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EXTRACTION OF PEPPERMINT VOLATILE OIL USING A SIMPLE CONSTRUCTED STEAM DISTILLATION SYSTEM

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Abstract

The main objective of the present work is to construct a simple steam distillation system for extracting volatile oil from peppermint plant. The constructed extraction system consists of the following main parts: electric heater, boiler, extracting unit, condenser and connection hoses. Experiments were carried out to study the effect of boiler inlet water flow rates (1.00, 1.25 and 1.50 l/h) and batch size of whole peppermint plant (300, 500 and 700 g) on system productivity, extraction efficiency, essential oil yield, power and energy requirements. Results indicated that the constructed extraction system using steam distillation technique gave the optimum conditions of system productivity (6.2 ml), extraction efficiency (88.57 %), essential oil yield (0.797 % (w/w)) and energy requirements (0.475 kW.h/ml) under 1.5 l/h boiler inlet water flow rate and 700 g batch size.
***Keywords*:** Extracting unit, Peppermint plant, Extraction efficiency, Essential oil yield, Power, Energy requirements

Introduction

Essential oils are the subtle aromatic and volatile liquids extracted from any part of plants through distillation. They are used in the food industry as flavoring in the cosmetic industry for fragrance and in the pharmaceutical industry for its functional properties. Adams (2001) reported that essential oils have an unexpected large range of applications finding uses in the food and beverage industry. Peppermint is one of the useful medicinal and aromatic plants. Peppermint essential oil has important usage to the industry. Ministry of Agriculture and land reclamation (2018) reported that the cultivated area with peppermint plants in Egypt amounted to be about 334.74 ha with total production of 16260 Mg.

Steam distillation uses heat from steam or water to break the oil glands in plants and vaporize the oil, which is then condensed and separated from water. Phineas (2005) developed new process design and operation for steam distillation of essential oils that increased oil yield. The packed bed sited above the steam source and only steam passes through it without the boiling water mixing with vegetable raw material (lavender and Artemisia) as is the case in hydro-distillation. This method determining the optimum amount of steam required for distillation of a given mass of vegetable material. Öztekin and Martinov (2007) mentioned that essential oils are generally obtained by various distillation techniques. Among them steam distillation is the most widely accepted method for the production of essential oils on a commercial scale. Handa *et al.* (2008) indicated that water distillation is the most commonly used distillation method because of its relatively low cost compared to steam distillation. But steam distillation has higher efficiency and higher quality of essential oil extraction compared to water distillation, since the water and plant materials are not directly in contact with each other. Cassel *et al.* (2009) evaluated a mathematical model to predict the essential oil recovery by steam distillation of rosemary, basil and lavender. They compared the data obtained in yield experimental with a mathematical model used in the simulation of essential oils extraction by steam distillation. The model parameter evaluation could be a useful tool during the scale-up of the extraction process and /or during pilot or industrial operation in order to evaluate the extraction time required to obtain a given yield. The maximum yield values obtained for rosemary, basil and lavender oils were 0.51%, 0.38% and 0.32% (w/w), respectively.

There are many factors affecting the essential oil extraction process, therefore, Arafa (2001) mentioned that there is a negative relation between the essential oil quantity of aromatic plants and different temperatures. The essential oil quantity was (0.34, 0.32, 0.3, 0.27, and 0.25 ml/100mg), (0.51, 0.48, 0.45, 0.41, and 0.32 ml/100mg) and (0.37, 0.34, 0.31, 0.29, and 0.27 ml/100mg) from plants leaves at 35, 40, 45, 50 and 60 ^{o}C, for M.Pulegium, Marjoram and peppermint, respectively. There is a clear relation between the losses in the essential oil quantity of aromatic plants and different relative humidity. The losses were (0.3, 0.32, 0.33, and 0.34ml/100mg), (0.46, 0.48, 0.49, and 0.50ml/100mg), and (0.33, 0.35, 0.36, and 0.37ml/100mg) from plants leaves at 25, 50, 65, and 75 % under the same previous plants.

Based on above mentioned literature review; the authors try to solve the problems arising during the extraction process. So, the objectives of the present investigation are to:

- Construct a simple steam distillation system for extracting peppermint volatile oil.
- Study some different parameters affecting the performance of the constructed system.

Materials and Methods

An extraction system based on steam distillation was constructed in workshop of Bilbeis city (30º 25' 17.9" N. 31º 30' 32.6" E), Sharqia Governorate, Egypt. The experiments were carried out though the period from February to March of 2020.

Materials

(i) Plant

Peppermint plant (*Mentha piperita. L.*) was used under study for extracting volatile oil by steam distillation. Properties of the experimental plant were illustrated in Table 1.

Table 1 : Some properties of peppermint plant

Properties	Values
Stem diameter, mm	2.37
Stem length, cm	15-20
Plant mass, g	3-5
Number of leaves	20-40

(ii) Steam distillation extraction system

Steam distillation system was consisted of electric heater, boiler, extracting unit, condenser and connection hoses as illustrated in Figs. (1 and 2).

- **Electric heater :** An electric heater (750 Watt) was used as a power source for heating water in the boiler to produce steam required for the extraction process.
- **Boiler :** The used boiler was made of stainless steel with two openings in the top. It was mounted above the electric heater. It is 20 cm in diameter and 30 cm in height. The boiler was insulated with fiber glass to reduce the heat loses.
- **Extracting unit :** The extracting unit was constructed to be suitable enough batch sizes of peppermint plant. The cylindrical unit shaped (30 cm diameter and 50 cm height) was made of stainless steel. A net was installed inside the extracting unit at a height of 7 cm from the unit bottom. There were two openings; the first opening was located in the unit bottom to deliver steam produced from the boiler, while, the second opening was put in the unit top to deliver steam with the extracted volatile oil to condenser.

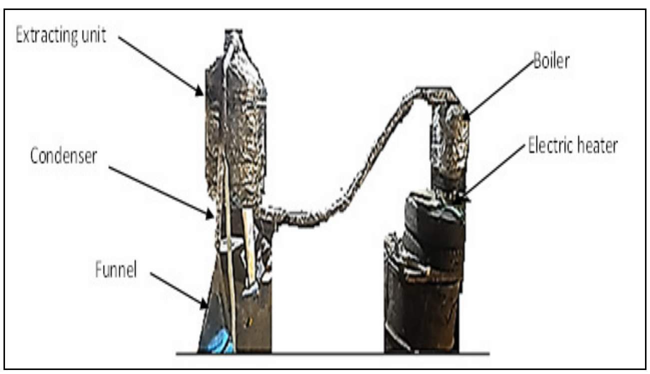
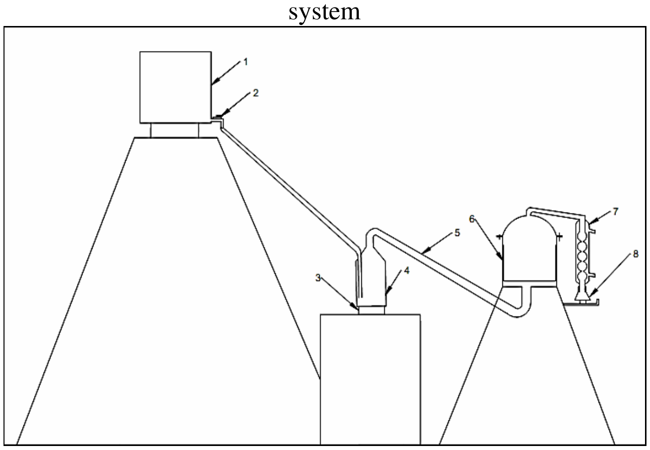


Fig. 1 : View of the constructed steam distillation extraction system



1- Water tank, 2- Control valve, 3- electric heater, 4- Boiler, 5- Connection hoses, 6 - Extracting unit, 7- condenser, 8- Funnel tube

Fig. 2 : The constructed steam distillation extraction system

- **Condenser :** It was made of glass and consisted of two tubes, one inside the other. The condenser used a system of tubes exposed to a constant flow of water to cool and condense a hot steam. There were four openings through the condenser: one for inlet of steam, the other for outlet of condensed water and two for inlet and outlet of cooling water. The condenser was connected with the extracting unit to receive steam and oil. The extracted volatile oil was collected in a funnel tube and then collected.
- **Connection hoses :** The connection hoses were made from rubber tubes and supported with hand valves to shut and open any parts of the system.

Methods

(i) Experimental conditions

Experiments were carried out under the following parameters:

- Boiler inlet water flow rates (1.00, 1.25 and 1.50 l/h)
- Batch sizes of whole plant (300, 500 and 700 g)

Whole peppermint plant was placed on the perforated tray in the extracting unit with moisture content of 79.4 % (wb) under all experimental conditions. The extracting time is started from 11:00 am to 15:00 pm.

(ii) Measurements

Performance of the extraction system was evaluated taking into consideration the following measurements:

- **System productivity :** The hourly extraction system productivity (*SP*, ml/h) was determined as:

$$SP = \frac{V}{t} \qquad ...(1)$$

Where: V - Volume of extracted volatile oil, ml and t - Operating time for extracting oil, h.

Cumulative productivity (ml) was estimated under all experimental conditions.

- **Extraction efficiency :** Efficiency of extracting oil (η_{Ex}, %) was estimated according to that 100 g peppermint contain 0.1-1.00 ml volatile oil and calculated according to (Anjum and oliver, 2009) using the following formula:

$$\eta_{EX} = \left(\frac{m_{oil}}{max_{oil}}\right) \times 100 \qquad ...(2)$$

Where: m_{oil} - Mass of extracted oil, g and max_{oil} - Maximum mass of oil per plant batch, g.

- **Essential oil yield :** It was calculated according to Anjum *et al.* (2014) as:

$$Essential\ oil\ yield = \left(\frac{m_{oil}}{m_{plant}}\right) \times 100 \qquad ...(3)$$

Where: m_{plant} - Mass of plant per batch, g.

- **Energy requirements :** The energy requirements (ER, kW.h/ml) can be calculated using the following equation:

$$ER = P / SP \qquad ...(4)$$

The required power (P, W) was measured using ammeter and voltmeter and calculated according to the following formula:

$$P = I \times V \qquad ...(5)$$

Where: I - current strength, amperes and V - voltage in volts being equal to 220 V.

Results and Discussion

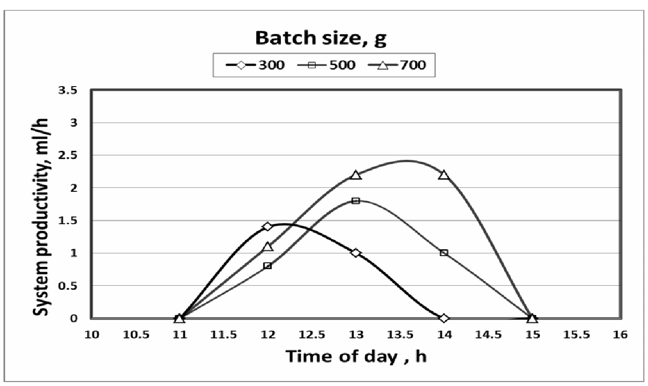
The discussion will cover the obtained results under the following heads:

Hourly and cumulative system productivity

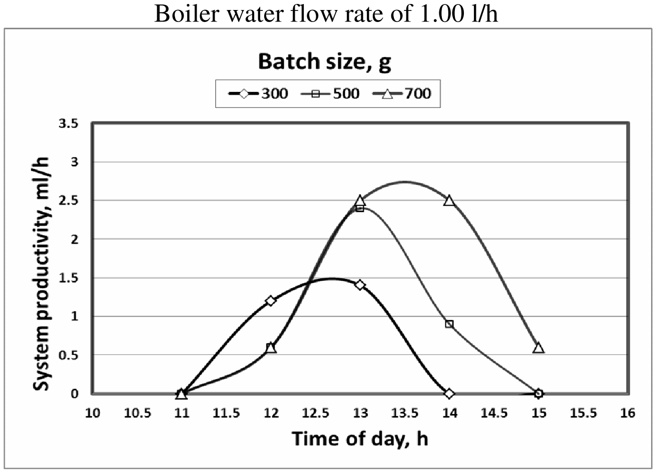
Fig. 3 appeared the effect of different peppermint plant batch sizes and boiler inlet water flow rates on hourly system productivity.

Results indicated that increasing water flow rate from 1.00 to 1.50 l/h at 13.00 pm, increased the hourly productivity from 1.00 to 2.2, from 1.8 to 2.8 and from 2.2 to 3.2 ml/h under batch sizes of 300, 500 and 700 g, respectively. This increase in productivity may be due to the increase of the generated amount of steam that accelerating the steam motion inside the extracting unit, which allowing extraction volatile oil easily. With the effect of batch size, results showed that increasing in batch size, increased the hourly system productivity, this may be due to the increase of the extracted volatile oil with the amount of plant batch.

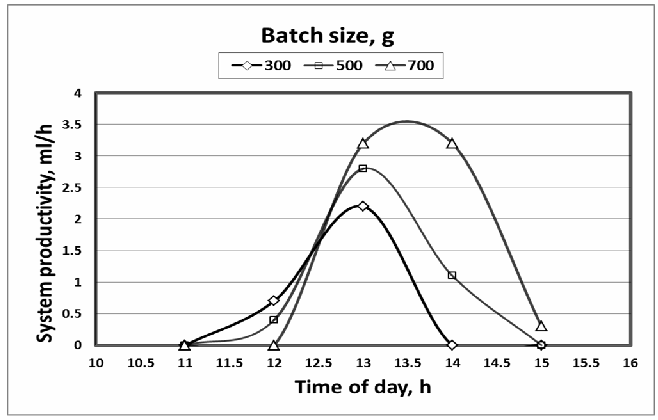
Respecting to cumulative system productivity, Fig. 4 showed that increasing boiler inlet water flow rate from 1.00 to 1.50 l/h at 15.00 pm, increased the cumulative system productivity from 2.4 to 2.9, from 3.6 to 4.3 ml and from 5.5 to 6.7 ml under batch sizes of 300, 500 and 700 g, respectively. Increasing the batch size, the cumulative system productivity was increased.



Boiler water flow rate of 1.00 l/h

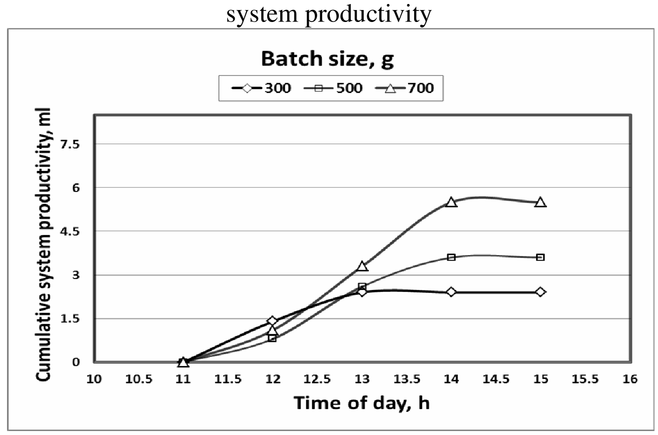


Boiler water flow rate of 1.25 l/h

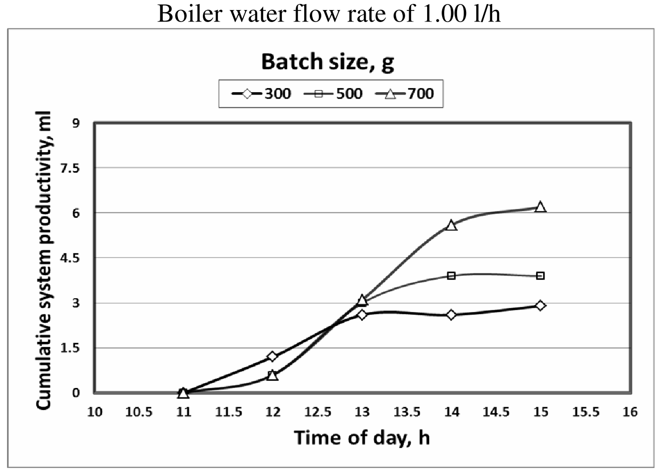


Boiler water flow rate of 1.50 l/h

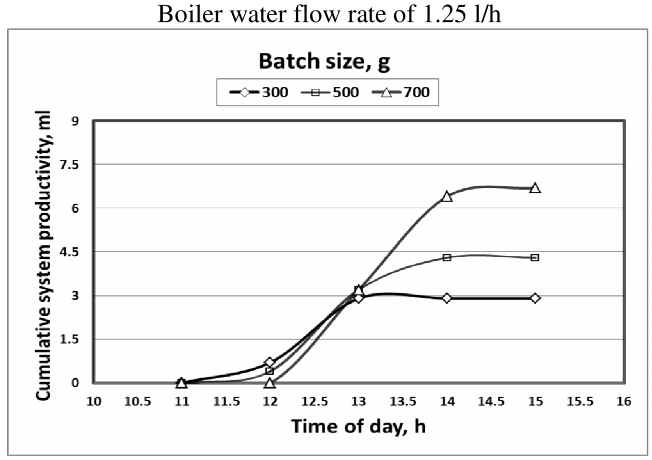
Fig. 3 : Effect of batch size and water flow rate on hourly system productivity



Boiler water flow rate of 1.00 l/h



Boiler water flow rate of 1.25 l/h



Boiler water flow rate of 1.50 l/h

Fig. 4 : Effect of batch size and water flow rate on cumulative system productivity

Extraction efficiency

The effect of peppermint plant batch size and boiler inlet water flow rate on the extraction efficiency was presented in Fig. 5.

It was evident that increasing water flow rate from 1.00 to 1.50 l/h, the extraction efficiency was increased from 70.37 to 84.81, from 72.89 to 86.89 and from 78.57 to 94.60 % under 300, 500 and 700 g batch sizes, respectively. Increasing in batch size, the extraction efficiency was increased. The increase in extraction efficiency by increasing water flow rate is attributed to the increase of the generated steam that improving the oil extraction operation.

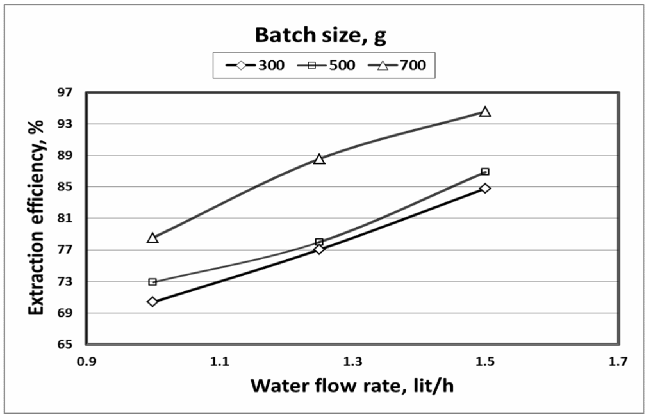


Fig. 5 : Extraction efficiency with relationship to batch size and water flow rate

Essential oil yield

Obtained results from Fig. 6 revealed that the highest yield of essential oil was 0.851% (w/w) under water flow rate of 1.50 l/h and 700 g batch size. Increasing the water flow rate from 1.00 to 1.50 l/h, the essential oil yield was increased from 0.633 to 0.763, 0.656 to 0.782 and 0.707 to 0.851% (w/w) under batch sizes of 300, 500 and 700 g, respectively. Increasing the batch size from 300 to 700 g, the yield of essential oil was increased. This increase of essential oil yield may be due to the increase of the generated steam that facilitating to extract most of the volatile oil by the increases in batch sizes.

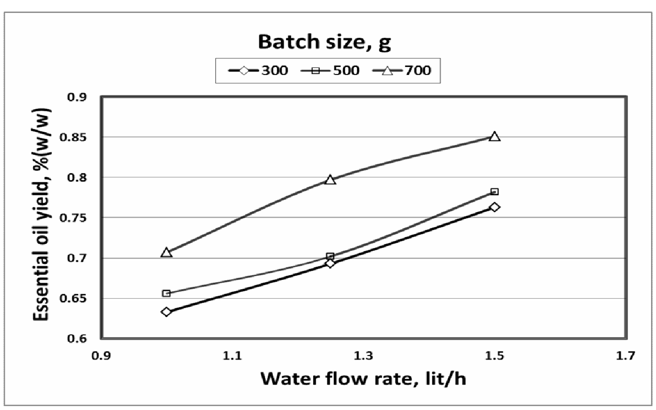


Fig. 6 : Relation between essential oil yield and both batch size and water flow rate

Energy requirements

Fig. 7 illustrates the relationship between the energy requirements and both peppermint plant batch size and boiler inlet water flow rate.

The energy requirements reached its maximum value of 1.140 kW.h/ml under boiler inlet water flow rate of 1.00 l/h and batch size of 300 g. While its minimum value was 0.447 kW.h/ml under boiler inlet water flow rate of 1.50 l/h and batch size of 700 g.

Regarding the effect of boiler inlet water flow rate on energy requirements, the obtained data show that increasing boiler inlet water flow rate from 1.00 to 1.25 to 1.50 l/h, decreased energy requirements from 1.140 to 0.980, from 0.782 to 0.675 and from 0.525to 0.447 kW.h/ml under batch sizes of 300, 500 and 700 g, respectively.

Relating to the effect of batch size on energy requirements, results show that increasing batch size from 300 to700 g, decreased energy requirements from 1.140 to 0.525, from 1.080 to 0.475 and from 0.980to 0.447 kW.h/ml under boiler inlet water flow rates of 1.00, 1.25 and 1.50 l/h, respectively.

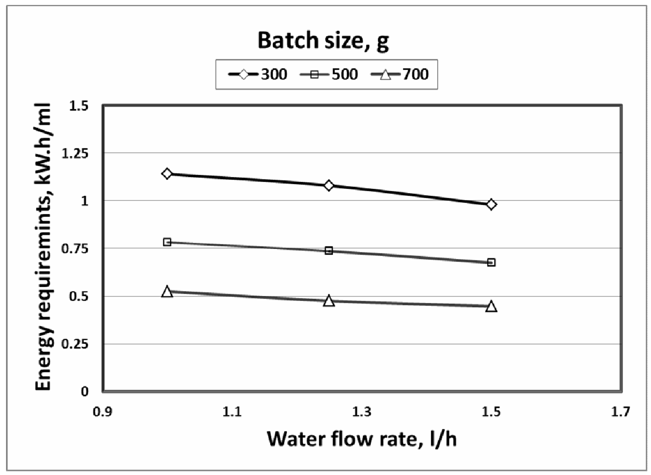


Fig. 7 : Effect of batch size and water flow rate on energy requirements

Conclusion

A simple extraction system is constructed using steam distillation technique for peppermint plant. Experiments were carried out to study the performance of the constructed system as a function of change in boiler inlet water flow rates (1.00, 1.25 and 1.50 l/h) and whole peppermint plant batch sizes (300, 500 and 700 g). Obtained results can be concluded as following:

- Increasing the boiler inlet water flow rate from 1.00 to 1.50 l/h, increased hourly and cumulative system productivity, extraction efficiency, essential oil yield, required power, while the energy requirements were decreased.
- Increasing the batch size from 300 to 700 g, increased hourly and cumulative system productivity, extraction efficiency, essential oil yield, required power, while energy requirements were decreased.
- The system productivity (6.2 ml), extraction efficiency (88.57%), essential oil yield (0.797 % (w/w)) and energy requirements (0.475 kW.h/ml) were in the optimum region under conditions of 1.5 l/h water flow rate and 700 g batch size.

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