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Performance Evaluation of a Newly Fabricated Steam Distillation Unit on Extracting Essential Oil from *Pogostomen heyneanus* Benth. (Lamiaceae)

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ABSTRACT

The study was conducted to evaluate the performance of a newly fabricated steam distillation unit on extracting essential oil from dried herbage of *Pogostemon heyneanus* in terms of particle size, layer arrangement, rounds of extraction and total water requirement for cooling the condenser. In thirty min intervals, the oil recovery and total water requirement for cooling the condenser were measured under three different particle sizes; less than 6 mm (T_1), in between 6 and 12 mm (T_2) and larger than 12 mm (T_3) with two different layer arrangements in the extraction vessel; single and double layer arrangements until the total oil extract reached to an equilibrium. With the single layer arrangement, T_3 recorded the maximum oil recovery of 8.5 mL/kg of dry leaves followed by T_1 and T_2. In the single layer arrangement, T_1 recovered 84.8% of the oil out of total yield during the first extraction. Similarly, in the double layer arrangement T_3 recorded the maximum oil recovery of 9.2 mL/kg of dry leaves and it was followed by T_2 and T_1. With the single layer particle arrangement, the highest water requirement for cooling was found in T_3 where the lowest in T_2. In terms of oil recovery, among the selected particle sizes, the particles of dried herbage as *Pogostemon heyneanus* larger than 12 mm could be selected as the best for the distillation unit. In terms of cost effectiveness, the particles smaller than 6 mm could also be recommended.

KEYWORDS: Condenser cooling, Extraction vessel, Oil recovery, *Pogostemon heyneanus*, Steam distillation

INTRODUCTION

Pogostemon heyneanus Benth. (Lamiaceae) is a large, struggling under shrub found from Western to Southern parts in India and commercially grown to extract Patchouli oil. Patchouli oil extraction is still new for Sri Lanka but has gained large market demand for the benefits on therapeutic and healing properties of this essential oil.

Essential oils can be manufactured using different methods. Distillation (steam distillation, hydrodistillation), carbon dioxide extraction, cold pressing and solvent extraction are the methods used in the production of essential oils (Kebede and Haylon, 2008). Among these methods, steam distillation is popular in extracting essential oil from aromatic plants because of its low technical sophistication and infrastructure requirement (Murugana *et al.*, 2010). Due to the same reason, steam distillation could be selected as one of the best options in patchouli oil extraction (Singh *et al.*, 2002). The studies revealed that the steam distillation could extract fraction of patchouli oil ranging between 1.5% and 3% (Doneliana *et al.*, 2009).

Steam distillation of essential oil is relatively uncomplicated. It can be done in rural areas, where the raw materials are extensively produced. Both the technology and the skills required are not sophisticated. The investment required are also relatively low. As a source of energy in distillation, different materials like fuel wood or fuel oil which are readily available in rural areas can be used.

The main problem of hindering the potential of crop development of *P. heyneanus* in Sri Lanka is the unavailability of technology which matches with the socio-economic level of local small and medium scale farmers. Currently, the Department of Plantation Management of Faculty of Agriculture and Plantation Management of Wayamba University, Sri Lanka has developed a prototype steam distillation unit for extracting essential oil from *P. heyneanus*. However, its performance is yet to be studied in detail.

Accordingly, the study was conducted to evaluate the performance of the newly fabricated steam distillation unit on extracting essential oil from dried herbage of *P. heyneanus* under different particle sizes and layer arrangements in the extraction vessel.

MATERIALS AND METHODS

Experimental Location

The study was carried out at the Department of Plantation Management, Faculty of Agriculture and Plantation Management, Wayamba University of Sri Lanka, Makandura, Gonawila (NWP) from January to April 2016.

Steam Distillation Unit

The distillation unit mainly consisted of main components; boiler, extraction vessel, condenser and collector. The boiler had a capacity of 25 L and it was heated using a gas burner. The extraction vessel was made of stainless steel with the maximum capacity of 33 L and with a rack inside it. The condenser was an aluminum tube of 12 mm and 10 m in diameter and length respectively. The length of the spiral was 75 cm and it was dipped in a 200 L water tank. At the bottom and top of the tank, water inlet and outlet were fixed by facilitating the removal of heated water from the tank to maintain cool water inside it. One end of the condenser tube was connected with the extraction vessel while the other was opened to the collector.

Material Preparation

Freshly harvested *P. heyneanus* herbage was collected from experimental plots and dried in the shade until the sample moisture content was reduced to less than 15%. Then using slow speed mechanical chopper, the dried herbage was ground. By sieving using standard meshes, the ground herbage was divided into three particle sizes; less than 6 mm (T_1), in between 6 and 12 mm (T_2) and larger than 12 mm (T_3).

Table 1. Tested particle sizes

Treatment	Particle Size
T_1	Particles less than 6 mm
T_2	Particles in between 6 mm and 12 mm
T_3	Particles larger than 12 mm

Distillation Study

In 30 min intervals, the oil recovery and total water requirement for cooling the condenser were measured under the three different particle sizes (less than 6 mm, in between 6 and 12 mm and larger than 12 mm) with two different layer arrangements in the extraction vessel (single and double layer arrangements) until the total oil extract reached to an equilibrium. In each trial, the pressure and temperature were maintained at 0.5±0.07 kg/cm^{-3} and 100±5 °C respectively. Then the contents of the vessel were mixed and the second extraction was performed as done previously. In each trial, during first and second extractions oil recovery and total water requirement for cooling were plotted against the time, taken.

RESULTS AND DISCUSSION

Effect of Particle Size with Single Layer Arrangement on the Yield of Essential Oil of P. heyneanus

The effect of the size of particles during the first and second extractions under single layer arrangement on the yield of *P. heyneanus* is given in Figure 1. In each extraction, the different particle sizes had an increase in oil recovery with the time. During the first extraction with single layer arrangement, at the end of 90 min, the highest oil recovery (4 mL) was found in T_1 while the lowest (2.8 mL) in T_3. Similarly, during the next half of the study, T_1 recorded the highest total oil recovery of 6.7 mL. However, the pattern observed in T_2 and T_3 changed as T_3 eventually, recorded the second highest oil recovery of 5.5 mL in last 90 min of the first extraction by leaving the recovery of total oil (4.9 mL) in T_2 as the least.

In the second extraction of oil, which was done after completely mixing the expelled from the first extraction, the highest (3 mL) oil yield was recorded in T_3, followed by T_2 (2.8 mL) and the least (1.2 mL) in T_1. T_1, T_2 and T_3 reached their maximum oil recovery at 90, 120 and 120 min respectively. Finally, at the end of the first and second extractions under the single layer arrangement of particles within the vessel, the maximum total oil recovery of 8.5 mL was recorded by T_3. This was followed by T_2 (8.3 mL) and T_1 (7.9 mL).

The oil recovery during the first extraction, with single layer arrangement out of the total in T_1, T_2 and T_3 were 84.8, 66.3 and 64.7% respectively while in the second extraction it was 15.2, 33.7 and 35.3% respectively. It could be clearly observed that with the increase in particle size, the amount of oil recovered during the second extraction increased.

The trend in oil recovery observed during the extraction of different particle sizes with single layer arrangement could be explained in terms of the surface area of particles of *P. heyneanus* in which the larger particle sizes had more surface areas filled with the essential oil than the particles with small surface area. Therefore, the small particle sizes yield more oil at shorter distillation time but with prolonging time duration, the recovery rate of oil was decreased as most of the oil cells was exhausted. On the contrary, the larger particles yield lesser amounts of oil in the beginning of the distillation but had larger surfaces to continue to yield more oil with an increase in distillation time. This was with the agreement of the results of Kiriamiti *et al.* (2001) which explained that the changes of the mean particle size had an effect on the extraction yield.

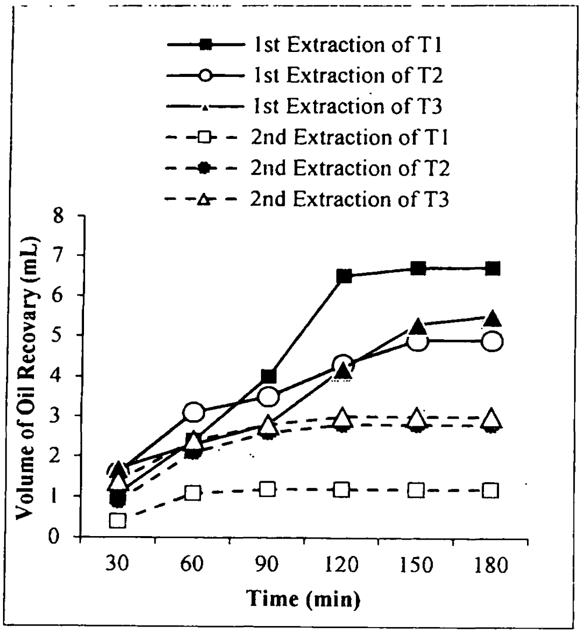

Figure 1. Oil yield of different particle sizes of *P. heyneanus* with single layer arrangement. *T_1- particle size less than 6 mm, T_2- particle size in between 6 mm and 12 mm, T_3- particle size larger than 12 mm*

Further, a similar trend in oil recovery with the particle size was also reported by Akhihiero *et al.* (2013) on the steam distillation of lemon grass.

Effect of Particle Size with Double Layer Arrangement on the Yield of Essential Oil of P. heyneanus

The effect of particle size during the first and second extractions under the double layer arrangement on the yield of *P. heyneanus* is given in Figure 2.

During the first extraction, the highest oil recovery (7.5 mL) was found in T_3. This was followed by T_2 (5 mL) and T_1 (4.6 mL). T_1, T_2 and T_3 reached to their maximum oil recovery at 120, 120 and 90 min respectively. In the second extraction, during the first 90 min of the study, the maximum oil yield (1.7 mL) was recorded by T_1. This was followed by T_3 (1.4 mL) and T_2 (0.5 mL). T_1, T_2 and T_3 reached their maximum oil recovery at 120, 120 and 150 min respectively during the second extraction.

As parallel with the single layer arrangement, T_3 showed the highest recovery of oil (9.2 mL) and when compared to single layer arrangement it was an 8.2% increase. The second highest and lowest oil yields were recorded in T_2 and T_1, respectively. However, with respect to single layer arrangement, T_2 and T_1 showed 30.1 and 20.3% reductions in oil recovery respectively.

With the double layer arrangement, 73, 86.2 and 79% of the total oil yield were recovered during the first extraction respectively in T_1, T_2 and T_3 while 27, 13.8 and 21% of oil recovered during the second extraction, respectively.

In double layer arrangement, the initial thickness of the particle column under each particle size was half as its single layer arrangement. The reduction in column thickness might have facilitated the formation of free channels along the leaf column especially with the particles less than 12 mm in size. Theses free channels may have reduced solid steam interface and thereby had resulted in a decrease in oil recovery when compared to the single layer arrangement.

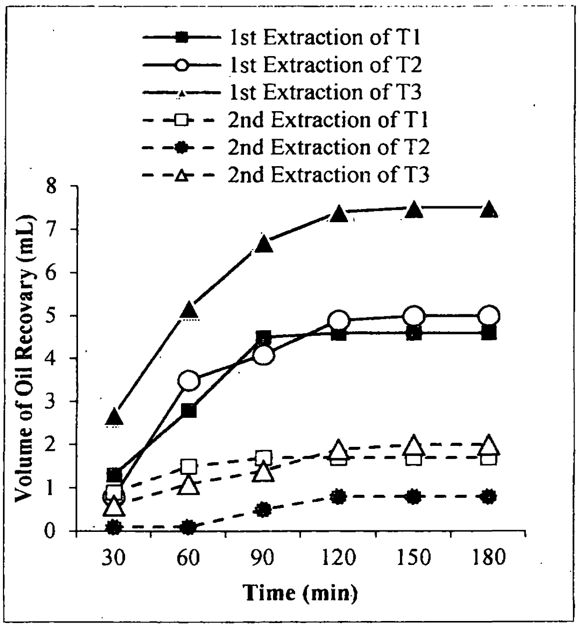

Figure 2. Oil yield of different particle sizes of *P. heyneanus* with double layer arrangement. *T_1- particle size less than 6 mm, T_2- particle size in between 6 mm and 12 mm, T_3- particle size larger than 12 mm*

However, due to reduced column thickness, the resistance against the steam flow in double layer arrangement was much lower than that of its single layer arrangement. This could facilitate better penetration of steam within double layer leaf columns into the places where the steam was unable to reach with the single layer arrangement. Further, this would be the reason in obtaining higher oil recovery in double layer arrangement of particles larger than 12 mm in size than the same size of particles with the single layer arrangement.

Effect of Particle Size with Single Layer Arrangement on Total Water Required in Cooling the Condenser

During the first extraction with the single layer particle arrangement, the highest water requirement for cooling (237.9 L) was found in T_3 while the lowest (187.5 L) was found in T_1

(Figure 3). It was observed that the amount of water required for cooling decreased with the particle size. The resistance against the steam flow could be much higher in smaller particles as they were densely packed within the extraction vessel when compared to that of the larger particles. This resistance may have reduced the rate of steam flow into the condenser tube resulting the lower amount of water for cooling the condenser tube in distilling particles with smaller in size.

During the second extraction with the single layer arrangement, T_1, T_2 and T_3 respectively recorded 16.1, 22.2 and 51.3% reduction in total water requirement for cooling with compared to the first extraction.

This was also due to the increase in density found in particles during the second extraction as they were exposed to continuous steam. The dense particles had created more resistance against the steam flow.

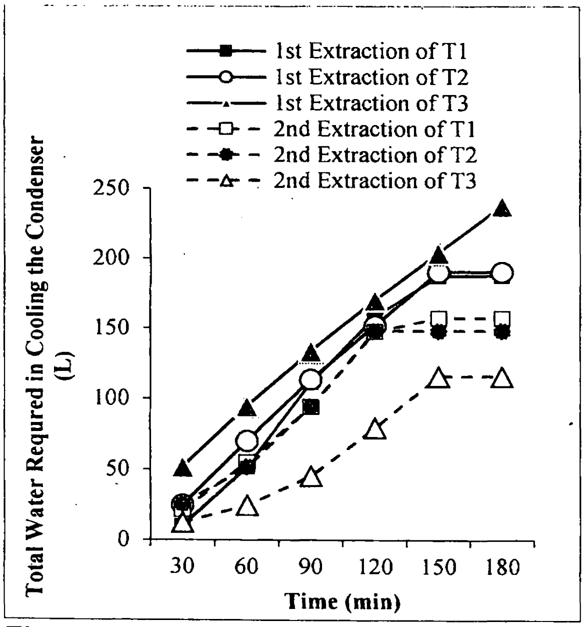

Figure 3. Total water required in cooling the condenser during distillation process under different particle sizes with single layer arrangement. *T_1- particle size less than 6 mm, T_2- particle size in between 6 mm and 12 mm, T_3- particle size larger than 12 mm*

Effect of Particle Size with Double Layer Arrangement on Total Water Required in Cooling the Condenser

In the first extraction of double layer particle arrangement, the highest water requirement for cooling (180.2 L) was found in T_2. This was followed by T_1 (176 L) and T3 (167.7 L; Figure 4). However, when compared to single layer arrangement, T_1, T_2 and T3 recorded 6.1, 5.5 and 26.6% reductions respectively in total water requirement for cooling.

In the second extraction with double layer arrangement, when compared to the first extraction in T_1 recorded 8.4% increase in total water requirement for cooling. This may be due to the formation of free channeling pathways as the column thickness was reduced with time in T_1. However, T_2 and T_3 respectively recorded 6.9 and 38.2% reductions in water requirements for cooling when compared to the first extraction of double layer arrangement.

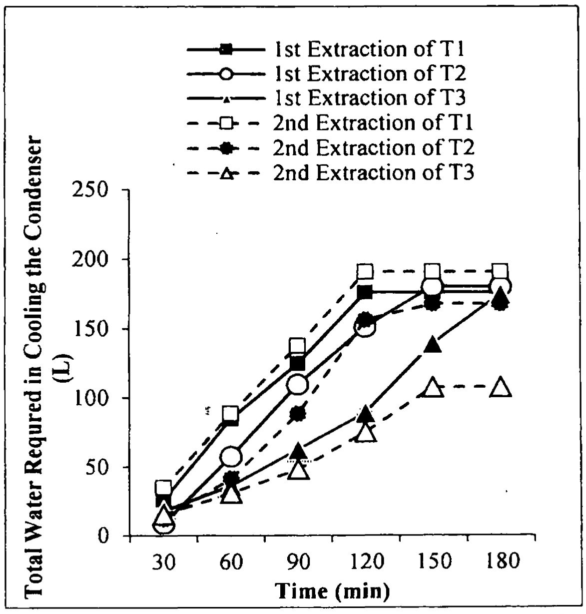

Figure 4. Total water required in cooling the condenser during distillation process under different particle sizes with double layer arrangement. *T_1- particle size less than 6 mm, T_2- particle size in between 6 mm and 12 mm, T_3- particle size larger than 12 mm*

CONCLUSIONS

Among the selected particle sizes with the single as well as double layer arrangements, the best performance of the steam distillation unit in terms of oil recovery of *P. heyneanus* was found with the particles larger than 12 mm. Based on the cost-effectiveness of the distillation process, the particles smaller than 6 mm could be partially recommended as it recovered more than 80% of oil within the shortest possible time and recorded the second lowest water consumption in single layer arrangement. However, further studies should be carried out with different capacities of leaf materials including more than two layers and even few sizes below 6 mm before firm recommendations.

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