Application Closed-End Oscillating Heat Pipe for Essential Oil Condensation of the Small Scale Essential Oil Refiner

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Abstract

This research aimed to investigate the design and building of a small scale essential oil refiner by using heat pipes for essential oil condensation. The device structure of the small scale essential oil refiner was divided into 3 sections as follows: 1) the boiler with a heater for heating, 2) the vapor tube, and 3) the condenser unit. Three patterns of condenser unit were investigated: 1) condensation by water circulation, 2) condensation using heat pipes, and 3) condensation using heat pipes with water circulation. The temperature for testing was 80, 90 and 100 °C. A closed-end oscillating heat pipe (CEOHP) was used in this research. The inner diameter of the heat pipe was 2 mm. R123 was used as the working fluid. 500 g of kaffir lime peels were used for each test with a time of 2 hours. It was found that the highest quantity of essential oil was 1.4 cc when using a CEOHP with a water circulation unit at 100 °C.

Keywords: Heat pipe, oscillating heat pipe, CEOHP, essential oil refiner

Introduction

Essential oils can be extracted from several parts of fruits, vegetables and herbs which are available in Thailand. The demand for aroma oil in the market is quite significant due to its qualities and usefulness. Essential oils can be extracted using a variety of methods, although some are not commonly used today. Currently, the most popular method for extraction is steam distillation. In steam distillation the plant material is placed in a still (very similar to a pressure cooker) where pressurized steam passes through the plant material. The heat from the steam causes globules of oil in the plant to burst and the oil then evaporates. The essential oil vapor and the steam then pass out the top of the still into a water cooled pipe where the vapors are condensed back to liquids. At this point, the essential oil separates from the water and floats to the top.

The normal essential oil refiner is large, making it difficult to move and expensive. In Thailand, researchers studied have studied the design and construction of essential oil refiners. For example, Sajjavatee and Kadking [1] designed and built a laboratory scale water and steam distillator for essential oils from herbs or medicinal plants which worked at atmospheric pressure. Magkong and Yamsiri's [2] design consisted of 3 main components as a still, condenser and separator. The still capacity was 95 liters. The holding capacity of water was 20 liters and the raw (plant) material was 10 - 13 kg/operation. The condenser included 3 straight pipes, with a total length of 6 m, with the holding capacity of water 320 L, but had no cooling system.

Heat pipes are a simple heat exchanger for heat transfer from the different temperature of the 2 sources. The oscillating heat pipe (OHP) is one type of heat pipe [3]. It is a new type of heat pipe, improved from the thermosyphon and is also called a pulsating heat pipe. The oscillation of slugs and plugs in the OHP are self-sustained by the evaporation of liquid slugs and the condensation of vapour plugs. Therefore the heat from the high temperature section can be transported to another section at lower temperature. The advantages of the OHP include simplicity of construction, only one tube, no capillary structure, high thermal performance, capability of operation in any positions, and operational flexibility. Normally, OHP is made from capillary tubes with 3 common types: closed end oscillating heat pipe (CEOHP), closed-loop oscillating heat pipe (CLOHP) and closed-loop oscillating heat pipe with check valves (CLOHP/CV) . In addition, the OHP has 3 evaporators, adiabatic and condenser sections [4,5]. The application of an oscillating heat-pipe has many advantages. In 2006, the CLOHP/CV air-preheated was applied by Meena *et al*. [6]. The CLOHP/CV air-preheater can reduce the relative humidity and achieve energy thrift. In Meena's research, the velocity increased from 0.5 to 1 m/s and led to a slight decrease in effectiveness. As the hot-air temperature increases from 50 to 70 °C, the effectiveness slightly increased; and the relative humidity was reduced to 54 - 72 % from 89 to 100 %.

CEOHP is very simply constructed and applied. Moreover, CEOHP can transfer heat in any axis. As a result of the advantages of CEOHP, it was used in this research the CEOHP to improve the condensation part of a normal essential oil refiner. The CEOHP can help condensation if set up before the water circulation condensation device.

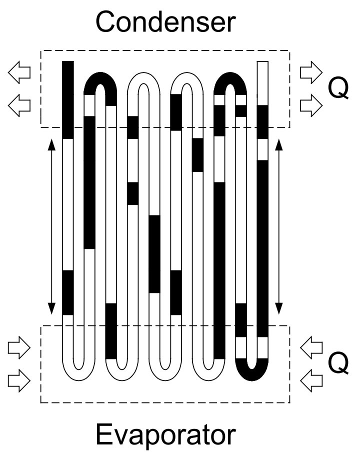


Figure 1 Close-end oscillating heat pipe (CEOHP).

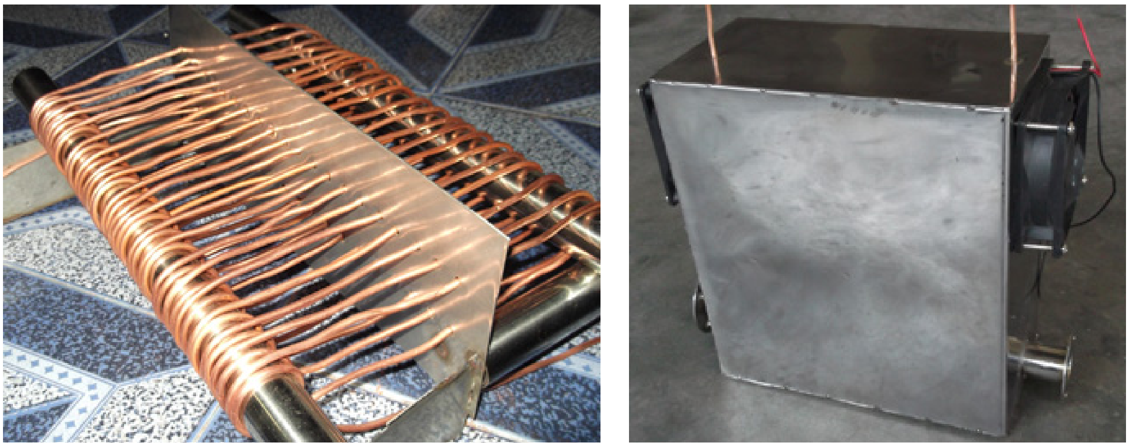
Experimental setup and procedure

CEOHP heat exchanger

The CEOHP was made from a copper capillary tube with an inner diameter of 2 mm. The inner diameter of the tube was calculated by Eq. (1) [3]. The working fluid in this case was R123 with a filling ratio of 50 % of total volume of the tube. As shown in **Figure 2a**, the lengths of the evaporator and condenser sections were 10 cm. And then the CEOHP was covered by a stainless steel sheet with 2 fans at the end of the box for control of air flow in the condenser section as shown in **Figure 2b**. The CEOHP was designed for a compact essential oil refiner as shown in **Figure 3**.

$$d_{\max} < 2\sqrt{\frac{\sigma}{\rho_l g}} \qquad (1)$$

where d_{max} is the maximum inner of capillary tube (m), σ is surface tension of the fluid (N/m). ρ_l is the density of the fluid (kg/m^3) and g is acceleration due to gravity (9.81 m/s^2).



(a) (b)

Figure 2 The CEOHP heat exchanger, (a) CEOHP without case and (b) CEOHP with case and fans.

The small scale essential oil refiner

The CEOHP and water circulation unit was set up as shown in **Figure 3**. The small scale essential oil refiner in **Figure 4** was made from stainless steel sheet number 304, and the volume of the pot was 6 L, with the refiner covered by a thermal insulator. The steam pipe was a stainless steel pipe of inner diameter 2.5 cm. The water condenser was made from a straight pipe with a diameter of 7.6 cm. The diameters of the water inlet and outlet pipe for condensation were 1.9 cm. The electric heater (1,500 W) was placed at the bottom of the pot for heating water.

Operating conditions

Two L of water was used to fill the pot with the product for testing placed on a stainless grating at the upper water level. In this study 500 g of kaffir lime peels were used as shown in **Figure 5**. The water flow rate was controlled at 0.12 L/s. The air velocity of the CEOHP was 1.5 m/s. The water temperature was set at 80, 90 or 100 °C. The temperatures of the air inlet and outlet of the CEOHP condenser section and the temperature of water inlet and outlet of condenser section of a normal essential oil refiner were measured and recorded every 5 min for 2 h using a Testo -177t 4v01.10 data collector. The essential oil and water were separated in separatory funnel and the water discarded. After that the essential oil quantity was measured and recorded. The heat transfer rate in heating air of heater is calculated as follows;

$$Q = \dot{m} c_p (T_{out} - T_{in}) \tag{2}$$

where *m* is the air mass flow rate (kg/s), C_p is the specific heat capacity of air (kJ/kg·°C), T_{in} and T_{out} are the inlet air temperature before entering the CEOHP condenser section (°C) and outlet air temperature after entering the CEOHP condenser section (°C).

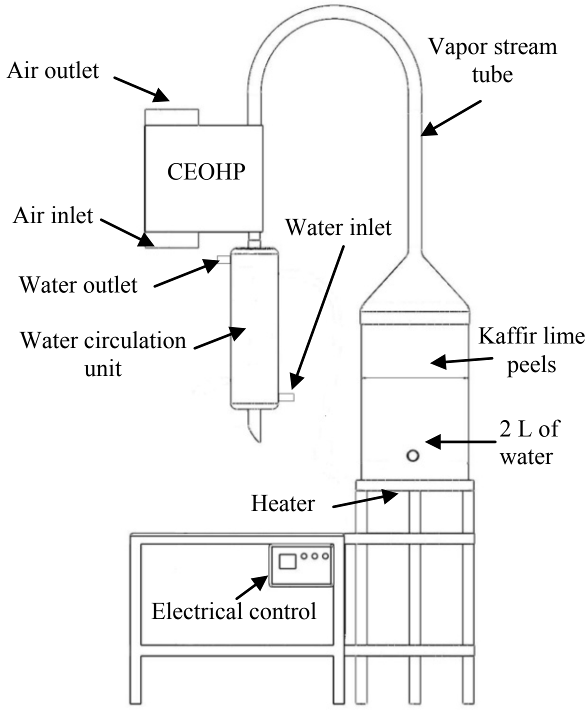


Figure 3 Schematic diagram of the small scale essential oil refiner with CEOHP.

Figure 4 The small scale essential oil refiner with CEOHP.

Figure 5 The kaffir lime peel.

Figure 6 The separatory funnel containing the essential oil.

Results and discussion

Figure 7 shows the result of the inlet and outlet temperatures of the CEOHP condenser section (only condensation with CEOHP). It was found that the temperature of the air outlet was higher than the temperature of the air inlet in any temperature test. The average temperature difference at the condenser section of the CEOHP was 1.82 °C. Therefore, CEOHP can condense steam in any temperature. In **Table 1** the results of the essential oil quantity reveal that the essential oil quantity increased as the operating temperature increased. This is because when the temperature increased, the stream water quantity from boiling water increases. Therefore, the stream water at high temperature can absorb more essential oil from kaffir lime peels than at lower temperatures. Moreover, the essential oil quantity increased when the CEOHP heat exchanger set up was used in the small scale essential oil refiner. The CEOHP heat exchanger can increase the essential oil quantity at any temperature because the area of the condenser section increases therefore the some part of the vapor condensed before condensation by the water circulation unit. Under the test conditions the highest quantity of essential oil was 1.4 cc when using the CEOHP in combination with normal condensation at 100 °C.

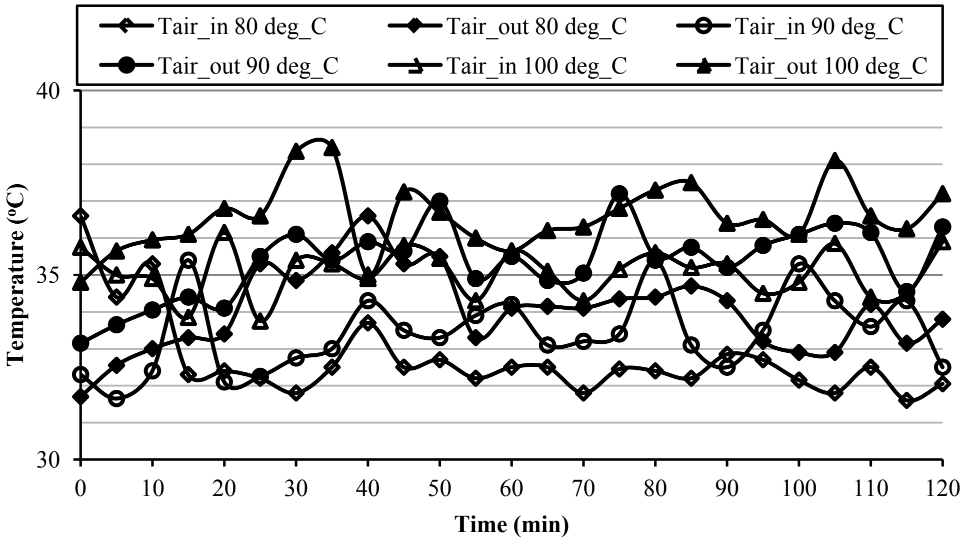


Figure 7 The inlet and outlet temperatures at CEOHP condenser part.

Table 1 The essential oil quantity results.

Type of condensation	Temperature (°C)	The average of essential oil quantity (cc)
Water circulation suit	80	0.2
	90	0.3
	100	1.2
CEOHP heat exchanger	80	0.1
	90	0.1
	100	0.3
CEOHP heat exchanger work with water circulation suit	80	0.4
	90	0.6
	100	1.4

Conclusions

In this research we investigated the increasing essential oil quantity of steam distillation using an essential oil refiner. The results indicate that a CEOHP heat exchanger increases the quantity of essential oil produced at any temperature because of the area of refiner condenser section increased leading to some part of the vapor condensing before condensation by the water circulation unit.

Acknowledgments

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References

[1] P Sajjavatee and C Kadking. 2000, Essential Oils Distillatory from Herbs and Spices. Bachelor of Engineering (Food Engineering). Kasetsart University, Kamphaeng Saen Campus, Thailand.
[2] T Magkong and S Yamsiri. 2002, Essential oil distiller, Bachelor of Engineering (Agricultural Engineering). Kasetsart University, Kamphaeng Saen Campus, Thailand.
[3] S Maezawa, YK Gi, A Minamisawa and H Akachi. Thermal performance of capillary tube thermosyphon. *In*: Proceeding of the 4th International Heat Pipe Conference, USA, 1996, p. 791-5.
[4] S Rittidech, N Pipatpaiboon and P Terdtoon. Heat-transfer characteristics of a closed-loop oscillating heat-pipe with check valves. *Appl. Energ.* 2007; **84**, 565-77.
[5] Y Miyazaki, F Polasek and H Akachi. Heat pipe with check valves. *In*: Proceeding of the 6th International Heat Pipe Symposium, 2000, p. 389-93.
[6] P Meena, S Rittidech and N Poomsa-ad. Closed-loop oscillating heat-pipe with check valves (CLOHP/CVs) air-preheater for reducing relative humidity in drying systems. *Appl. Energ.* 2007; **84**, 363-73.