

## KINETICS OF EXTRACTION OF ESSENTIAL OIL OF *EUCALYPTUS TERETICORNIS* LEAF USING STEAM DISTILLATION

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### ABSTRACT

*Kinetics of extraction of Eucalyptus tereticornis oil was reported in this paper. The kinetics was found to be adequately described by a 3-parameter model. Fit-statistics such as coefficient of determination R<sup>2</sup>, root mean square error (RMSE), and sum of square error (SSE) indicated appropriateness of the equation. Trend of effective diffusivity with rate of steam was also investigated using a model based on Fick's second law of diffusion. Parity plot of the oil yield from the model and the experimental data indicated closeness of the two yields. The diffusivity was found to increase with increasing steam rate, the relationship fitted a polynomial model with R<sup>2</sup> = 0.986. Values obtained for the diffusivity D were 6.2898 x 10<sup>6</sup> m<sup>2</sup>/s, 9.0733 x 10<sup>6</sup> m<sup>2</sup>/s and 9.7498 x 10<sup>6</sup> m<sup>2</sup>/s for steam rate of 0.03 kg/h, 0.11 kg/h, and 0.22 kg/h respectively. These differ in terms of order of magnitude from those reported in literature (10<sup>11</sup>) for some aromatic plant materials.*

**KEYWORDS:** Kinetics model, *Eucalyptus tereticornis*, Steam distillation, Diffusivity

### INTRODUCTION

Essential oils are the odoriferous constituents of plants. They occur in various sites of the plant anatomy and in some cases are found throughout the plant organs and in other cases are restricted to specific sites (Wijesekera 1983). Plant species of the genus *Eucalyptus* (family *Myrtaceae*) are much studied for their essential oil contents. There are approximately 700 species worldwide and only about 1% are used for industrial purposes (Zhang et al., 2010). The uses of *Eucalyptus* oils, mostly obtained from the leaves, are grouped as medicinal, industrial, aromatic and flavouring purposes, depending on their chemical composition (Isiaka et al., 2005). Kubatova et al., (2002) studied kinetic models for extraction of essential oil using hot water and supercritical carbon dioxide. Cassel and Vargas, (2006) modeled the extraction of *Cymbopogon winterianus* essential oil using a diffusion model, also Cassel, et al., (2009) applied the same mass transfer mathematical model, to predict the essential oil extraction process behaviour in three species of *Labiatae*: *Rosmarinus officinalis* L., *Ocimum basilicum* L., and *Lavandula dentate* L.

This paper is aimed at investigating extraction kinetics of essential oil of *E. tereticornis* and also applies a mass transfer model used by Cassel, et al., (2009) to investigate the dependence of the effective

diffusion parameter on steam rate in steam distillation of essential oil of *Eucalyptus tereticornis*.

### MATERIALS AND METHODS

The essential oil was extracted from dried leaves of *E. tereticornis* grown in Ahmadu Bello University Zaria, Nigeria (Latitude 11° 05' N, Longitude 7° 43' E). 200g dried eucalyptus leaves were steam distilled for 120 minutes using a Clevenger - type apparatus (Coffil et al., 2012; Khajeh, 2011). The kinetics of the extraction and other parameters of the steam distillation process were then evaluated using curve fitting software packages Microsoft Excel 2007 and DataFit 9.0. (Olawale, 2012).

The oil collected was dried using anhydrous magnesium sulphate (Kaur et al., 2011; Galadima and Salau, 2012) and stored at a temperature of < 10 °C in a refrigerator for analysis. GC-MS analyses of the oil were conducted using Shimadzu QP 2010 equipment (Cassel, et al., 2009; Babu, and Singh, 2009; and Pino et al., 2002). The steam distillation was modelled based on Fick's second law of diffusion in one dimensional unsteady - state process (Equation 1). The steam rate was determined by condensate collected per time. Rate of steam was varied and the diffusivity was evaluated in each case.

$$e(t) = \frac{m_A(t)}{m_A(\infty)} = \frac{\sum_{m=0}^{\infty} \frac{(1 - e^{-D \frac{\pi^2 (2m+1)^2}{x_{max}^2} t}}{(2m+1)^2}}{\sum_{m=0}^{\infty} \frac{1}{(2m+1)^2}} \quad (1)$$

Where:

$e(t)$  = extent of extraction,  $m_A(t)$  = mass of oil extracted at time  $t$ ,  $m_A(\infty)$  = mass of oil extracted at infinite time,  $D$  = effective diffusivity,  $x_{max}$  = plate thickness

**RESULTS AND DISCUSSION**

The time rates (kinetics) of steam distillation of essential oil of *E. tereticornis* were presented in Figures 1 - 3 for various steam rates. The oil yield increased with time significantly from 0 - 80 minutes extraction time. Beyond this time there was no significant increase in the yield as seen from the figures. Equation 2 was found to be the most appropriate kinetic model for the process.

$$y = t / (K_1 + K_2 t + K_3 \sqrt{t})$$

where:

$y$  = oil yield (wt %),  $t$  = time, and  $K_1$ ,  $K_2$ , and  $K_3$  are the kinetic parameters,  $K_1$  and  $K_3$  decreased with increased rate of steam but  $K_2$  increased. Kinetic parameter  $K_1$  is the most significant model parameter due to its numerical value; this was followed by  $K_2$  and then  $K_3$ . The fit-statistics indicated that the values of coefficient of determination ( $R^2$ ), root mean square error (RMSE) and sum of square error (SSE) obtained for the different rates of steam as presented in Table 1 indicated the appropriateness of the equations and their similarities. This implies that the model fitted the experimental data very well.

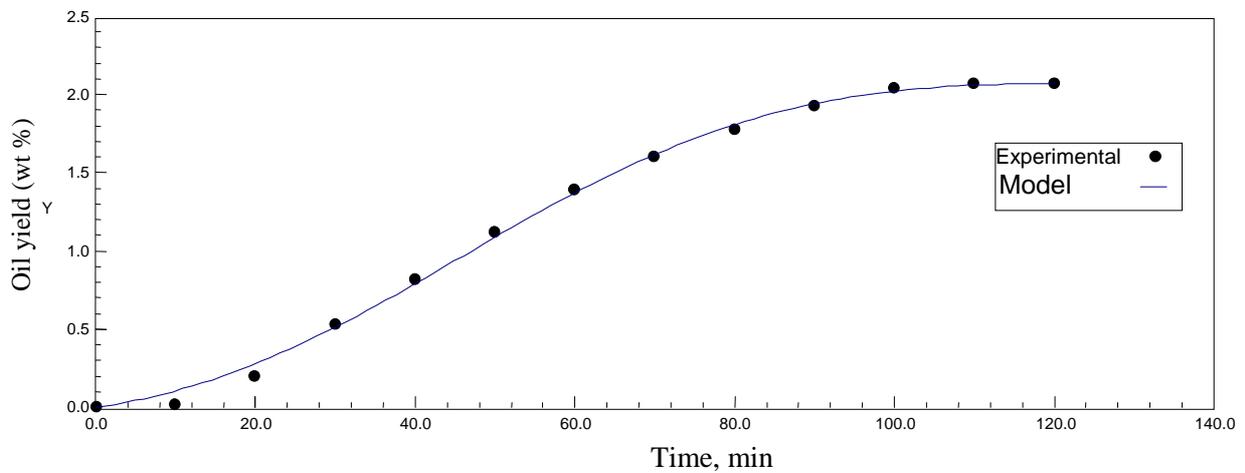


Figure 1: Validation of kinetic model in hydrodistillation of *E.tereticornis* oil (Steam rate = 0.03 kg/h)

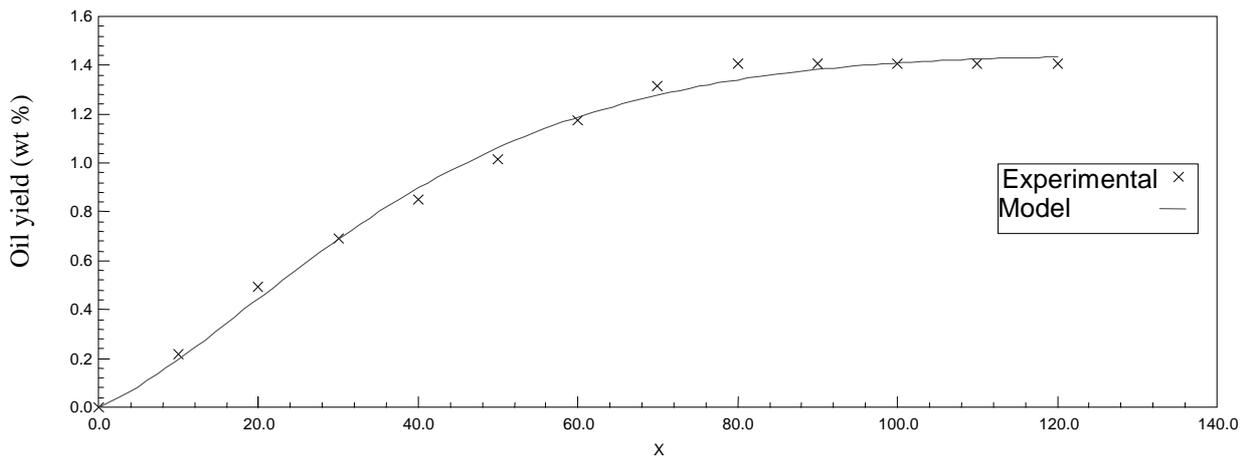


Figure 2: Validation of kinetic model in hydrodistillation of *E.tereticornis* oil (Steam rate = 0.11kg/h)

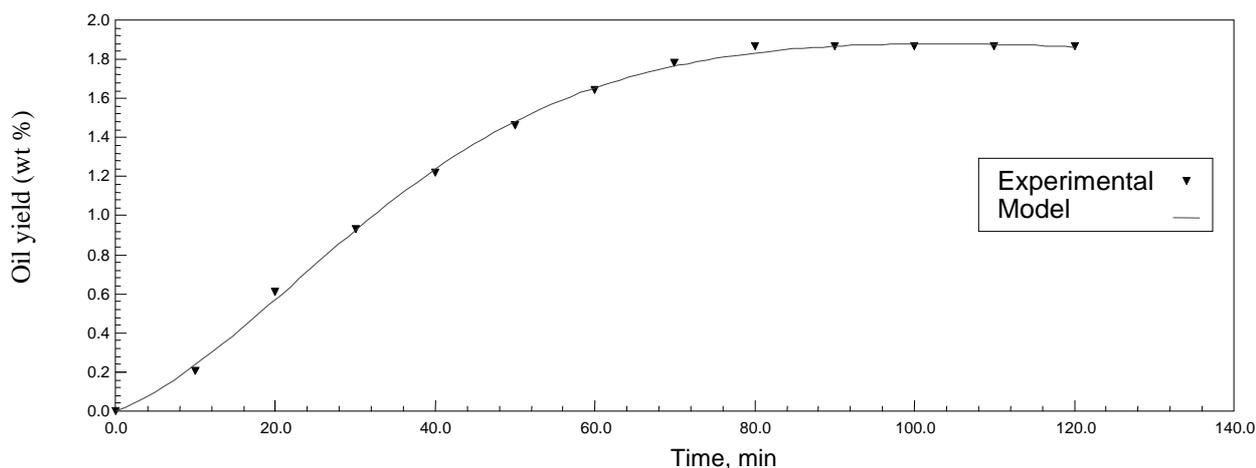


Figure 3: Validation of kinetic model in hydrodistillation of *E.tereticornis* oil (Steam rate = 0.22 kg/h)

Table 1: Kinetic model parameters for steam distillation of *E. tereticornis* oil

Steam rate (kg/s)	Parameters			Fit - statistics		
	K <sub>1</sub>	K <sub>2</sub>	K <sub>3</sub>	R <sup>2</sup>	RMSE	SSE
8 E-06	178.933	1.999	-32.939	0.997	0.00203	0.0203
3E-05	83.431	1.330	-14.555	0.995	0.00149	0.0149
6E-05	77.972	1.292	-15.393	0.999	0.00049	0.0049

Values obtained for the diffusivity  $D$  were  $6.2898 \times 10^{-6} \text{ m}^2/\text{s}$ , and  $9.7498 \times 10^{-6} \text{ m}^2/\text{s}$  for steam rate of  $8 \times 10^{-6} \text{ kg/s}$ , and  $8 \times 10^{-5} \text{ kg/s}$  respectively. Variation of the diffusivity with the steam rate was modelled and found to fit experimental data (Figure 4).

$$D = 1.66 \times 10^3 x^2 - 4.2 \times 10^{-2} x + 7.27 \times 10^{-6} \quad (2)$$

Where:  $D = \text{diffusivity (m}^2/\text{s)}$  and  $x = \text{steam rate (kg/s)}$

The diffusivities obtained for *E. tereticornis* oil are of the order of  $10^{-6} \text{ m}^2/\text{s}$  while, those reported by Cassel *et al.*, (2009) are of order of magnitude of  $10^{-11} \text{ m}^2/\text{s}$  for rosemary, basil, and lavender oils. The diffusivity of *E. tereticornis* oil in this study was also found to increase with increasing steam rate. This may be attributed to the increase in turbulence flow due to the presence of eddy diffusivity (Coulson *et al.*, 1999). Figure 5 presents parity plot of the oil yield obtained from

diffusion model (Equation 1) and that of experimental data for various steam rates. It can be seen from the figure that the data points are relatively close to the straight line. This indicated that the oil yield from the model and the experimental data differed slightly. GC-MS analysis (Table 1) indicates that there were 6 constituents of the oil and 1,8-Cineole was the major component 72.15 %; this classified the oil as pharmaceutical grade.

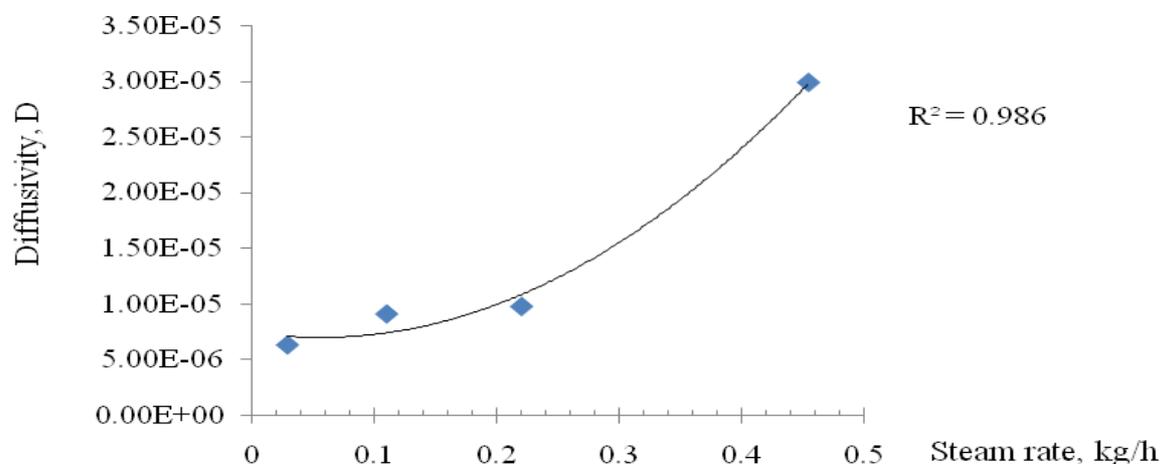


Figure 4: Trend of the effective diffusivity with steam rate in steam distillation of essential oil of *E. tereticornis*

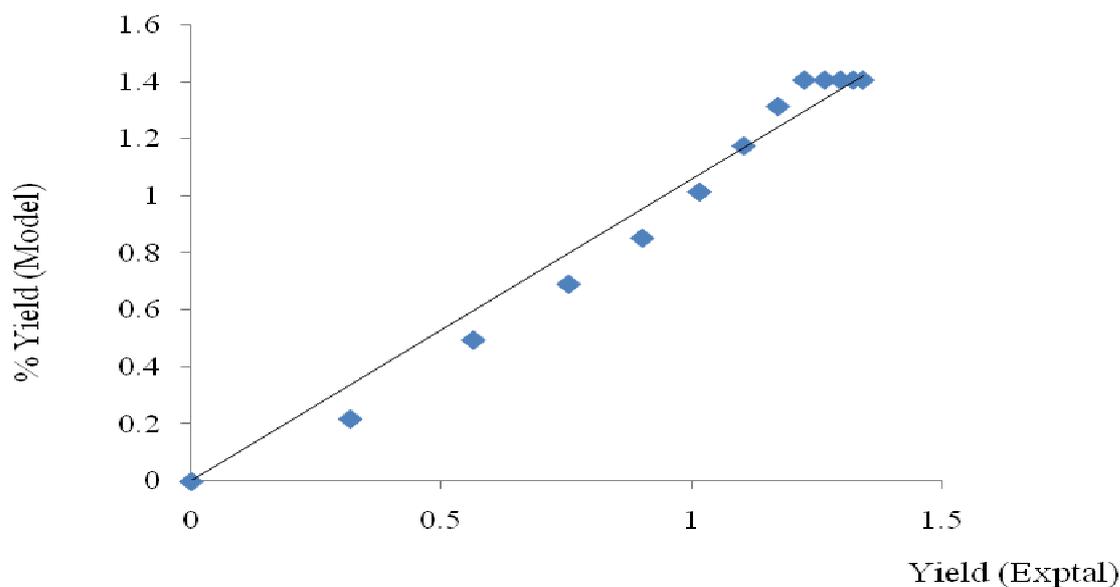


Figure 5: Parity plot of yield from the diffusion model and the experimental data in steam distillation of Eucalyptus oil (Steam rate 6E-05 kg/s)

Table 2: GC-MS results of essential oil of *E. tereticornis*.

Compound	R. Time (min)	Percentage
$\alpha$ -Pinene	6.781	21.13
$\beta$ -Pinene	7.485	2.52
1,8-Cineole	8.631	74.15
p-menth-1-en-8-ol	9.322	0.70
Fenchol	10.132	0.80
Borneol	11.075	2.70

## CONCLUSIONS

The kinetics of extraction of *E. tereticornis* oil in steam distillation was found to be adequately described by a 3- parameter model ( $K_1$ ,  $K_2$ , and  $K_3$ ). The parameters  $K_1$ , and  $K_2$  were found to increase with increasing steam rate, while opposite trend was observed with the third parameter ( $K_3$ ). Effective diffusivity,  $D$  was also

found to increase with increasing steam rate; this gives more insight into the mechanism of steam distillation of *Eucalyptus tereticornis* oil.

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