Brief of 2014 Essential Oils (HS 3301)” (in Indonesia language) Berlin : Indonesian Embassy
[2] Mahfud, M et al 2017 Microwave-assisted Hydrodistillation for Extraction of Essential Oil from Patchouli (Pogostemon cablin) Leaves Institut Teknologi Sepuluh November
[3] Ogata, K 2010 Modern Control Engineering (5th ed) Prentice Hall inc
[4] Pahalati, S 2018 Effects of Microwave Pretreatment on Hydrodistillation of Ginger (Zingiber Officinal) Against Yield and Levels of Zingiberine in Ginger Oil (Study Power and Pretreatment Time) (in Indonesian language) Malang: Universitas Brawijaya
[5] Permadi, Indra et al 2013 Temperature Control in Electric Furnace Plant uses sensors with the Fuzzy Method (in Indonesian language) Universitas Diponegoro
[6] Prasetyo, AW, Wignyanto, dan Arie FM 2015 Ginger Oleoresin Extraction (Zingiber officinale, Rosc.) With the Soylet Extraction Method (Study the Ratio of Materials with Solvents and the Most Efficient Extraction Circulation Amount) (in Indonesian language). Jurnal Industria
[7] Purwanto, Helmy., Indah Hartati, dan Laeli K 2010 Microwave Development Assisted Extractor (MAE) in Ginger Oil Production with High Zingiberine Levels (in Indonesian language). Momentum. 6(2): p 9-16
[8] Mohammad-Taghi G, Karamatollah R 2007 Comparison of microwave-assisted hydrodistillation with the traditional hydrodistillation method in the extraction of essential oils from Thymus vulgaris L. University of Tehran
[9] Uquiche, Edgar, Marcia Jerez dan Jaime Ortiz 2008 Effect of Pretreatment with Microwaves on Mechanical Extraction Yield and Quality of Vegetable Oil From Chilean Hazelnuts (Gevuina avellana Mo). Innovative Food Science & Emmerging Technologies 9(4): 495-500