Optimization and modeling of extraction of solid coconut waste oil

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A R T I C L E I N F O

Article history:
Received 27 February 2012
Received in revised form 22 August 2012
Accepted 23 August 2012
Available online 31 August 2012

Keywords:
Coconut waste
Optimization
Mass transfer
Batch extraction
Soxhlet extraction

A B S T R A C T

Solid coconut waste was produced after coconut milk extraction process and may still contain up to 24 wt.% oil content. In this work, extraction of oil from coconut waste using batch and soxhlet extractor was studied. Effect of particle size diameter, type of solvent and solvent to solid ratio on the kinetic and thermodynamic parameters; entropy, enthalpy and free energy of extraction were investigated. The maximum oil yields for soxhlet and batch reactor were 23.6% at 80 °C and 21.9% at 65 °C, respectively for particle size diameter <0.5 mm when hexane was used as solvent. The kinetic of coconut waste oil extraction was found to be a first order mass transfer model. The ΔG, ΔS and ΔH values were 10.94–13.35 kJ/mol, 33.10–39.57 J/(mol K) and 0.12–1.25 kJ/mol, respectively shows that the extraction process was spontaneous, irreversible and endothermic based on thermodynamic parameters.

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1. Introduction

Coconut milk is extracted and the flesh is grated before being pressed to produce milk. The byproduct of this process is coconut waste. In Malaysia, both coconut oil and milk industry produces 78,000 metric tons of solid coconut waste in 2010 and normally used as fertilizer, biomass or to feed the animals or left to decay on the fields (MARDI, 2010; Poarch, 2007; Vetayasuporn, 2007). Furthermore, coconut is abundant in Malaysia and the area of coconut plantation is around 115,000 hectares in 2010 (MARDI, 2010). Vetayasuporn, 2007 reported that coconut waste is widely used as feed for milking cows, pigs and poultry (Epa, 2012; Vetayasuporn, 2007). Coconut waste is also used as coconut flour, biomass; firewood or cooking fuel and this is not a good option as at the world market, coconut oil is sold at a higher price (Guarte et al., 1996; Poarch, 2007). The oil obtained from coconut waste can be used as edible oil or for other purposes such as biodiesel production.

Waste can be extracted either by mechanical pressing or with solid liquid extraction using solvent (Amin et al., 2010; Sriti et al., 2011). Extraction using solvent gives a higher yield and less turbid oil (Amin et al., 2010; Liauw et al., 2008). Hexane and petroleum ether are used extensively as the solvent in the oil extraction from salmon skin, jatropha seed and neem (Aryee and Simpson, 2008; Liauw et al., 2009; Sayyar et al., 2009). There are many researchers who studied the kinetic model of the oil extraction (Amarini and Kadi, 2010; Kumoro and Hassan, 2006; Liauw et al., 2008; Meziane et al., 2006; Meziane and Kadi, 2008; Perez et al., 2011; Sayyar et al., 2009; Topallar, 2000). Kinetic study of solid liquid extraction depends on the nature of the oil and solvent, temperature of the process, particle size of the meal, reaction time and the ratio of the solid to the solvent (Sayyar et al., 2009). Effect of solvent to solid ratio studies the maximum extractability of oil. Increasing the ratio no longer changes the extraction yield because particles have been almost extracted (Li et al., 2009).

Therefore, the objective of this paper was to study the oil extraction process from solid coconut waste using batch and soxhlet extractor. Effective solvent was chosen based on the yield, solubility of oil in solvent and density. This study also focuses on determination of the oil yield, effects of particle size, reaction time and temperature and solvent to solid. These optimum parameters were applied to a kinetic model based on mass transfer coefficient. Mass transfer within the particle was also calculated to determine that in oil extraction there is no internal diffusion limitation. Thermodynamic parameters which include entropy, enthalpy and Gibb Free Energy of extraction of oil were also determined.

2. Materials and methodology

Coconut waste was collected from a premise that produces coconut milk at Petaling Jaya, Malaysia. Analytical Grade n-hexane and petroleum ether were purchased from Merck (Malaysia), respectively.

2.1. Extraction of oil

The extraction process was conducted using soxhlet and batch extractors. The soxhlet and batch extractors’ setup includes 100 ml laboratory soxhlet and a 250 ml jacketed glass reactor. Mix-
ing and heating of the solvent was provided by a hot digital magnetic stirrer. Cold water circulation was controlled by water bath, RC (LAUDA). Solid coconut waste was weighted and experiment was conducted using batch and soxhlet extractor. Solid coconut waste was grinded for 10 min using a coffee grinder and separated with sieve plates.

Temperature for batch reactor was varied between 55 and 65 °C, which is below the boiling point of the hexane and for the soxhlet extractor; the temperature range was between 70 and 80 °C, above the boiling point of the solvent. Hexane and petroleum ether were used as solvents for both of the setup to separate the oil from the waste. The coconut waste was separated by sieving into three types of particle size, 0.5 mm and below and 0.7 mm and below and 1.2 mm and below to determine the optimum size and to obtain the highest oil yield. Solvent to solid mass of coconut waste were varied from 6:1 to 12:1. The extraction was conducted for 15, 30, 45 min and 1, 2, 3, 4 and 5 h. After the equilibrium was reached, the solvent was recovered using a distillation system. For batch extractor, the mixture was filtered using Buchi filter attached to vacuum pump to separate the coconut waste and solution which contains oil. Solvent was used to wash the meal for few times to obtain all the oil. The oil yield (oil content) of the coconut waste was calculated as below:

\[
\text{Oil yield} = \frac{\text{Oil collected (g)}}{\text{Mass of coconut waste (g)}} \times 100\%
\]  

(1)

Solubility measurement of oil in hexane was conducted in a closed jacketed reactor and the mixture was mixed continuously. The reactor was maintained at different temperature, controlled by a RC (LAUDA) water bath. After 30 min, an aliquot of supernatant solution was extracted into a sample bottle, weighed to obtain the solution withdrawn. After distillation and evaporation of solvent, the weight of oil was determined. Oil solubility in petroleum ether and hexane was measured.

Density measurement was carried out using DMA 4500 density/ specific gravity meter (Anton Paar, Austria). The adjustment of the density was measured three times using distilled water at temperatures 15, 20, 30 and 40 °C to obtain the mean values and the uncertainty was ±0.00001 g cm⁻³.

2.2. Kinetic model

Mass transfer kinetic model was used to represent the experiment data because of there is no reaction between the oil and the solvents, hexane and petroleum ether (Liauw et al., 2008). Assumption is made that the main mechanism which controls the rate of extraction of oil is mass transfer of oil from the waste (solid) to the solvent (liquid). This assumption is in accordance with other findings (Amin et al., 2010; Saxena et al., 2011). Mass transfer rate can be written as (Liauw et al., 2008):

\[
\frac{dW_A}{dt} = k \cdot A(C_A - C_s)
\]  

(2)

where \(dW_A/dt\), mass transfer rate of the coconut waste oil (g/s); \(C_A\) and \(C_s\), concentration of coconut waste oil in liquid (solvents) at time \(t\) (g/m³) and at equilibrium (g/m³), respectively; \(k\), mass transfer coefficient, m⁻¹ s⁻¹; \(A\), surface area for mass transfer process, m².

Since the extraction was conducted in a batch process and the volume was constant throughout the experiment, Eq. (2) can be written as:

\[
\frac{dW_A}{dt} = k \frac{A}{V} [W_{A_i} - W_A]
\]  

(3)

\[
\frac{dW_A}{dt} = k \cdot a \cdot [W_{A_i} - W_A]
\]  

(4)

where, \(k\), is volumetric mass transfer coefficient. To solve Eq. (4) by integration, following condition was used where the mass of coconut waste oil is zero in liquid (\(W_{A_i}\)) at the beginning of the extraction process. Considering this condition, integration of Eq. (4) resulted as:

\[
W_A = W_{A_i}[1 - \exp(-k \cdot a \cdot t)]
\]  

(5)

Rearranging Eq. (5) in terms of yield per mass of coconut waste, the kinetic model used in this study was:

\[
Y_A = Y_{A_i}[1 - \exp(-k \cdot a \cdot t)]
\]  

(6)

where, \(Y_A\) and \(Y_{A_i}\) is yield of coconut waste oil in liquid at time, \(t\), and \(k\)-a-volumetric mass transfer coefficient.

To determine the value of \(k\cdot a\) (s⁻¹), \(Y_A\) and \(Y_{A_i}\), a nonlinear least square method was used to calculate numerically. “Origin 8.5” Program was used to fit the data in order to obtain the mass transfer value and the yield of oil.

2.3. Mass transfer within the particle

The study of mass transfer within the particle was conducted to determine that extraction of oil using soxhlet extractor or batch reactor was not controlled or limited by the internal diffusion. Thiele modulus was used to investigate the mass transfer within the particle. To determine the value of Thiele modulus, effective diffusivity (\(D_{eff}\)), m² s⁻¹ was calculated. Fick's second law was used to determine effective diffusivity by assuming \(D_{eff}\) is constant with the \(Y\), yield at time, \(t\) and initial yield of the oil. Pinelo et al. (2006) calculated effective diffusivity using following equation (Pinelo et al., 2006):

\[
\ln Y = \ln \left(\frac{6}{\pi^2}ight) - \frac{\pi D_{eff} t}{r^2}
\]  

(7)

where, \(r\) is the radius of particles diameter (mm).

By using Eq. (4), a plot \(\ln Y\) versus time of experiment was plotted. The value of the slope was used to determine the effective diffusivity.

To determine the effect of mass transfer within the particle on the extraction of the oil, Thiele Modulus, \(\phi\) was calculated based on Giri and Sharma, 2000 equation (Giri and Sharma, 2000):

\[
\phi = \frac{D_p}{6} \left(\frac{K \rho_p}{D_{eff}}\right)^{0.5}
\]  

(8)

The value \(D_p\) represents the particle diameter, \(K\) is the extraction rate, s⁻¹, \(\rho_p\) is the density of the coconut waste. The system is assumed to have no internal mass transfer limitation if the Thiele Modulus is <2, and the system suffers from the internal mass transfer limitation if it is above 10 (Giri and Sharma, 2000).

2.4. Thermodynamic parameters

Thermodynamic parameters (\(\Delta H\), \(\Delta S\) and \(\Delta G\)) for the oil extraction of coconut waste using hexane and petroleum ether were estimated using following equation (Liauw et al., 2008):

\[
\ln K = -\frac{\Delta G}{R T} = -\frac{\Delta H}{R T} + \frac{\Delta S}{R}
\]  

(9)

\[
K = \frac{Y_t}{Y_u} = \frac{m_t}{m_s}
\]  

(10)

where \(K\) is equilibrium constant, \(Y_t, Y_u\) is the yield percent of oil at temperature \(T\). \(Y_t, Y_u\) is the percent unextracted oil in coconut waste, \(m_t\) is the amount of coconut waste oil in liquid at equilibrium temperature, \(m_s\) is the amount of coconut waste oil in solid at \(T\); \(C\) equilib-
rium temperature, $R$ is a gas constant, $\Delta H$, (kJ/mol) is enthalpy, $\Delta S$, (J/mol K) is entropy and $\Delta G$, (kJ/mol) is a free energy of extraction. The plot of $\ln K$ against $1/T$ is used to find the value of $\Delta H$ and $\Delta S$ from the slope and intercept, respectively.

3. Results and discussion

3.1. Characterization of coconut waste oil

Hexane was used as co-solvent throughout the oil extraction process. Hexane improves the mass transfer and diffusivity of oil with the seed if compared with other solvent such as methanol. Coconut waste oil is mainly composed of saturated short length fatty acid chains, 2.3% of C8:0, 30.7% of C12:0, 17.91% of C14:0, 17.69% of C16:0, 22.29% of C18:0 and unsaturated fatty acids, 6.10% and 3.01% of C18:1 and C18:2, respectively. The highest composition of methyl ester in the coconut waste oil is lauric acid and the acid value and density were 2.3226 mg/g KOH and 0.925 g/cm$^3$, respectively.

3.2. Solubility and density

Fig. 1 shows the solubility data of hexane and petroleum ether in solid coconut waste oil. Vegetable oil, hexane and petroleum ether were non polar and becomes easily miscible. Coconut oil was most soluble in the non polar solvent because contain high amount of lauric acid (Kanth Rao and Arnold, 1957). The composition of lauric acid in this study was 30.70%. Solid coconut waste oil was partially miscible in both the solvents, hexane and petroleum ether at temperature of 30 °C. Solubility increases about 10 to 30 w/w% for hexane and petroleum ether when the temperature of the oil increases (Bera et al., 2006; Franco et al., 2007; Wakelyn, 1997). The solubility of oil in hexane was high because of the strong solute–solvent interactions (Wakelyn, 1997).

Fig. 2 shows the measurement of density data as a function of temperature of coconut waste oil. The sample was measured three times and the uncertainty was ±0.00001 g cm$^{-3}$. The uncertainty of oil yield was ±0.01 wt%. For coconut waste oil extracted from hexane, the density decreases from 0.925 g/cm$^3$ to 0.907 g/cm$^3$ when the temperature increased from 15 to 40 °C. It is reported that the densities of vegetable oil decrease linearly when temperature increases because the molecules move apart as their kinetic energy increases (Rodenbush et al., 1999; Veny et al., 2009). This causes the volume to increase and the oil become less dense. The density of oil extracted from both the solvent, hexane and petroleum ether were almost similar with difference of 0.006 g/cm$^3$ at temperature 15 °C. Stanisavljević et al. (2007) reported that density of tobacco oil extracted using hexane and petroleum ether were 0.923 g/cm$^3$ and 0.9175 g/cm$^3$ respectively with 0.0055 g/cm$^3$ difference

3.3. Effect of solvent

Fig. 3 illustrates the oil extraction yield of hexane and petroleum ether at 80 °C and particle size of 0.5 mm. The oil yield using soxhlet extractor and hexane showed 1.3 % of oil is extracted if compared with petroleum ether under same conditions. Sayyar et al., 2009 reported that extraction of jatropha seed using n-hexane showed that the extraction yield was 1.3% more than petroleum ether under the same condition at (temperature of boiling point, 6:1 solvent to solid ratio) (Sayyar et al., 2009). However using batch extractor as shown in Fig. 3, the extraction yield using hexane was 0.9 % more than petroleum ether. Stanisavljević et al. (2007) also reported that the oil yield from the native Tobacco seeds were 3.1% and 2.9% by using hexane and petroleum ether, respectively. It shows hexane extracted 0.2% of oil more than petroleum ether. Mani et al. (2007) also reported that hexane extracted 1.3% of oil more than petroleum ether (Bassim et al., 2003; Kushwaha, 2010; Lawson et al., 2010; Mani et al., 2007; Nwabueze & Okocha, 2008; Zaher et al., 2002). Hexane is a non polar solvent and able to penetrate into matrix of a seed during extraction process. This is because they lack of O–H end which if not would interfere with the extraction process (Nwabueze & Okocha, 2008).

3.4. Effect of temperature and reaction time

Fig. 4a and b shows the effect of temperature and reaction time on extraction of oil. The oil yield increases from 19.7% to 21.9% and 21.3% to 23.6% at temperature 70 °C and 80 °C for batch extraction and soxhlet extraction respectively. The increase in temperature increases the oil yield during extraction process. This is because

![Fig. 1. Solubility of solid coconut waste oil in hexane and petroleum ether.](image1)

![Fig. 2. Density data of solid coconut waste oil in hexane and petroleum ether.](image2)

![Fig. 3. Effect of solvent on oil extraction process at 80 °C and particle size of 0.5 mm.](image3)
3.5. Effect of particle size

The rate of extraction increases with the decrease in the size of particle (Sirisompong et al., 2011). Fig. 5 shows the effect of particle size on oil extraction using soxhlet and batch extractors. Different particle size of coconut waste namely 0.5 mm and below; and 0.7 mm and below; and 1.2 mm and below were used to extract maximum amount of oil. From Fig. 5, oil yield using hexane and soxhlet extractor was 23.6%, 22.7% and 22.5% with particle size diameter of 0.5 mm, 0.7 mm and 1.2 mm and below, respectively. This shows that smaller particle size extracted more than 1.1% of oil if compared with the larger particles. The extraction yield for 0.7 and 1.2 mm size particles were relatively close to each other. These findings are in line with those found by Sirisompong et al. (2011). Sirisompong et al. (2011) found that the rate of extraction increases with the decrease in the size of particles during oil extraction from rambutan kernel.

Fig. 5 also shows that there was an increase of 0.9% in extraction of oil using batch extractor with hexane and smaller particle size. More oil was extracted from smaller particle size due to the bigger interfacial area of the solid. The shorter distance the solvent has to travel to extract the oil from the solid increases the pore diffusion between solid and solvent. The larger particle has a smaller contact surface area and is more resistant to solvent entrance and oil diffusion. Smaller amount of oil will be transferred from inside the larger particle to the surrounding solution (Sayyar et al., 2009). Sayyar et al. (2009) used three different particle sizes of jatropha seeds, 0.5 mm and below, 0.5–0.75 mm and 0.75 mm and above. It was concluded that the intermediate size particle, 0.5 to 0.75 mm produced the highest oil yield. 47.3% using hexane. This is because when particle was too small, below 0.5 mm, the agglomerations of the fine particles reduces the effective surface area available for the free flow of solvent to solid and prevent the interaction between solid and solvent (Sayyar et al., 2009).

3.6. Kinetic of oil extraction

Tables 1 and 2 shows the calculated values of the mass transfer coefficients using Eq. (3) and the yield of oil, for both soxhlet and batch extractor respectively at equilibrium at various temperatures, particle size diameter, type of solvent and solvent to solid ratio. Parameters of kinetic model, Y_m and k_a were estimated by non linear square fit from equation to experimental data using OriginLab 8.5. It is found that the mass transfer coefficients increase with the increase in the temperature of extraction. The k_a (s⁻¹) value varies from 0.89 to 1.43 for soxhlet extractor and from 1.23 to 2.06 for batch extraction. The plotted graph shows a linear relationship with R² values were above 0.9879 for soxhlet and batch extraction. Increasing the temperature causes the reaction time to be reduced as reaction occurs faster. The final concentration increases with temperature because of the effect of thermodynamic on the solubilization of oil inside the solid (Liauw et al., 2008). The k_a also increases around 23% when hexane was used when compared with petroleum ether and extraction occurs significantly. This proves that higher yield is achieved using hexane in the soxhlet extractor. This is in agreement with Giri and Sharma, 2000 that particle size and extracting and solubilising power of the solvent affects the mass transfer (Giri and Sharma, 2000). Table 3 shows the comparison value of mass transfer coefficient with previous work. In this study, the mass transfer coefficient obtained was $0.386 \times 10^{-3}$ s⁻¹ using particle size of 0.5 mm. Liauw et al.
Effect of mass transfer within the particle

Effect of mass transfer within the particle was studied to determine if the diffusion to the surface controls and solvent diffuses well into the particles. The following data was used in Eqs. (7 and 8) in order to calculate the Thiele Modulus, density of coconut waste: 2.413 g/cm³, effective diffusivity (D_{eff}) = 7.26 × 10⁻³ cm²/s, and average value of particle diameter, d_p = 0.5 mm.

Table 4 represents the Thiele Modulus calculate for the soxhlet extractor. However, overall both the system was not affected by the mass transfer within the particle. This shows that the process was not affected by the mass transfer diffusion limitation (Giri and Sharma, 2000). The reaction was surface reaction limited and decreases the internal mass transfer diffusion limitation (Giri and Sharma, 2000). The batch reactor shows a higher value of Thiele modulus if compared to the soxhlet extractor. However, overall both the system was not affected by the mass transfer within the particle. This was due to the small value of the Thiele modulus, which was <2. Gir and Sharma (2000) reported that the Thiele Modulus values of coal were 0.1057 and 0.016 for particle size of 0.1278 mm and 0.016 cm, respectively. This shows that the process was not affected by the internal mass transfer limitation.

3.7. Thermodynamic parameters

Tables 5 and 6 show the values of equilibrium constant and thermodynamic parameters for the oil extraction process of coconut waste. Fig. 6 shows the plot of lnK vs. 1/T which was used to determine the value of thermodynamic parameters. The values used respectively. The results shows that the Thiele modulus value decreases when smaller size particles were used (Scott, 2006). Small value of Thiele Modulus indicate surface reaction controls and the solvent diffuses well without reacting (Scott, 2006). The reaction was surface reaction limited and decreases the internal mass transfer diffusion limitation (Giri and Sharma, 2000). The batch reactor shows a higher value of Thiele modulus if compared to the soxhlet extractor. However, overall both the system was not affected by the mass transfer within the particle. This was due to the small value of the Thiele modulus, which was <2. Gir and Sharma (2000) reported that the Thiele Modulus values of coal were 0.1057 and 0.016 for particle size of 0.1278 mm and 0.016 cm, respectively. This shows that the process was not affected by the internal mass transfer limitation.

Table 1

<table>
<thead>
<tr>
<th>Parameters fitted for soxhlet extraction of coconut oil.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{T}{\text{(K)}}$</td>
</tr>
<tr>
<td>$\frac{Y_a}{\text{wt.%}}$</td>
</tr>
<tr>
<td>10:1 Solvent to solid ratio</td>
</tr>
<tr>
<td>343</td>
</tr>
<tr>
<td>348</td>
</tr>
<tr>
<td>353</td>
</tr>
</tbody>
</table>

Table 2

<table>
<thead>
<tr>
<th>Parameters fitted for batch extraction of coconut oil.</th>
</tr>
</thead>
<tbody>
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<td>$\frac{T}{\text{(K)}}$</td>
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<tr>
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3.6.1. Mass transfer within the particle

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Table 4 represents the Thiele Modulus calculate for the soxhlet and batch reactors at 10:1 hexane to solid ratio at temperature 70–80 °C and particle size of 1.2, 0.7 and 0.5 mm. Thiele Modulus ranges between 0.1645 to 0.4339, 0.2315 to 0.3211 and 0.3025 to 0.4310 when particle size of 0.5 mm, 0.7 mm and 1.2 mm were used respectively. The results shows that the Thiele modulus value decreases when smaller size particles were used (Scott, 2006). Small value of Thiele Modulus indicate surface reaction controls and the solvent diffuses well without reacting (Scott, 2006). The reaction was surface reaction limited and decreases the internal mass transfer diffusion limitation (Giri and Sharma, 2000). The batch reactor shows a higher value of Thiele modulus if compared to the soxhlet extractor. However, overall both the system was not affected by the mass transfer within the particle. This was due to the small value of the Thiele modulus, which was <2. Gir and Sharma (2000) reported that the Thiele Modulus values of coal were 0.1057 and 0.016 for particle size of 0.1278 mm and 0.016 cm, respectively. This shows that the process was not affected by the internal mass transfer limitation.

3.7. Thermodynamic parameters

Tables 5 and 6 show the values of equilibrium constant and thermodynamic parameters for the oil extraction process of coconut waste. Fig. 6 shows the plot of lnK vs. 1/T which was used to determine the value of thermodynamic parameters. The values
the enthalpy were in the range of 10.94–12.37 kJ/mol for soxhlet extractor and 12.01–13.35 kJ/mol for batch extractor using hexane. The value obtained was in the range (4–13.5 kJ/mol) obtained by other researches for extraction of melon, rubber seed and olive nut waste using hexane and petroleum ether with $R^2$ above 0.99. The rate of extraction increases by 1.9% for soxhlet extraction using hexane when the temperature (80 °C) and solvent to solid ratio (10:1) was increased. Increasing the temperature from 70 to 80 °C; increases the yield by 2.3% for soxhlet extractor. Solubility and density data showed hexane as a better solvent if compared with the petroleum ether with more 1.3% oil yield for soxhlet extractor. The mass transfer coefficients also increase with solvent to solid ratio and temperature by 0.1% and 0.2%, respectively. This study demonstrated that the mass transfer model showed good fit with the experimental data for the oil extraction of coco-

4. Conclusion

This study demonstrated that the mass transfer model showed good fit with the experimental data for the oil extraction of coco-

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**Table 4**

Thermodynamic parameters for batch extraction of coconut oil.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Batch extractor</th>
<th>Soxhlet extractor</th>
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</thead>
<tbody>
<tr>
<td>70 °C</td>
<td>0.3645</td>
<td>0.1645</td>
</tr>
<tr>
<td>75 °C</td>
<td>0.1850</td>
<td>0.0420</td>
</tr>
<tr>
<td>80 °C</td>
<td>0.1954</td>
<td>0.0264</td>
</tr>
</tbody>
</table>

**Table 5**

Thermodynamic parameters for soxhlet extraction of coconut oil.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Hexane – 10:1 solvent to solid ratio</th>
<th>Petroleum ether – 10:1 solvent to solid ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>343 K</td>
<td>1.14 10.94 35.1</td>
<td>1.26 11.19 33.31</td>
</tr>
<tr>
<td>348 K</td>
<td>1.59 1.28 1.29</td>
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</tr>
<tr>
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**Table 6**

Thermodynamic parameters for batch extraction of coconut oil.

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**Fig. 6.** Plot of $\ln K$ (equilibrium constant) vs. $1/T$ (temperature, °C) – particle size of 0.7 mm.
ele modulus value shows that the batch and soxhlet extraction were not affected by the mass transfer within the particle. The ΔΓ, ΔS and ΔH values were 10.94–13.35 kJ/mol, 33.10–39.57 J/ mol K and 0.12–1.25 kJ/mol, respectively proves that the extraction process was spontaneous, irreversible and endothermic, respectively. The maximum yields obtained from extraction of coconut waste oil with particle size diameter of 0.5 mm were 23.6% at 80 °C for soxhlet extractor and 21.9% at 65 °C for batch extractor.

References


