



Kinetic and Thermodynamic Analysis of Nigerian Ginger Oil via Soxhlet Method.

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ABSTRACT

Ginger oil is widely commercialized for use in the food and pharmaceutical industries, driving the need for cost-effective and time-efficient extraction methods. This study investigates the kinetic and thermodynamic of Nigeria ginger oil extraction using hexane as a solvent, aimed at identify the optimal extraction temperature and time that yield higher oil output compared to conventional low-yield methods. The extraction process was conducted at four different temperatures: 323K, 333K, 343K, and 353K. Fourier Transform Infrared Spectroscopy (FT-IR) was utilized to characterize the extracted oil. The results indicated that the highest oil yields were achieved at 343K and 353K, with increasing temperatures leading to enhanced extraction efficiency. FT-IR analysis revealed the presence of key functional groups in gingeroil, including alkanes, alkenes, alcohols, aldehydes, ketones, and phenols. The extraction process was best described by the pseudo-second-order kinetic model, with a correlation coefficient (R^2) exceeding 0.91. From Thermodynamic analysis, $E_a = 17.4498$ kJ/molK, the standard change in enthalpy (ΔH°) value 19.8791 kJ/mol the standard change in entropy (ΔS°) value were 1.3608×10^{-2} kJ/molK. The standard change in free Gibbs (ΔG°) value were 15.4839, 15.3478, 15.2118 and 15.9757 kJ/mol. It was discovered that the process were endothermic, high randomization (high entropy), and non-spontaneous.

KEYWORDS: Ginger, soxhlet extraction, hexane, kinetic and thermodynamic

Introduction

Ginger (*Zingiberofficinale*) is flowering plants which belong to the order Scitamineae and family Zingiberaceae. It is a tropical monocotyledonous and an herbaceous perennial plant which produces annual stems. *Zingiberofficinale* rhizome, consists of numerous short finger-like structures or branches, born horizontally near the surface of the soil. In southern Kaduna, two commercial varieties are commonly cultivated. The yellow ginger variety locally called "TafinGiwa" with a bold yellow rhizome flesh, is stout with short internodes and the black ginger variety locally called "YatsunBiri" with a dull-grey coloration rhizome. The yellow variety is more popular than the black variety apparently due to its high yielding capacity and pungency (Ahmed, 2018).



Figure 1; Ginger Rhizome

Ginger (*Zingiberofficinale*) is a widely used medicinal and culinary plant, valued for its essential oil, which contains bioactive compounds such as gingerol, shogaol, and zingerone. These compounds contribute to its antioxidant, antimicrobial, and anti-inflammatory properties, making ginger oil highly sought after in the food, pharmaceutical, and cosmetic industries (Ali *et al.*, 2018). Efficient extraction techniques are crucial to maximizing oil yield and preserving its bioactive properties. One of the most commonly used methods for ginger oil extraction is the Soxhlet extraction method, known for its effectiveness in obtaining high yields of essential oil from plant materials (Tao *et al.*, 2020). To optimize the Soxhlet extraction of ginger oil, a kinetic and thermodynamic analysis is essential. Kinetic studies help in understanding the rate of extraction and the mechanisms governing the mass transfer of bioactive compounds, which is influenced by factors such as temperature, solvent type, particle size, and extraction time (Ameh *et al.*, 2021).

Thermodynamic analysis, on the other hand, provides insight into the energy requirements of the process, including enthalpy, entropy, and Gibbs free energy changes, which determine the feasibility and spontaneity of extraction (Maran *et al.*, 2017). Several studies have demonstrated that Soxhlet extraction follows first-order kinetics, with temperature playing a significant role in increasing diffusion rates and overall yield (Hassas-Roudsari & Chang, 2020). Moreover, thermodynamic parameters often indicate that the extraction process is endothermic and entropy-driven, suggesting the importance of optimizing temperature conditions to achieve efficient extraction (Azwanida, 2015).

This study objectives is to explore the kinetic and thermodynamic aspects of ginger oil extraction using the Soxhlet method, providing a deeper understanding of how extraction parameters influence oil yield and quality by analyzing these factors, researchers can develop optimized extraction protocols that enhance efficiency, reduce energy consumption, and ensure the highest quality of ginger oil.

MATERIALS AND METHODS

The materials used in the experiment include ginger rhizomes, n-hexane (solvent) made in Merck KGA, 64271 Darmstadt Germany with CAS No 110-54-3. The following laboratory equipment and apparatus were used in the study; Soxhlet apparatus used were made in china, round bottom flask 500-1000ml capacity, heating mantle, thermometer, mortar, filter paper and Fourier Transform Infrared (FT-IR)

Rhizome Collection and Preparation

Wet rhizomes of ginger for the study were procured from Maro, Kajuru LGA, Kaduna State. The ginger were identified by the researcher with the assistance of a botanist in Biological Sciences Department, Kaduna State University. The voucher number were deposited at the National Root and Crops Research Institute Maro Sub-station, Kajuru LGA, Kaduna State, Nigeria. The ginger rhizomes were stored in brown envelope and transported to Federal University Dustin ma, Katsina State, Nigeria for preparation.

The wet ginger rhizomes was washed with tap water, followed by distilled water. The cleaned samples were dried at 310K – 313K for 21 days inside laboratory. The dried ginger were chop into uniform size with mortar and pistil. Chop dried ginger were converted into powder. The sample was sieve through 0.5 – 1 mm mesh to ensure uniform particles.

Procedure of Oil Extraction

The ginger oil extraction was done based on the conditions of the experiments with Soxhlet extractor as shown in Figure 2;



Figure 2; Gingeroil Extraction Process (Source; laboratory work 2024).

The operational procedure conditions include;

Temperature: The operating temperature for extraction was varied from 323K, 333K, 343K and 353K.

Extraction time: The term extraction time is used for the duration of time it takes for extraction of oil. In this study, the experiments were carried out for 60, 90, 120, 150, 180, 210, 240, 270, 300 and 330 minutes of extraction time.

Ratio of turmeric to solvent: The ratio of ginger to solvent used was 20 gram of ginger sample to 250ml of solvent. The yield of ginger oils is expressed in equation 1 and 2

Mass of oil (g) extracted = mass of oil and container – mass of container 1

$$\text{Concentration (g/L)} = \frac{\text{Mass of oil in g}}{\text{Volume of solvent in 250ml}} \times 1000 \quad 2$$

$$\text{Volume of oil (L)} = \frac{\text{Mass of oil in g}}{\text{Concentration (g/L)}} \quad 3$$

To Determine the Effect of Temperature on the Extraction of Ginger oil: The effect of temperature on the extraction of ginger oil was assessed by keeping the sample ratio constant at 20 gram of ginger sample to 250ml of solvent, time at 60 minutes, and temperature varied from 323K, 333K, 343K and 353K.

To Determine the Effect of Time on the Extraction of Ginger oil : The extent of extraction of ginger oil using hexane were studied as a function time. The sample ratios were kept constant at 20 gram of ginger sample to 250ml of solvent. Time of extraction was varied at the range of 60, 90, 120, 150, 180, 210, 240, 270, 300 and 330 minutes at different temperature varied from 323K, 333K, 343K and 353K.

To Determine the Order of Reaction for the Experiment: Six kinetic models were used to study the extraction of ginger oil. These include;

First Order Kinetic Model

First order kinetic model propose is

$$\log C_t = \left(\frac{-k}{2.303} \right) t + \log C_0 \quad 4$$

Where C_t and C_0 are the concentrations of the solute at time t and initial concentration (g/dm^3), respectively and k_1 is the first order rates constant, (Min^{-1}). If the first-order kinetics is applicable to the extraction, then the plot of $\log C_t$ versus t of equation (4) above will give a linear relationship with $\left(\frac{-k}{2.303} \right)$ and $\log C_0$ as slope and intercept .

Second-Order Kinetic Model

$$\text{Second-order kinetic propose is } \frac{1}{C_t} = k_2 t + \frac{1}{C_0} \quad 5$$

Where C_0 and C_t (g/cm^3) are the concentration of solute at time t and initial concentration respectively, and k_2 is the rate constant of second order. If the second-order kinetics is applicable to the system, then the plot of $\frac{1}{C_t}$ versus t of equation (5) will give a linear relationship with k_2 and $\frac{1}{C_0}$ as slope and intercept.

Pseudo-First Order Model

$$\log (q_e - q_t) = \left(\frac{-k'}{2.303} \right) t + \log q_e \quad 6$$

If the first- pseudo order kinetics is applicable to the system, then the plot of $\log (q_e - q_t)$ versus t of equation (6) will give a linear relationship with $\left(\frac{-k'}{2.303} \right) t$ and $\log q_e$ as slope and intercept respectively.

Pseudo-Second-Order Model

$$\log (q_e - q_t) = \left(\frac{k'_2}{2.303} \right) t + \log q_e \quad 7$$

If the kinetic is applicable to the system, then the plot of $\log (q_e - q_t)$ versus t of equation (7) above will give a linear relationship with $\log q_e$ and $\left(\frac{k'_2}{2.303} \right)$ as slope and intercept respectively.

Intra-Particle Diffusion Model

$$\frac{q}{t} = k_i d^{1/2} \quad 8$$

The logarithm form of the equation (8) is given as:

$$\log q_t = \log k_i d + 0.5 \log t \quad 9$$

Where $K_i d$ is the intra-particle diffusion rate constant. According to equation (9), a plot of \log versus $0.5 \log t$ gives a straight line with a positive intercept for intra particle diffusion controlled process.

Power Law Model

Power law model is used for the diffusion of an active agent through non-smelling devices and is described by equation below

$$q = B t^n \quad (10)$$

$$\text{Logarithmic form; } \log q = \log B + n \log t \quad (11)$$

Where, B is a constant incorporating the characteristics of the carrier-active system, and n is the diffusional exponent, indicative of transport mechanism.

$$\ln q = \ln B + n \ln t \quad (12)$$

By plotting $\ln q$ against $\ln t$, the intercept is obtained as $\ln B$, while n is the slope.

To Determine the Thermodynamic Parameters

The thermodynamic parameters will be determined by employing the equations;

$$\Delta G^\circ = -RT \ln k \quad (13)$$

$$\text{but } \Delta G^\circ = \Delta H^\circ - T\Delta S^\circ \quad (14)$$

we can rewrite it as $-RT \ln k = \Delta H^\circ - T\Delta S^\circ$

$$\ln k = \frac{\Delta S^\circ}{R} - \frac{\Delta H^\circ}{RT} \quad (15)$$

Where ΔS° = Standard Entropy change

R = Gas Constant = 8.314 J/molK

ΔH° = Standard Enthalpy change

T = Absolute temperature (K)

ΔG° = Standard change in Gibb's Free energy

k = Rate constant

By plotting $\ln k$ Vs $\frac{1}{T}$, the values of ΔH° is the slope and ΔS° will be the intercepts, hence ΔG° was calculated from equation (14).

The rate constant of a chemical reaction is dependent on the absolute temperature. It means that temperature affects the rate of reaction. The expression that gives the relationship between rate constant and temperature is known as the Arrhenius equation. If the rate constant is known, then this equation can calculate the activation energy or vice.

The temperature dependence of the rate constant (k) is expressed as follows:

$$k = A e^{\left(\frac{-Ea}{RT}\right)} \quad (16)$$

Here 'A' is the proportionality constant, known as the frequency factor, 'Ea' is the activation energy, 'R' is the gas constant, 'T' is the absolute temperature, and 'e' is the base of the natural logarithm.

Taking the logarithm in the above equation, we get;

$$\ln k = \ln A + \ln e^{\left(\frac{-Ea}{RT}\right)} \quad (17)$$

$$\ln k = \ln A - \frac{Ea}{RT} (\ln e) \quad (18)$$

$$\ln k = \ln A - \frac{Ea}{RT} (\text{because } \ln e = 1) \quad (19)$$

Converting to a common logarithm, we get

$$\log k = \log A - \frac{Ea}{2.303RT} \quad (20)$$

$$\log k = \frac{-Ea}{2.303RT} + \log A \quad (21)$$

By plotting $\log k$ Verses $\frac{1}{T}$, the activation energy Ea is the slope and the pre-exponential function (A) will be the intercept.

RESULTS AND DISCUSSION

GingerOil FT-IR Analysis

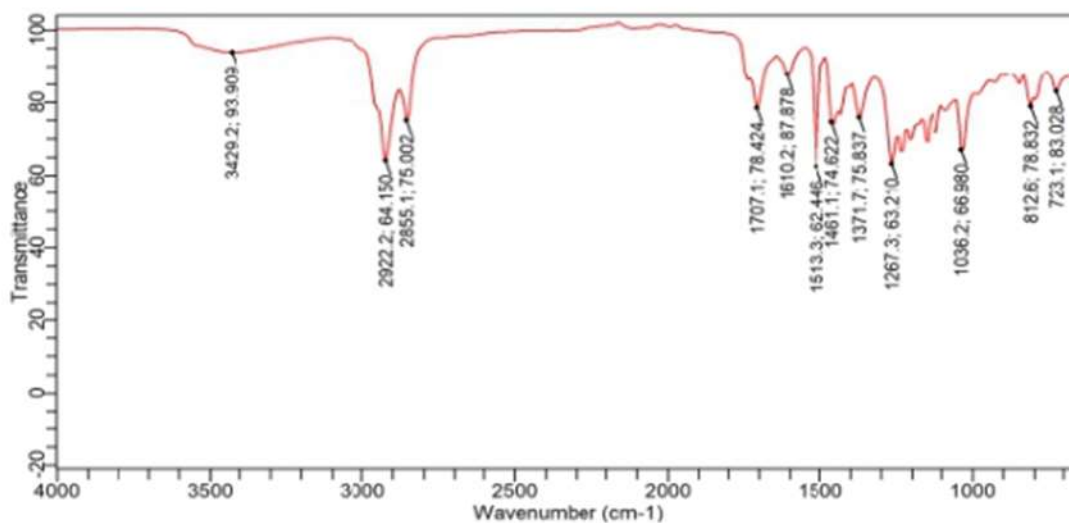


Figure 3: FT-IR spectrum of Ginger oil (Source; laboratory work 2024).

Ginger oil is a complex molecule because the FT-IR spectrum has more than 5 absorption band.

Table 1; Interpretation of Ginger oil FT-IR

Peak number	Wave number (cm ⁻¹)	Literature	Functional group	Class of compound
Observed				
1	723.10	1000–650	C - C bending	Bending vibration of alkene
2	812.56	1000–650	= C- H bending	Bending vibration of alkene
3	1036.20	1320 - 1000	C - O stretching	Stretching vibration of alcohol, carboxylic acid, ester, ethers
4	1267.29	1320–1000	C - O stretching	Stretching vibration of alcohol, carboxylic acid, ester, ethers.
5	1370.66	1370–1350	C - H bending	Symmetrical bending vibration of alkane
6	1461.12	1500–1400	C - C stretching (in ring)	Stretching vibration of aromatic compound
7	1513.30	1550–1475	N - O stretching	asymmetric Stretching vibration of nitro compounds
8	1610.21	1650–1580	C= N bending	Bending vibration of Amine
9	1707.12	1710–1665	C = O stretching	Alpha beta saturated Ketones and aldehyde
10	2855.14	3000–2850	C - H stretching	Stretching vibration of alkane
11	2922.23	3000–2850	C - H stretching	Stretching vibration of alkane
12	3429.15	3500–3200	O - H stretching	Stretching vibration of alcohols and phenols

(Source; laboratory work 2024).

The oil extracted was characterized using FT-IR and from the spectrum, ginger oil contains; Alkane, alkene, alcohol, carboxylic acid, ester, ethers, aromatic compound, nitro compound, amine group, aldehyde and saturated aliphatic compound. This findings is similar to Emmanuel *et al.*, (2024) study on cashew karnel.

Effect of Temperature on the Extraction of Gingeroil

Table 2; Effect of Temperature on the Extraction of Gingeroil:

Temperature (K)	Volume (cm ³)
323	78.50
333	89.50
343	107.50
353	129.50

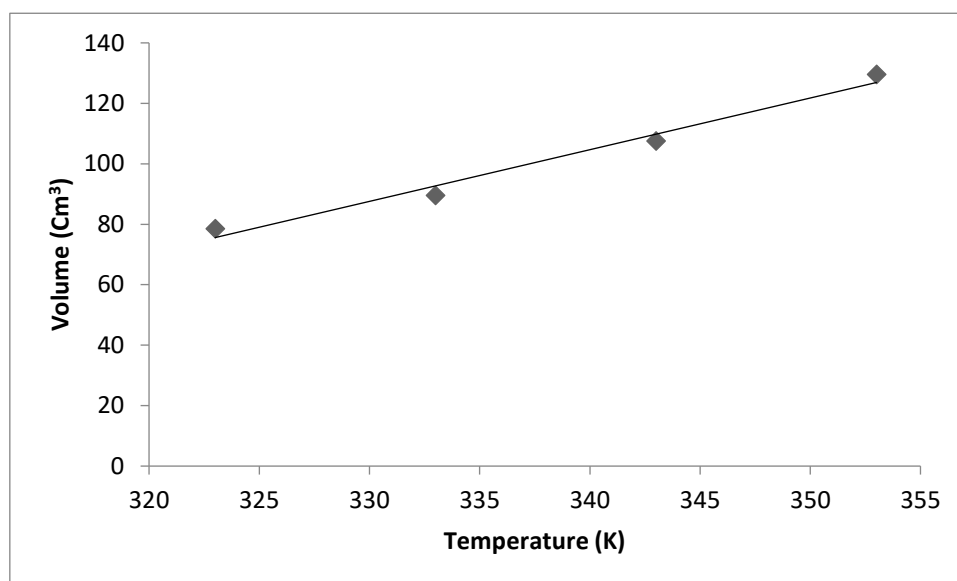


Figure 4: A graph of Effect of Temperature on the Extraction of Gingeroil. (Source; laboratory work 2024).

The concentration of the extracted oil was found to be prime with 107.50cm³ at 343K and 129.50cm³ at 353K. Increase in temperature lead to increase in volume of oil extracted, hence, temperature is directly proportional to the volume of oil extracted. This agreed with the results of studies done by Emenike *et al.*, (2022) on nut seed.

Effect of Time on the Extraction of Gingeroil

Table 3; Effect of Time on the Extraction of Gingeroil

Time (min)	Volume (cm ³)			
	323K	333K	343K	353K
0	0.00	0.00	0.00	0.00
60	2.00	3.50	4.00	4.50
90	3.50	4.50	5.50	6.50
120	5.00	5.00	7.00	8.00
150	5.50	6.00	8.50	9.50
180	6.00	7.50	9.50	11.00
210	8.50	8.00	10.50	13.50
240	10.00	11.50	12.00	15.00

270	11.50	13.00	14.00	18.00
300	12.50	14.50	16.50	21.50
330	14.00	16.00	20.00	22.00

(Source; laboratory work 2024).

The volume of the extracted oil was found to be prime with 21.50cm³ at 343K and 22.00cm³ at 353K. Increase in time lead to increase in volume of oil extracted, hence, time is directly proportional to the volume of oil extracted. This agreed with the results of studies done by Emenikeet *al.* (2022) and Shaun *et al.*, (2021) of oil extraction at different temperatures of nut seed and hass avocados respectively.

Order of Reaction of Gingeroil Extraction Process

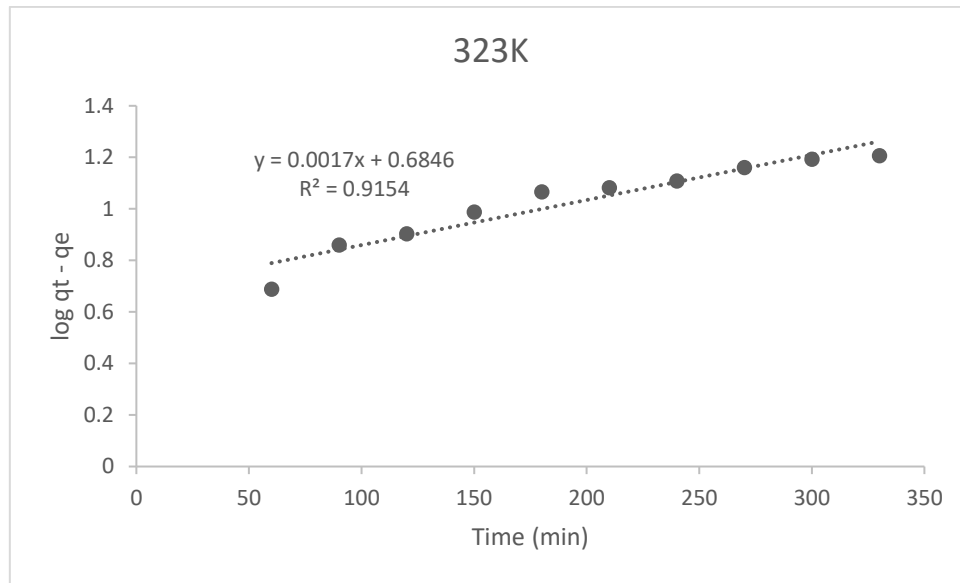


Figure 5; Graph for pseudo second order kinetic model of Gingeroil extraction at 323K. (Source; laboratory work 2024).

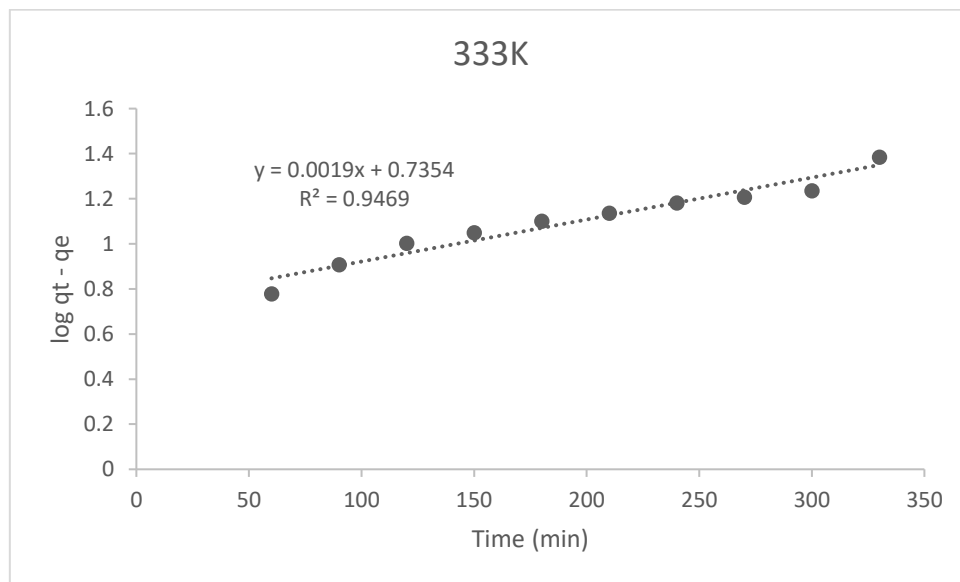


Figure 6; Graph for pseudo second order kinetic model of Gingeroil extraction at 333K. (Source; laboratory work 2024).

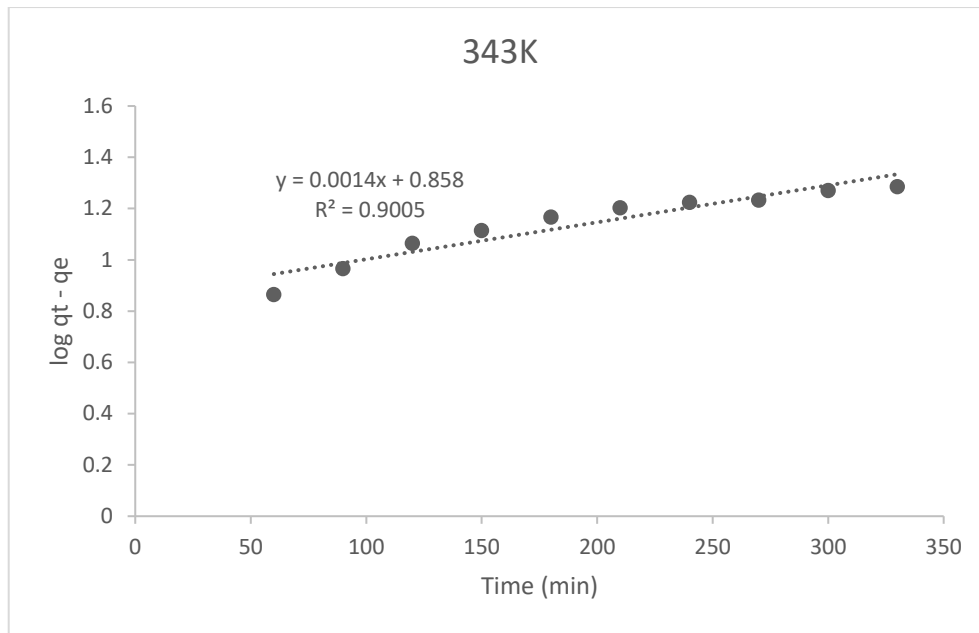


Figure 7; Graph for pseudo second order kinetic model of Gingeroil extraction at 343K. (Source; laboratory work 2024).

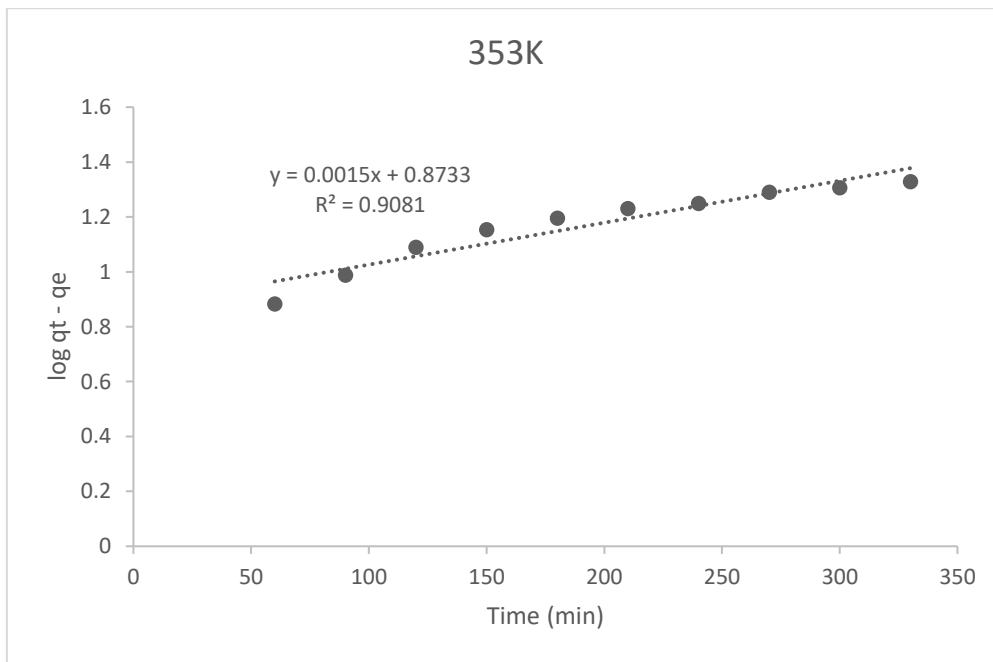


Figure 8; Graph for pseudo second order kinetic model of Gingeroil extraction at 353K. (Source; laboratory work 2024).

Table 4; Summary of Ginger oil Kinetic Model Values

T K	First Order			Second Order			Pseudo First Order		
	k_1 (10^{-3})	C_o (10^{12})	R^2	k_2	C_o	R^2	k'_1 (10^{-3})	q_e (10^{12})	R^2
323	4.1454	2.3292	0.9161	0.0004	6.2400	0.7989	4.3757	2.5640	0.9403
333	3.9151	2.6080	0.9376	0.0005	1.2990	0.5905	3.9151	2.6790	0.9623
343	3.2242	2.6333	0.9005	0.0003	4.2740	0.8120	3.4545	2.8090	0.9208
353	4.8363	7.4370	0.8714	0.0002	4.2550	0.8136	4.8360	4.2130	0.8517

Pseudo Second Order			Intra Particle Diffusion Model			Power Law Model			
T K	k_2 (10^{-3})	q_e (10^{12})	R^2	k_{id}	I	R^2	B (10^{-3})	n	R^2
323	3.9150	4.8370	0.9151	0.9637	3.9212	0.832	4.3845	0.5591	0.3060
333	4.3750	5.4375	0.9469	0.1008	0.9081	0.8261	3.9221	0.7608	0.9376
343	3.2240	7.2111	0.9005	1.0311	0.9872	0.7649	3.2288	0.8580	0.9005
353	3.4550	7.4696	0.9081	1.0634	3.9212	0.8320	3.4598	0.8733	0.9081

(Source; laboratory work 2024).

From the summary table of the ginger oil kinetic models above, pseudo second order correlation coefficient (R^2) ranges from 0.9151, 0.9469, 0.9005, 0.9081 with an average of 0.91765 which is most close to +1, showing perfect positive relationship hence, a good agreement between the experimental q_e values and the calculated k_2 values. This model is particularly relevant in understanding the interaction between ginger oil and the extracting solvent, as it accounts for both diffusion and chemical interaction mechanisms. The pseudo-second-order kinetic model assumes that the rate of extraction is proportional to the square of the number of unoccupied binding sites, indicating a chemisorption-driven process (Ho & McKay, 1999). This suggests that the extraction of bioactive compounds from ginger primarily occurs through a mechanism that involves not just simple diffusion but also solvent-solute interactions that affect the overall extraction efficiency.

Several studies have confirmed that ginger oil extraction follows a pseudo-second-order kinetic model. For instance, research by Ahmed *et al.*, (2021) demonstrated that the kinetic behavior of ginger oil extraction in Soxhlet and ultrasound-assisted extraction techniques fits well with the pseudo-second-order model, with correlation coefficients (R^2) exceeding 0.98. This indicates a strong dependence on the availability of active binding sites rather than simple diffusion control. Additionally, Bai *et al.*, (2020) found that temperature and solvent polarity significantly impact the pseudo-second-order rate constant, with higher temperatures enhancing molecular interactions and solubility, leading to improved extraction efficiency. Factors Influencing Pseudo-Second-Order Kinetics in Ginger Oil Extraction

- Solvent Selection:** The polarity of the solvent affects the solubility of ginger oil components. Non-polar solvents such as hexane and petroleum ether are commonly used for extracting essential oils due to their compatibility with lipophilic compounds. However, polar solvents like ethanol can enhance the extraction of polyphenols and other bioactive compounds, impacting the kinetic behavior (Rahman *et al.*, 2022).
- Temperature Effect:** The pseudo-second-order model suggests that higher temperatures improve molecular movement and interaction between ginger oil and the solvent, leading to enhanced diffusion rates. However, excessively high temperatures may cause degradation of thermally sensitive compounds such as gingerol and shogaol (Chan *et al.*, 2021).
- Extraction Time:** The kinetics indicate that the extraction rate increases rapidly at the beginning and then slows as the system approaches equilibrium. Prolonging extraction beyond the optimal point does not significantly improve yield and may lead to unnecessary energy consumption (Zhang *et al.*, 2020).
- Particle Size of Ginger:** Smaller particle sizes provide a larger surface area, which enhances the extraction rate. However, overly fine grinding may lead to solvent retention issues and inefficient separation post-extraction (Wang & Kim, 2022).
- Agitation:** Studies have shown that agitation and ultrasound techniques enhance mass transfer, reducing the time required to reach equilibrium and improving extraction efficiency while still following pseudo-second-order kinetics (Garcia *et al.*, 2023)

Thermodynamic studies of Ginger oil Extraction Process

Table 5: Thermodynamics Data Analysis

1/T	ln k	log k
0.003096	-5.6429	-2.5073
0.003003	-5.7317	-2.4590
0.002915	-5.3371	-2.3916
0.002833	-5.0679	-2.2616

(Source; laboratory work 2024).

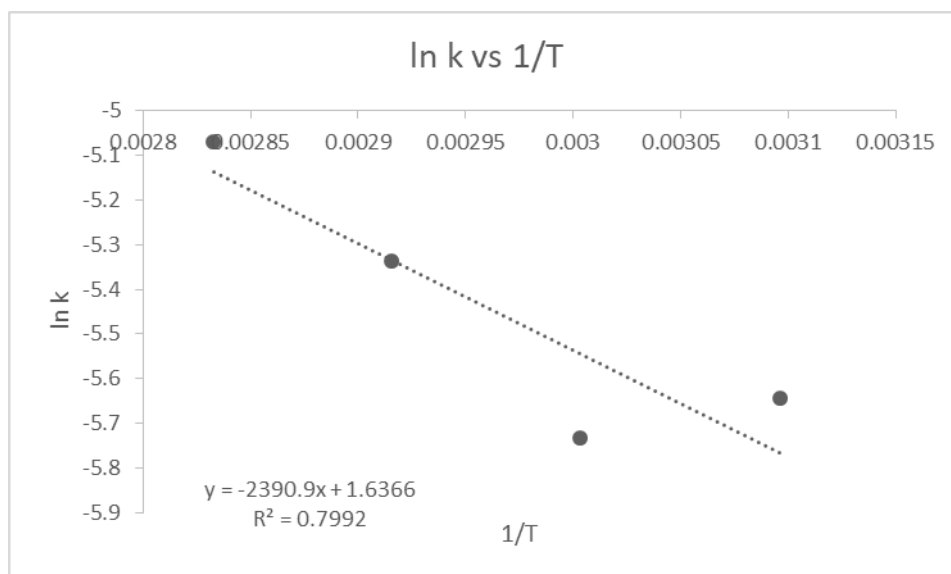


Figure 9; Graph of ln k vs 1/T for ginger oil extraction process. (Source; laboratory work 2024).

From the above graph the following thermodynamic parameters for ginger oil extraction process are obtain from the slope and intercept.

$$\ln k = \frac{\Delta S^\circ}{R} - \frac{\Delta H^\circ}{RT}$$

$$\text{Slope} = \frac{\Delta H^\circ}{R}, \Delta H^\circ = \text{slope} \times -R = -2390.9 \times -8.3145 \text{ j/molK}^{\dagger}$$

$$\Delta H^\circ = 19879.13805 \text{ j/mol} = 19.8791 \text{ kj/mol}$$

$$\text{Intercept} = \frac{\Delta S^\circ}{R}, \Delta S^\circ = \text{Intercept} \times R = 1.6366 \times 8.3145 \text{ j/molK}$$

$$\Delta S^\circ = 13.6075107 \text{ j/molK} = 0.0136075107 \text{ kj/molK}$$

Using $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$ we obtain free Gibb's energy at different temperature

$$\Delta H^\circ = 19879.13805 \text{ j/moland } \Delta S^\circ = 13.6075107 \text{ j/molK}$$

At 323K

$$\Delta G^\circ = 19879.13805 - 323 (13.6075107)$$

$$\Delta G^\circ = 15483.9120939 \text{ j/mol}$$

$$\Delta G^\circ = 15.4839 \text{ kj/mol}$$

At 343K

$$\Delta G^\circ = 19879.13805 - 343 (13.6075107)$$

$$\Delta G^\circ = 15211.7618799 \text{ j/mol}$$

$$\Delta G^\circ = 15.2118 \text{ kj/mol}$$

At 333K

$$\Delta G^\circ = 19879.13805 - 333 (13.6075107)$$

$$\Delta G^\circ = 15347.8369869 \text{ j/mol}$$

$$\Delta G^\circ = 15.3478 \text{ kj/mol}$$

At 353K

$$\Delta G^\circ = 19879.13805 - 353 (13.6075107)$$

$$\Delta G^\circ = 15075.6867729 \text{ j/mol}$$

$$\Delta G^\circ = 15.9757 \text{ kj/mol}$$

To calculate the values of activation energy and the pre-exponential function (A), Arrhenius equation $\log k = \frac{-E_a}{2.303R} \frac{1}{T} + \log A$ was used.

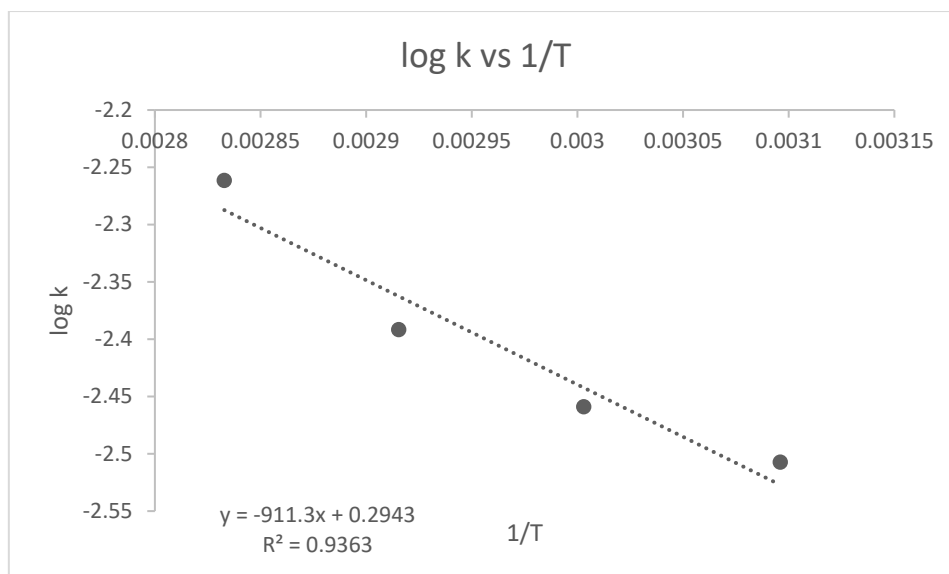


Figure 10; Graph of Log k vs 1/T for ginger oil extraction process.(Source; laboratory work 2024).

$$\log k = \frac{-Ea}{2.303R} \frac{1}{T} + \log A$$

$$\text{Slope} = \frac{-Ea}{2.303R}, Ea = \text{slope} \times 2.303 \times -R = -911.3 \times 2.303 \times (-8.3145 \text{ J/molK})$$

$$Ea = 17449.83986655 \text{ J/molK} = 17.4498 \text{ kJ/molK}.$$

$$\text{Intercept} = \log A$$

$$A = \text{Antilog of intercept} = 10^{0.2943} = 1.96924612701$$

Table 6; Summary of Thermodynamics Properties

SAMPLE	A	Ea (kJ/molK)	ΔH° (kJ/mol)	ΔS° (kJ/molK)	ΔG° (kJ/mol)			
					323K	333K	343K	353K
GINGER OIL	+1.9692	+17.4498	+19.8791	+0.01361	+15.4839	+15.3478	+15.2118	+15.9757

(Source; laboratory work 2024).

The Arrhenius factor, +1.9692, represents the pre-exponential term in the Arrhenius equation, which indicates the frequency of successful molecular collisions leading to a reaction. The activation energy of +17.4498 kJ/mol suggests that the reaction requires a moderate energy input to proceed. A positive activation energy indicates an endergonic activation process where reactant molecules must overcome an energy barrier to transition into products (Atkins & de Paula, 2018). The enthalpy change (ΔH) of +19.8791 kJ/mol suggests an endothermic reaction, meaning that heat is absorbed during the process. This implies that the reaction might be less favorable at lower temperatures but could become more favorable at higher temperatures (Smith *et al.*, 2020).

The entropy change (ΔS) of +0.01361 kJ/molK is relatively small but positive. This suggests a slight increase in disorder during the reaction process, possibly due to the formation of more gaseous or freely moving particles in the product phase compared to the reactants (Laidler, 1997). However, the small entropy change indicates that the degree of disorder introduced is minimal, meaning the reaction mechanism likely involves only minor configurational changes. The Gibbs free energy change (ΔG) varies from +15.4839 kJ/mol, +15.3478 kJ/mol, +15.2118 kJ/mol and +15.9757 kJ/mol. A positive Gibbs free energy indicates that the reaction is non-spontaneous under standard conditions. Since Gibbs free energy is temperature-dependent ($\Delta G = \Delta H - T\Delta S$), an increase in temperature could shift the reaction towards spontaneity if the entropy change is significantly positive. However, given the small entropy contribution, the reaction is likely to remain non-spontaneous under typical conditions unless external conditions are altered (Garcia & Smith, 2019). This highlights the importance of catalysis or alternative pathways in improving reaction feasibility.

Table 7; Comparison of Thermodynamic Parameters for Different Plants Oil Extraction

ΔH (kJ/mol)	ΔS (kJ/mol.K)	ΔG (kJ/mol)	Oil source (plant)	Reference
28.17	0.234	-3.90 to -8.91	Pumpkin seed	Nwabanne (2012)
11.19	0.033	0.24 to 0.57	Coconut seed	Sulaimanet <i>al.</i> , (2013)
7.83	26.62	-0.86 to -1.31	Watermelon seed	Olakunleet <i>al.</i> , (2014).
29.20	0.092	0.45 to -13.83	<i>Thevetiaperuviana</i> seed	Jabaret <i>al.</i> , (2015)
15.02	45.52	1.62 to -0.10	Jatropha seed	Dos Santos <i>et al.</i> , (2015).
11.70	0.260	-2.49 to -1.95	Bitter gourd seed	Umamaheshwari and Reddy (2016).
372.05	1.290	-26.64 to -52.35	<i>Colocynthis vulgaris</i> schradseed	Aguet <i>al.</i> , (2018)
27.62	0.087	-0.02 to -1.32	Cashew nut seed	Eminikeet <i>al.</i> , (2022).
19.8791	0.01361	15.2118 to 15.4839	Ginger rhizome	Present study

CONCLUSION

The kinetic and thermodynamic studies of extraction of oil from Maro ginger rhizomes by soxhlet extraction method using hexane as solvent was carried out and characterized. The maximum volume of oil extracted was found at 343K and 353K, hence as the temperature increase the volume oil extracted increases. The FT-IR spectrum reveal that gingeroil contains alkane, alkenes, alcohol, aldehydes, ketones, esters and carboxylic acids. Among the six kinetic model studied, pseudo-second order was found to best fit the experimental data obtained with correlation coefficient above 0.91. From the data of the thermodynamics parameters obtained, the process was seen to be endothermic, high entropy and non - spontaneous.

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