An Optimized Honey Dehydration System with Drying Air Temperature and Relative Humidity Control

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***Abstract*—This paper presents a system that can reduce the water percentage of stingless bee honey with a microcontroller to control the drying process employing temperature, drying air speed, relative humidity, and optimized honey exposure surface. The main objective is to reduce water content in stingless bee honey at 22 % in order to prevent rapid fermentation and delay crystallization. This water reduction process is important to preserve the quality and extend the storage period of honey. The system comprises of a programmed microcontroller, a main insulated container, a 12 V and 400 ml/min peristaltic pump, a 2800 Watt hair dryer, a temperature and relative humidity sensor, an exhaust fan, a relative humidity control system made of a smaller insulated container and a thermoelectric Peltier cooler module, a perforated stainless steel tray, and a switching circuit / a controller circuit. In this system, the temperature control was achieved using an on-off controller. The results showed that stingless bee honey samples between 2 and 8 kg was processed, where the percentage of water dropped from between 29 – 28 % to 21.2% with dehydration rate of 53.39 g/h.**

Keywords—Stingless Bee honey, Honey Dehydration, Dehydration rate, Moisture content, Honey Dewatering.

I. INTRODUCTION

The market quality of stingless bee depends on the ability of stingless bee honey to remain unspoiled for an extended period of time. Raw stingless bee honey can have a water-in-honey content of more than 28 %, and can climb up to 40 % during the rainy season. In the honey industry, the lower the water content, the higher the perceived value of the honey. It is recognized that good quality stingless bee honey should contain less than 22 % water content as stated in the MS 2683: 2017 *Kelulut* (Stingless Bee) Honey – Specification [1]. Low water content is desirable because honey may begin to ferment and lose its fresh quality if the water-in-honey is greater than 22 % [1]. Raw and natural honey contains wild yeast that can cause fermentation which reduces the important nutrients and renders the taste too sour. Pasteurizing process through heating helps to reduce the water in the honey and causes the wild yeast to enter a dormant phase.

A conventional way to reduce water content in the stingless bee honey is double-boiler method. A double-boiler typically consists of secured insertion of a flat-bottomed (usually made of glass) over a pan of simmering water; there is a space between the water level and the bottom of the double boiler insert so the stingless bee honey in the top of the double boiler is heated indirectly by the steam from the liquid water below, not the hot water. The trapped steam releases heat which is just about 100 °C. Although the quality of honey is maintained, the process has an inconsistent dehydration rate and only a limited amount of stingless bee honey can be dehydrated.

For any types of heating techniques, to preserve the important nutrients in the stingless bee honey or any kind of honey [1-4], it is very important to note that the drying air must be hot enough but not exceeds the temperature limit. In such application, honey dehydration was performed by using drying air where the heat was controlled with a requirement of a hot water jacket enclosure over a total large system dimension [5]. In another application, the honey circulation was carried out from the bottom to the top compartment where the warm drying air convection and exhaust fan were used [6]. Moreover, a front honey loading access with limited size of honey reservoir tank specification was made available [6]. A moisture reducing apparatus for removing moisture from honey in an enclosed housing was developed with an evaporator coil that dries the recirculated air by condensing moisture, and a heater unit warms the dry air to increase its moisture-absorbing capabilities [7]. In another occasion, a system that removes water from honey at ambient pressure was designed that utilizes a flow of warm air to dry the honey [8, 9]. The temperature of the warm air is higher than the ambient temperature, even in tropical climates but less than about 75 °C where the contact between air and honey was carried out by spreading out the honey on a wide surface area [8, 9]. In a recent development of stingless bee honey dewatering system, an analysis on a low-temperature vacuum drying with induced nucleation technique for dewatering stingless bee honey was reported [10]. However, due to the complexity of the system, it requires the preparation of vacuum pump and transportation of warm water that flows inside pipelines that contact the stingless bee honey inside the main chamber [10].

Unlike the conventional methods of stingless bee or other type of honey bee dehydration technique, our aim is to optimize the stingless bee honey dehydration specif cally.

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Therefore in this paper, a portable system that reduces moisture content in pure stingless bee honey is presented. An electronic sensor temperature and relative humidity sensor, a peristaltic pump, and a micro-processor module were used to control the process. The system takes advantage of the properties of liquids and uses condensation process to dehydrate pure stingless bee honey. In order to heat up the stingless bee honey for condensation, a heating source or element which simply hair dryer was used. The general ideas about the processing cycle of system are as follows: initially, the raw stingless bee honey is poured onto the bottom of the main insulated container of a 40 liter cooler box. The user select the operation mode: manual mode or automatic mode and set the desired input parameters. When the start button is pressed, a peristaltic pump with the specification of 12 V and 400 ml/min, runs continuously and transfers the raw stingless bee honey through a silicon tubing from the bottom of the container to the surface of a perforated stainless steel tray (inside the 40 liter cooler box) that positioned at a location close to the source of drying hair to expose heat to the flowing honey as much as possible. The pure stingless bee honey then settled underneath the bowl prior to trickling from the perforated stainless steel bowl, and the whole cycle repeats. At the same time, the liquid is exposed to warm air produced by the 2800 Watt hair dryer, the temperature is controlled at 40°C, otherwise, the heater is turned off and the warm air inside the container is purged out through an outlet with an exhaust fanned. To optimize the drying air relative humidity, the air intake was sourced from a relative humidity control system with a thermoelectric Peltier cooler module as the main element of dehumidifier and the condensed air inside the main container was feed backed into the relative humidity control system.

II. System Design

A. Main Container

Fig. 1 shows a front side cut-off view of a stingless bee honey dehydrator system consists of a main air flow intake, a 2800 Watt hair dryer, a main insulated container with the dimension of 580 mm × 340 mm × 345 mm, a digital relative humidity and temperature sensor, a 12 V DC exhaust fan with the dimension of 120 mm × 120 mm × 25 mm , a perforated stainless steel tray with the dimension of 530 mm × 300 mm × 20 mm, suspended using hooks 60 mm under the main container lid, a hot air with evaporation flow, and a hot and dry air flow from the hair dryer.

B. Controller Circuit

Fig. 2 illustrates a switching circuit/a controller circuit consists of a microcontroller board, a 4 × 4 matrix keypad, a “START” push button, a “STOP” push button, an LCD display, an electrically operated relay that opens and closes the circuit that connects the DC positive electrical potential to the positive terminal of the 12 V DC exhaust fan, an electrically operated relay that opens and closes the circuit that connects the ac live line to the live terminal of the AC wall outlet, an AC plug of the hair dryer, an electrically operated relay that opens and closes the circuit that connects the DC positive electrical potential to the positive terminal of a 12 V and 400 ml/min peristaltic pump, a 12 V and 400 ml/min peristaltic pump, a DC 12 V power supply, and a main ac power line supply.

C. Smaller Container: Relative Humidity Control System

Fig. 3(a) illustrates a front side cut-off view of a relative humidity control system comprises a smaller insulated container with the dimension of 240 mm × 180 mm × 175 mm, a heat sink for the cold side of the Peltier plate, a 12V 60 Watt Peltier plate, a heat sink for the hot side of the Peltier plate, a

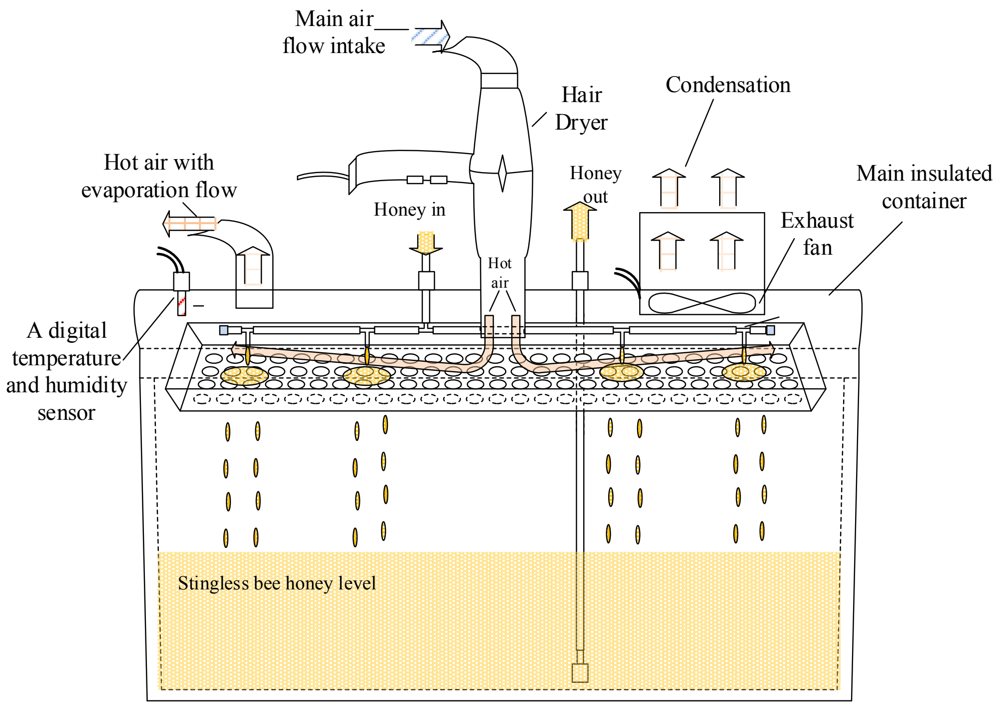

Fig. 1. The 3D Model of the Overall Prototype Design

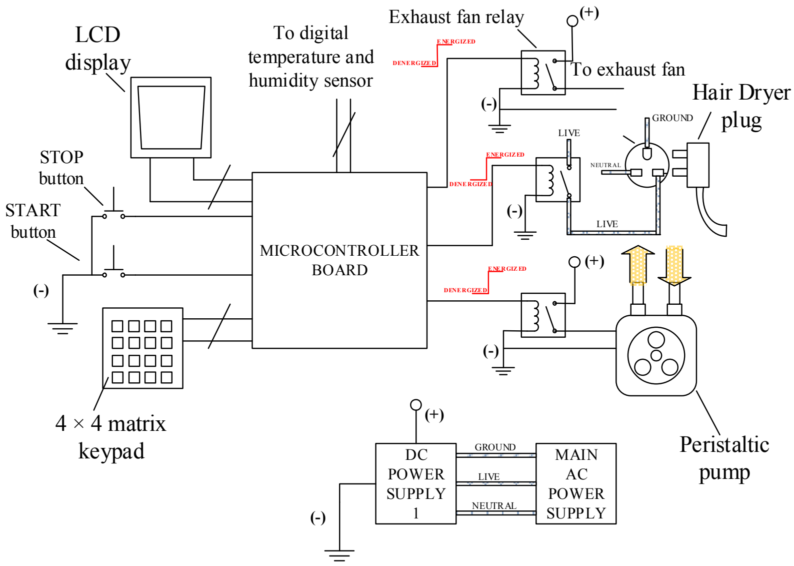

Fig. 2. Schematic of the switching/controller circuit

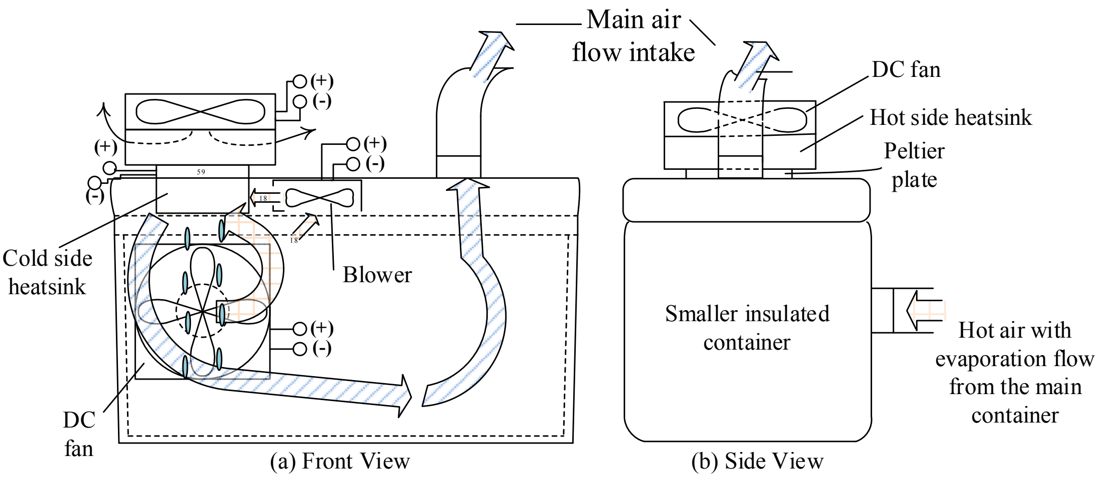

Fig. 3. (a) Front view and (b) side view of the relative relative humidity control system

DC 12V 0.36 A, a DC 12 V 0.36 A fan blower, and a DC 12 V DC hot air intake fan.

Fig. 3(b) shows a side view of a relative humidity control system comprises a hot air with evaporation flow a 30 mm diameter hot air purge out plastic hose, a hot air with evaporation flow from the stingless dehydrator system, and other parts that have been explained in Fig. 3(a).

III. Working Principle of the System

Four factors that contribute to the dehydration process which are temperature level, airflow over the stingless bee honey, relative humidity level, and surface area. The working steps of the system are illustrated in the flow chart as shown in Fig. 4. To explain the main working principles of the system, the following steps are explained:

Step 1: Open the lid of the main insulated container and pour the stingless bee honey into it (the said maximum volume of the stingless bee honey is 40 kg / 40000 g). The stingless bee honey level is shown in Fig. 1.

Step 2: Switch on the power of the main controller microcontroller board and the relative humidity control system as shown in Figs. 2 and 3, respectively. All electrical components in the relative humidity control system will be turned ON.

Step 3: From the LCD display, one of the operating modes is selected as following:

i. “MANUAL” mode: the operating time is set between 1 minute and 9 hours by using the 4 × 4 matrix keypad as shown in Fig. 2.

ii. “AUTO” mode: the initial stingless bee honey water content percentage is preset, the total amount of stingless bee honey volume in grams, and the final stingless bee honey water content percentage by using the 4 × 4 matrix keypad as shown in Fig. 2. Then, the microcontroller board will calculate the operating time based on (1):

$$t = \frac{\dfrac{(m.c._1 - m.c._2)}{(100 - m.c._2)} \times W_1}{R} \qquad (1)$$

where

t is the operating time, (hours:minutes:seconds),
R is the dehydration rate, (g/h),
$m.c._1$ is the initial water content, percentage, (%),
$m.c._2$ is the final water content, percentage, (%),
W_1 is the initial weight of honey loaded, (g).

The calculated operating hour values is set to be not more than 9 hours. The said dehydration rate parameter, R value is determined from the experiments prior to the operation, which will be discussed in the next section.

Step 4: When the operating mode is set, the "START" push button is pressed, sending the interrupt signal into the microcontroller board through a digital input pin. Then, the microcontroller board sends a "HIGH" output signal through a digital output, energizing the relay, turning ON the peristaltic pump and continuously pumps the stingless bee honey that flows inside the 10 mm silicone tubing system from the bottom to the surface (through the 10 mm barb tee connectors) of the perforated stainless steel tray. To ensure high distribution of stingless bee honey, four outlets of 100 mm barb tee connecters were evenly positioned above the perforated stainless steel tray as shown in Fig. 1. The stingless bee honey flows through the hole and trickles down to the bottom of the main container.

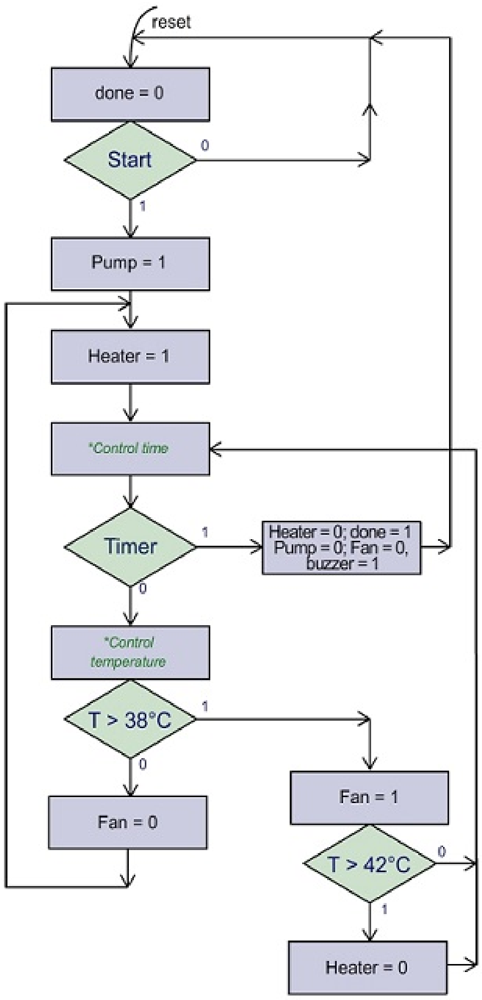

Fig. 4. The process flow of the working steps

Step 5: The temperature and relative humidity sensor starts to measure the relative humidity and temperature of the air inside the main container and shows the temperature and relative humidity values on the LCD display, if the temperature value is less than 42 °C, the microcontroller board sends a "HIGH" output signal through, energizing the relay and completing the AC connections through the AC pin and turning ON the hair dryer, the hair dryer provides hot and dry air flow into the main container. The source of air intake is from the relative humidity control system as shown in Fig. 3. The said air flow speed is between 10 and 15 m/s and this is to make sure wider surface area for dehydration process. A threshold of 2 °C is given since the measured temperature is not directly on the stingless bee honey.

Step 6: If the temperature value exceeds 38 °C, the microcontroller board sends a "HIGH" output signal to the relay, completing the DC electrical potential connection and turning ON the 12 V DC exhaust fan, then the 12 V DC exhaust fan will stay ON as long as the temperature value is higher than 38 °C, while states of the other components will remain be unchanged. The hot air with evaporation is purged out through the exhaust chimney.

Step 7: If the temperature value exceed 42 °C, the microcontroller board sends a "LOW" output signal to the relay, de-energizing the relay and disconnecting the AC connections through the AC pin and turning off the hair dryer and it will stay OFF as long as the temperature is higher than 42 °C. At this point, the hair dryer will return to ON state when the temperature value is at 38 °C and lower. During the temperature interval between 38 °C and 42 °C, both 12 V DC of the exhaust fan the hair dryer are turned ON.

Step 8: The process will stop, turning off all the electrical devices connected to the controller circuit when the operating period ends as indicated on the LCD display or when at any time the "STOP" push button is pressed, sending the interrupt signal into the microcontroller board through a digital input pin. Fig. 5 shows the picture of the honey dehydration system.

Fig. 5. The picture of the whole setup of the dehydration system

IV. Results and Discussions

To ensure relative humidity control, a relative humidity control system is used, which comprises of a smaller insulated container as shown in Fig. 3. A 12V 60 Watt thermoelectric Peltier module was used as one of the main components. Basically, the hot air with evaporation from the main container is channeled back into the smaller insulated container through the 30 mm diameter hot air purge out plastic hose and 12 V DC hot air intake fan . The hot air will be evaporated when it contacted the cold heat sink . The dried and cooled air is then flows as the main air intake of the hair dryer through the 30 mm diameter main air intake plastic hose. Several stingless bee honey dehydration experiments were performed using stingless bee honey volumes between approximately 2 kg and 8 kg. Every hour, a small amount of the stingless bee honey is taken out from the main container and put on a refractometer to measure the value of the water percentage. Fig. 6 shows the results of dehydration process for honey volumes of 2697 g, 4335 g, and 8635 g. From Fig. 6, it can be seen that the water content percentage values decreased with increasing processing time (hour). This shows that the water content in the honey was able to be reduced gradually. The dehydration rate can be calculated from the following equation [5]:

$$R = \frac{\frac{(m.c._1 - m.c._2)}{(100 - m.c._2)} \times W_1}{t} \qquad (2)$$

where

t is the operating time, (hours:minutes:seconds),
R is the dehydration rate, (g/h),
$m.c._1$ is the initial water content, percentage, (%),
$m.c._2$ is the final water content, percentage, (%),
W_1 is the initial weight of honey loaded, (g).

The average dehydration value obtained from the experiments is 56.92 g/h. Another set of experiment was carried out to investigate how the relative humidity control system controls the relative humidity level. Two different sets of temperature and relative humidity sensors were used. The sensors were placed inside the main insulated container and the smaller insulated container each. Fig. 7(a) shows the difference between the temperature values profiles inside the main insulated container and inside the smaller insulated container. It is observed in the beginning that both temperature values are the same at around 22 °C. Moreover, inside the main container and in the first hour, the temperature gradually increases until around 45 °C. This is due to the time taken for thermal equilibrium is longer after the dehydration system starts. Between 1 hour and five hours, the temperature fluctuates between 45 °C and 37 °C. However, the temperature in the smaller container is maintained at around 24 °C as illustrated in Fig. 7(a).

Fig. 7(b) illustrates that the relative humidity level inside the main container is successfully maintained at around 30 % and 46 %. The relative humidity values inside the smaller container is between 67 % and 85 %. The relative humidity profile inside the main container is inversed of the relative humidity profile inside the smaller container which indicates that the relative humidity inside the main container was successfully transferred into the smaller container.

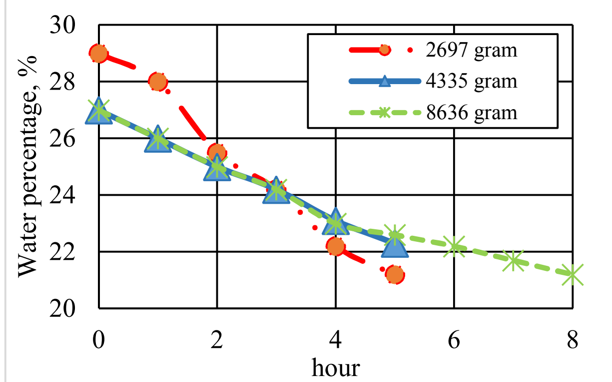

Fig. 6. The results of dehydration process for honey volumes of 2697 g, 4335 g, and 8635 g

V. Conclusion and Future Recommendation

In conclusion, the overall process of the system, the specifications, the design requirements and the performance of the on-off controller of the system were discussed and compared to all relevant ideas. For better quality stingless bee honey and for storage and marketing purposes, the water moisture content need to be reduced. Therefore, considering all properties of the stingless bee honey and its relation with the variation in temperature and humidity, a stingless bee honey dehydrator system was developed as shown in the main content of the paper. The system reduced the percentage of water in the stingless bee honey from 29 % to 21.4 % with the dehydration rate of 56.92 g/h.

It is possible to realize the implementation of PID (proportional-integral-derivative) control in the future where the output power of the main heater equals to the sum of three coefficients: proportional, integral and differential. The advantage of PID will be faster warming up time, close to zero set point temperature error, and immunity to disturbances.

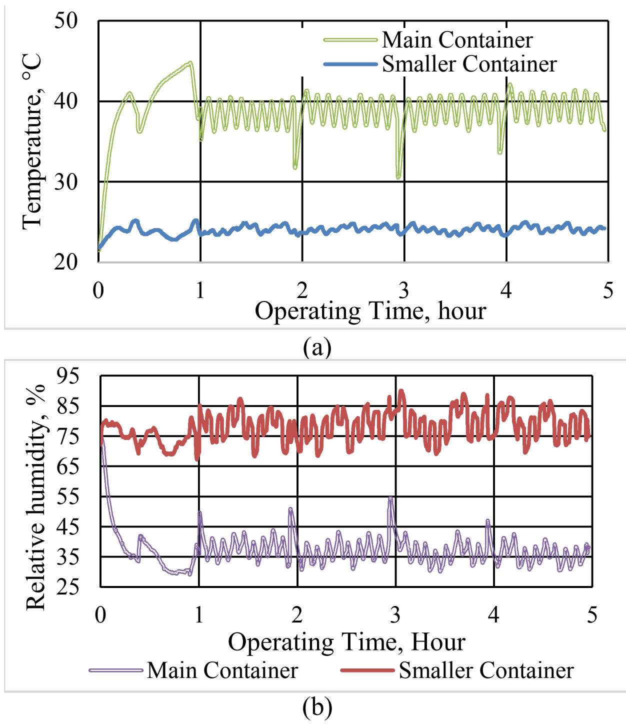

Fig. 7. The results of dehydration process for honey volumes of 2697 g, 4335 g, and 8635 g

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