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Distillation of tea-tree *(Melaleuca alternifolia)* oil. II. Comparison of different fuels for steam generation using a prototype distiller

[Penyulingan minyak tea-tree *(Melaleuca alternifolia)*. II. Perbandingan pelbagai bahan bakar untuk penjanaan wap dengan penyuling prototaip]

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Key words: tea-tree, steam distillation, liquefied petroleum gas, kerosene, diesel

Abstrak

Kajian ini dijalankan untuk mencari bahan bakar yang sesuai bagi penjanaan wap pada tekanan atmosfera dalam penyulingan wap minyak tea-tree. Penjana wap bagi penyuling prototaip dipanaskan dengan tiga jenis bahan bakar iaitu gas petroleum cecair (LPG), minyak tanah dan diesel. Perbandingan telah dibuat antara ketiga-tiga bahan bakar ini bagi hasil minyak, isipadu minyak yang terhasil pada 95% EVE, ketinggian sebenar penyuling, kadar aliran air, masa pengekstrakan yang diperhatikan dan dikira, masa pemanasan dan tempoh masa keseluruhan pengekstrakan. Hasil purata minyak bagi penyulingan dengan menggunakan minyak tanah dan diesel ialah 0.7% dan berbeza secara ketara dengan penyulingan yang menggunakan LPG iaitu 0.6%. Kadar purata aliran air dan tempoh purata masa keseluruhan pengekstrakan bagi penyulingan dengan diesel masing-masing 1 140.9 mL/min/m^2 dan 121.4 min. Nilai ini nyata berbeza dengan penyulingan yang menggunakan LPG iaitu masing-masing 739.7 mL/min/m^2 dan 151.7 min. Bagi penyulingan yang menggunakan minyak tanah pula, tempoh purata masa keseluruhan pengekstrakan sebanyak 145.5 min nyata berbeza dibandingkan dengan penyulingan yang menggunakan diesel. Hasil daripada kajian ini menunjukkan bahawa penggunaan diesel sebagai bahan bakar lebih baik daripada LPG dalam hubungan hasil minyak dan tempoh masa keselurahan pengekstrakan. Hasil daripada kajian ini juga menunjukkan bahawa penyulingan yang menggunakan diesel sebagai bahan bakar lebih baik daripada penyulingan yang menggunakan minyak tanah dari segi tempoh masa keselurahan pengekstrakan.

Abstract

This study was conducted to find out the appropriate fuel for steam generation at atmospheric pressure in the distillation of tea-tree oil. The evaporator of a prototype distiller was heated using three different fuels, i.e. liquefied petroleum gas (LPG), kerosene and diesel. A comparison was made between the fuels for parameters such as the oil yield, oil produced at 95% EVE, virtual height of distiller, water flow rate, observed and calculated extraction times, heating time and total extraction time. The mean oil yield for distillation using kerosene and diesel was 0.7% and significantly different compared with 0.6% for LPG. The mean water flow rate and the mean total extraction time for distillation using

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diesel were 1 140.9 mL/min/m^2 and 121.4 min respectively and significantly different from that of LPG which were at 739.7 mL/min/m^2 and 145.5 min. The mean total extraction time for distillation using kerosene was 151.7 min and significantly different from that of diesel. These results indicated that the use of diesel as fuel for steam generation in the steam distillation of tea-tree oil was better than that of LPG in terms of oil yield and total extraction time. The results also showed that distillation using diesel as fuel was better than that of kerosene in terms of total extraction time.

Introduction

Developing the most effective method to extract an essential oil efficiently from a plant will require knowledge of the cellular structure of the plant, composition of the essential oil, and distillation theory and practice (Hunter 1994). Repeated changes in the methods used and many modifications of the extraction equipment to perfect the optimal extraction processes for the plant concerned are often required. Basically, there are three types of commercial distillation of essential oils, i.e. water distillation, water-steam distillation and steam distillation (Guenther 1972). Steam distillation of tea-tree oil was found to be better than water-steam distillation (Ahmad et al. 1998) and the results also showed that the use of fairly dry steam could minimise losses of oil through run-off and hydrophilic effects.

This study aimed to investigate the use of different fuels to generate steam from an evaporator at atmospheric pressure and to observe the effects of these fuels on the distillation of tea-tree oil.

Materials and methods

The prototype distiller 2 (P2) which is a steam distillation type (Ahmad et al. 1998) was used in this study. This distiller was equipped with an evaporator and the steam generated at atmospheric pressure was directed into the distillation pot of P2 through an inlet steam manifold. The evaporator of P2 was heated using liquefied petroleum gas (LPG), kerosene or diesel. Two high pressure stoves located at the bottom of the evaporator were used. An oil burner (Model K10KL, Bentone, Switzerland) was used to accommodate the diesel and kerosene fuels.

Preparation of charge material for distillation

Tea-tree from the experimental plot in Beseri, Perlis was harvested, weighed and transported to the distillery. The tea-tree was then passed through a chipping machine to reduce the leaves, twigs and branches into smaller pieces and transferred into the distillation pot of P2. Four distillation runs were made for each fuel type.

Measurement of parameters during distillation

The heating time of P2 was recorded and this was the period from the first admission of the steam into the distillation pot until the point when the steam passed through the top of the charge and the distillate could be taken as flowing steadily at the intended flow rate. The bucket experiment (Denny 1990) was followed where exact 1-min fractions of the distillate were taken at precise intervals of 5 min throughout the whole distillation using a 1-L measuring cylinder. The volumes of water and oil were measured. The volumes of water and oil were estimated for the period between measurements by using the mean volumes of water and oil in the elapsed time. The total volume of oil produced by distillation was also recorded to obtain the correction factor between the calculated and actual volume of oil collected. The distillation run was 120 min.

The distillation data recorded were used to plot the oil produced against distillation run time and oil produced against the water passed. The curves obtained were used to indicate the asymptotic values on the distillation run time or water passed axis at the estimated virtual exhaustion (EVE) oil content. The value at 95% EVE from these plots was used to derive the observed extraction time and the actual water flow rate since 95% EVE is regarded as the commercial end-point for tea-tree oil distillation (Denny 1990).

Statistical analysis

The data such as oil produced at 95% EVE, virtual height, oil yield, observed and calculated extraction time, heating time, total extraction time, error percent, water flow rate, lag factor and $Y^{2/3}$ were subjected to statistical analysis using analysis of variance as outlined in the SAS system (SAS Institute Inc. 1985).

Results and discussion

The plot of the mean volume of oil produced against the distillation run time for LPG, kerosene and diesel as fuels for steam generation is shown in *Figure 1.* All curves showed linear trends for the first 20 min and then became curvilinear as the oil content of the distillate declined in the latter part of the distillation run, i.e. the curves became asymptotic with the distillation run time axis at the EVE oil content. The standard error for the diesel and LPG curves overlapped for the first 18 min and showed a significant difference in the latter part of the distillation run. These plots indicated that the overall distillation of tea-tree oil using diesel and LPG as fuels for steam generation was not similar in both the volume of oil produced at 95% EVE and the extraction time. The kerosene curve superimposed the diesel curve up to 42 min of the distillation run time and then became curvilinear with a lower gradient at the latter part of the distillation run. The standard error calculated for the kerosene curve (not shown in *Figure 1*) overlapped the diesel and LPG curves. Thus, the kerosene curve was much closer towards the diesel curve than the LPG curve.

Values of various parameters *(Table 1* and *Table 2)* were obtained from the study based on the basic parameters and standard conditions for the distillation of tea-tree oil *(Table 3)*. The mean oil yield, mean oil produced at 95% EVE and mean virtual height of distillation using kerosene and diesel were significantly different from distillation using LPG. The oil yields for distillation using kerosene and diesel were higher (0.7%) and significantly different compared with distillation using LPG (0.6%). This showed that distillation using kerosene and diesel was better than LPG in terms of oil yield. The oil yields obtained by distillation using kerosene and diesel could be categorised as medium and that of LPG as low (Colton and Murtagh 1990).

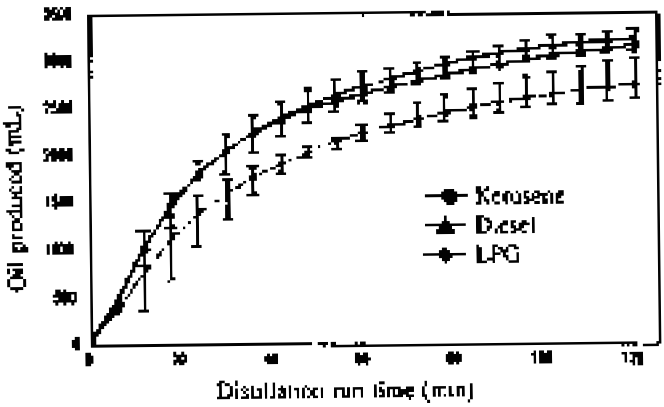

Figure 1. The mean oil produced against the distillation run time using three fuels for steam generation. Values are means of four replicates ± standard error (for diesel and LPG only)

Table 1. Oil yield, oil produced at 95% EVE, virtual height, extraction time and heating time of tea-tree oil distilled using three types of fuel

Fuel type	Oil yield (%)	Oil produced at 95% EVE (mL)	Virtual height (cm)	Extraction time (min)		Heating time (min)
				Observed	Calculated	
LPG	0.6b	2 669.4b	92.3b	99.0a	89.0a	52.7a
Kerosene	0.7a	3 105.3a	107.5a	92.2ab	89.2a	53.3a
Diesel	0.7a	3 124.3a	108.1a	89.4b	82.0a	32.0b

Mean values with the same letter(s) within a column are not significantly different according to LSD ($\alpha = 0.05$)

Table 2. Total extraction time, water flow rate, lag factor and $Y^{2/3}$ of tea-tree oil distilled using three types of fuel

Fuel type	Total extraction time (min)	Error (%)	Water flow rate ($mL/min/m^2$)	Lag factor	$Y^{2/3}$
LPG	151.7a	–9.3a	739.7b	0.9737a	1.0672b
Kerosene	145.5a	–3.3a	875.9b	0.9269a	1.1942b
Diesel	121.4b	–9.1a	1 140.9a	0.8494b	1.4215a

Mean values with the same letter(s) within a column are not significantly different according to LSD ($\alpha = 0.05$)

Table 3. Basic parameters and standard conditions for distillation of tea-tree oil

Parameter	Value at 95% EVE
Pressure	1 atmosphere
Basic time	53.0 min
Increment parameter/ charge height	0.4247 min/cm
Standard water flow rate	671 $mL/min/m^2$
Standard oil content	36.78 $mL/cm/m^2$

Source: Ahmad et al. (1998)

The virtual height was computed using the standard oil content as shown in *Table 3*. This meant that the virtual height was dependent on the volume of oil produced. Results of this study showed that the mean virtual height in distillation using kerosene and diesel was significantly different from that using LPG. It was expected that the lower mean virtual height for distillation using LPG would give a faster evaporation rate of oil than distillation using kerosene and diesel. This was based on the fact that the evaporation rate of the oil is directly proportional to the magnitude of the temperature gradient leading heat from the general vapour to the point of vaporisation on the herb surface (Denny 1990). This did not happen probably due to tea-tree oil being a fairly volatile subcutaneous oil and the temperature gradient at atmospheric pressure is already relatively large (Denny 1990). This meant that the effect of using different fuels to heat up the evaporator to produce fairly dry steam at atmospheric pressure did not have any significant change in the temperature gradient.

It is recognised that the recovery of subcutaneous oils can be speeded up by faster flow of steam (Denny 1990). This suggests that, under any given flow of steam, there is a corresponding quantity of oil on the herb surface causing a surface concentration which sets an orderly limit to the rate of oil diffusion. Faster flow of steam will remove this oil more quickly, thereby reducing its surface concentration. Diffusion from within the herb to its surface will accelerate accordingly since the oil's concentration on the herb surface is reduced. Results of the study showed that the mean water (steam) flow rate for distillation using diesel was significantly different and higher compared with distillation using LPG and kerosene. The higher mean water flow rate resulted in a higher factor of increase in the rate of steam flow (Y) for distillation using diesel as fuel. The mean value of $Y^{2/3}$ for distillation using diesel was significantly different from that of kerosene and LPG *(Table 2)*. These results indicated that the mean factor of increase in oil diffusion from within the herb to its surface for distillation using diesel was higher than that of distillation using LPG and kerosene resulting from higher flows of steam.

In practice, it is also recognised that there must always be a lag factor for the forces resisting oil diffusion. This is given by Denny's equation (1990):

$Z = R.Y^{2/3}$

where Z = factor of change in speed of oil recovery per unit time (which is also similar to the factor of increase in oil diffusion from within the herb to its surface per unit time)

Y = factor of change in speed of steam over the herb surface

R = lag factor for the forces resisting diffusion

The lag factors (R) were obtained from *Figure 2* for the respective factors of change in speed of steam over the herb surface (Y) for all distillation reported. It was observed that the mean lag factor (R) for distillation using diesel was significantly different from distillations using LPG and kerosene as shown in *Table 2*. The results indicated that the amount of resistance increased and the numerical value of R declined when using any faster rate of steam flow.

The mean observed extraction time for distillation using diesel was significantly different from distillation using LPG *(Table 1)*. A shorter mean observed extraction time for distillation using diesel was obtained compared with distillation using LPG. This was consistent with the higher mean water flow rate in distillation using diesel and a lower mean water flow rate for distillation using LPG. The higher mean water flow rate had sped up the oil recovery for distillation using diesel as fuel. The mean observed extraction times for all distillations were also comparable wth that observed by Australian distillers of tea-tree oil (Colton and Murtagh 1990). The mean calculated extraction times for all distillation in this study were not significantly different. The mean percentage error (the percentage difference between the mean calculated extraction time and the observed extraction time) between the fuel types was also not significantly different. The magnitude of the mean percentage error was considered small (range 3.3–9.3%) and the distillation could be regarded as acceptable within the experimental limits.

The mean heating time for distillation using diesel was 32.0 min, much shorter and significantly different compared with distillation using LPG (52.7 min) and kerosene (53.3 min). The shorter mean

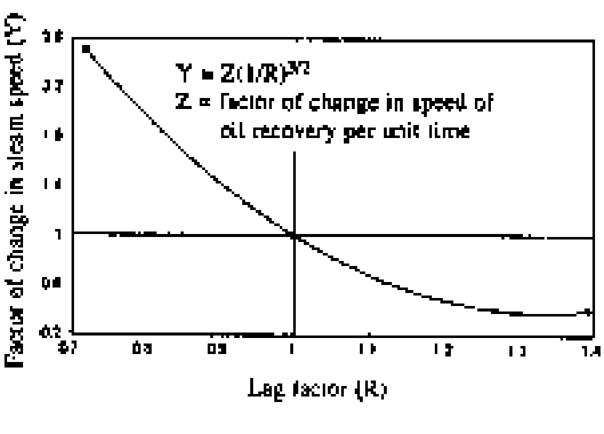

Figure 2. Empirical relation between lag factor and factor of change in steam speed for tea-tree oil (Ahmad et al. 1998)

observed extraction time and mean heating time resulted in a shorter mean total extraction time (observed extraction time + heating time) for distillation using diesel (121.4 min) and was significantly different compared with distillation using LPG (151.7 min) and kerosene (145.5 min). This is desirable as a shorter mean total extraction time is related to lower fuel cost.

Conclusion

The distillation of tea-tree oil using a prototype distiller 2 (P2) equipped with a separate evaporator which was heated using diesel and kerosene as fuel gave higher oil yields than that of LPG. Distillation using diesel as fuel gave a higher mean steam flow rate causing an increase in oil diffusion per unit time from within the herb to the herb surface. This resulted in a shorter observed extraction time in distillation using diesel as fuel. The mean total extraction time for distillation using diesel as fuel was shorter than that of LPG and kerosene.

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