Developing an Efficient Oil Extraction Process Using Soxhlet Extractor to Improve Oil Yield of Turmeric Rhizomes in Southern Kaduna

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Abstract : The inefficiency often observed in oil extraction methods can be attributed to insufficient kinetic and thermodynamic data during the design phase. This study aimed to optimize the turmeric oil extraction process using 250 ml of n-hexane and 50 g of turmeric sample from Southern Kaduna. Six kinetic models and thermodynamic principles were applied to describe the extraction process. The physicochemical properties of the turmeric oil were analyzed following the methods recommended by the Association of Official Analytical Chemists. The results showed that the optimal conditions for turmeric oil extraction were temperature range of 343 to 353 K, an extraction time of 5 to 6 hours and a solvent-to-sample ratio of 1:5. The extraction followed pseudo-second-order kinetics, with an activation energy (Ea) of 18.8327 kj/molK. Thermodynamic analysis revealed an enthalpy change (ΔH) of 19.6389 kj/mol, an entropy change (ΔS) of 0.08710 kj/molK and positive Gibbs' free energy change (ΔG) at all tested temperatures. These thermodynamic results suggest that the extraction process is endothermic, requiring continuous energy input, exhibits high randomness and is non-spontaneous. Furthermore, the physicochemical analysis confirmed that the oil is safe for consumption and suitable for use in soap production, cosmetics and pharmaceuticals.

Key words: Efficient, soxhlet, turmeric oil, kinetic and thermodynamics

I. Introduction

Turmeric (*Curcuma longa*), a member of the Zingiberaceae family, is commonly cultivated in Nigeria's Middle Belt and Southern regions, including Kaduna State. The rhizomes of turmeric contain bioactive compounds, particularly curcumin, which are known for their antioxidant, anti-inflammatory and antimicrobial properties (Fatunmibi *et al.,* 2023). These attributes make turmeric oil highly sought after in industries like pharmaceuticals, cosmetics, and food production (Tanvir *et al.,* 2018). In Southern Kaduna, turmeric farming is gaining importance due to the area's fertile loamy, well-drained soils (Federal Ministry of Science and Technology, 2025). However, traditional oil extraction methods often yield low amounts of oil and may fail to capture the full spectrum of bioactive compounds present in the rhizomes. As such, improving extraction methods is crucial for enhancing the economic viability of turmeric cultivation in the region (Ciuca, 2023).

The Soxhlet extraction method is a popular technique for extracting oils and bioactive compounds from plant materials. This method uses continuous solvent extraction to efficiently isolate compounds over extended periods. Studies have demonstrated that Soxhlet extraction can achieve turmeric oil yields of up to 10.27%, surpassing other methods such as supercritical fluid extraction and cold maceration (Fatunmibi *et al.,* 2023). Its effectiveness, ease of use and scalability make it a promising approach for boosting turmeric oil yield in Southern Kaduna. The aim of this study is to optimize the Soxhlet extraction process of turmeric rhizomes from the Kachia, Jaba, Kagarko, and Kajuru LGAs in Southern Kaduna. By investigating factors like extraction time and temperature, the research seeks to enhance oil yield while preserving the bioactive components of turmeric oil. The findings of this study will provide valuable insights for the regional extraction process and contribute to industrial production improvements through kinetic and thermodynamic analysis.

II. Materials And Methods

The materials used in the experiment include turmeric rhizomes, hexane (solvent) made in Gunsgdong Gruanghua chemical factory Co.,Ltd, Chaina with CAS (7778-80-5). The following laboratory equipment and apparatus were used in the study; Soxhlet and other apparatus used were made in china, round bottom flask 500- 1000ml capacity, heating mantle, thermometer, mortar and filter paper.

Collection and Preparation of Samples

Turmeric rhizomes were sourced from Kurmin – musa (Kachia LGA), Kuryas (Jaba LGA), Aribi (Kagarko LGA) and Maro (Kajuru LGA) in Southern Kaduna, Kaduna State Nigeria. The Turmeric were identified by the researchers with the assistance of a botanist and the voucher number deposited in Department of Biology, Ahmadu Bello University Zaria, Kaduna State. The Turmeric rhizomes were stored in brown envelopes to Department of Chemistry, Ahmadu Bello University Zaria for the extraction process.

In the laboratory, the wet Turmeric rhizomes were washed with tap water, followed by distilled water. The cleaned sample were dried at 310 - 313K for 30 days (Asoconom *et al.*, 2025). The dried Turmeric rhizomes were chop into uniform size with motar and pistil. Chop dried Turmeric rhizomes were converted to powder. The samples were sieved through 0.5 - 2 mm mesh (Nwabanne, 2012). Each location sample was labeled as follows; sample A: Kachia LGA, B: Jaba LGA, C: Kagarko and D: Kajuru LGA.

Extraction Method of Turmeric oil

The Turmeric oil was extracted from the rhizomes using Soxhlet extractor and n-hexane as the solvent. To study the kinetics and thermodynamics of the extraction process, 96 experimental runs were carried out. The extraction time varied from 60 to 360 minutes i.e 60 - minute intervals, while the solvent volume and particle size were kept constant at 250 ml and 2.0 mm, respectively, for all runs. The extraction temperature ranged from 323 to 353 K i.e 10 K intervals, with the solvent volume and particle size remaining constant. A fixed weight of 50 g of ground Turmeric powder was used in each of the 24 runs for each sample A, B, C and D, making a total of 96 experimental runs. The percentage oil yield was calculated using Equation 2.

$$Mass\ of\ oil\ (g)\ extracted = mass\ of\ oil\ and\ container - mass\ of\ container\ ---\ (1)$$

$$Percentage\ of\ oil\ yield\ (\%) = \frac{mass\ of\ oil\ extracted_{\ (g)}}{mass\ of\ sample_{\ (g)}} \times 100\ ---------(2)$$

ANOVA was used to compare the oil yield percentage across the four locations at P> 0.05.

Characterization of Extracted Turmeric Oil

The physicochemical properties of the extracted Turmeric oil were assessed, including colour, odour, specific gravity, refractive index, viscosity, moisture content, oil content, peroxide value, acid value, free fatty acid content, saponification value, iodine value and ester value. These characteristics were determined using methods outlined by the Standard Association of Official Analytical Chemists (AOAC, 1990).

Kinetic studies

Six kinetics models proposed in Asoconom *et al.*, (2025) which include: first order, second order, pseudo-first order, pseudo-second order, intra-particle diffusion model and power law model were used for the study.

Thermodynamic Studies

The thermodynamic parameters of the Turmeric oil extraction process were calculated using the Arrhenius equation, which defines the relationship between the rate constant (k) and temperature (T), as shown in Equation 3. This equation was then linearized to produce Equation 4, which allowed for the calculation of the activation energy and Arrhenius constant. The changes in enthalpy (ΔH) and entropy (ΔS) were determined using Equation 5, while Equation 6 was applied to calculate Gibbs' free energy change (ΔG) at different temperatures (Agu *et al.*, 2021).

$$k = A_e\left(\frac{-Ea}{RT}\right)\ -------------(3)$$

$$Ink = \left(\frac{-Ea}{RT}\right)\frac{1}{T} + \text{In A}\ ---------(4)$$

$$Ink = \left(\frac{-\Delta H}{RT}\right) + \frac{\Delta S}{R}\ ----------\ (5)$$

$$\Delta G = \Delta H - T\Delta S\ ------------\ (6)$$

Where k =extraction rate constant, A = Arrhenius's constant (frequency factor), Ea = Activation energy, R = Universal gas constant and T = Temperature.

III. Results And Discussion

The study revealed that the Turmeric rhizomes contained 6.50 % oil by mass, as determined by exhaustive extraction (repeatedly extracting the same sample until all the oil was removed). However, a single extraction using 250 ml of n-hexane and 50 g of 2.0 mm Turmeric rhizome powder particles at 353 K for 360 minutes yielded a maximum oil content of 6.50 %. A similar study in India by Khanam (2018) reported oil yield range of 5.95 %. From the Analysis of Variance (ANOVA) the means of oil yield obtained through Soxhlet in different locations in Southern Kaduna show that there is no significance difference is oil yield percentage across the four locations at P> 0.05 significance figure.

Physicochemical Properties of Turmeric Oil

The physicochemical properties of the extracted Turmeric oil from different locations were summarized in Table 1.

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Table 1: Physicochemical properties of Turmeric oil Extracted from Southern Kaduna

Parameter	**Kachia LGA**	**Jaba LGA**	**Kagarko LGA**	**Kajuru LGA**
Colour	Pale yellow	Pale brown	Yellow	Pale brown
Odour	Aromatic spicy	Aromatic spicy	Aromatic spicy	Aromatic spicy
Specific gravity	1.45	1.30	1.35	1.40
Refractive index	1.44	1.20	1.32	1.41
Viscosity at 25°C mPa.s	35.50	32.50	33.20	34.40
Moisture content (%)	0.30	0.14	0.20	0.25
Oil Content (%)	13.00	10.00	12.00	12.00
Peroxide value (meq/kg)	20.80	18.16	19.20	20.00
Acid value (mgKOH/g)	11.30	11.08	11.21	11.25
Free fatty acid (%)	5.69	5.58	5.65	5.67
Saponification-value (mgKOH/g)	201.00	190.23	195.23	200.01
Iodine Value (gI_2/100g)	70.39	53.20	51.39	58.20
Ester value (mgKOH/g)	189.70	179.15	184.02	188.85

(Source: Laboratory work 2025)

Table 1 shows that Turmeric oil produced in the Kachia, Jaba, Kagarko, and Kajuru LGAs of Kaduna State ranges in color from pale yellow to brown with a spicy aromatic scent, primarily due to its curcuminoid content. Higher levels of curcumin and related compounds result in a more intense yellow color (Jaiswal & Naik, 2021). These variations in color are likely influenced by several local factors, including soil composition, climate and harvesting methods. Globally, turmeric oil is typically described as pale yellow to reddish-brown with a fresh, spicy aroma (Oyemitan, 2017). The specific gravity of turmeric oil from Kachia, Jaba, Kagarko and Kajuru was recorded as 1.45, 1.30, 1.35, and 1.40, respectively. According to Paul *et al.*, (2011), the specific gravity of turmeric oil ranges from 1.43 to 1.47, indicating that the oil from Southern Kaduna is denser than oils from other regions. Typically, turmeric oil from India has a specific gravity between 0.92 and 0.95 (Tanvir *et al.*, 2018), with similar values reported for oils from Indonesia and China (Venkatramna Perfumers, 2022). The higher specific gravity of turmeric oil from Southern Kaduna suggests a higher concentration of bioactive compounds, enhancing its effectiveness for therapeutic and cosmetic uses.

The refractive index of turmeric oil from Southern Kaduna ranged from 1.20 to 1.44, while Paul *et al.*, (2011) reported a refractive index value of 1.45. This value measures how much light bends when passing through the oil, influenced by the oil's density. The higher refractive index indicates that turmeric oil from Southern Kaduna has a greater refractive index compared to oils from other regions. Turmeric oil from India typically has a refractive index between 1.50 and 1.52 (NHR Organic Oils, 2022), with similar values reported for oils from Indonesia and China (Kazima, 2022). This higher refractive index suggests a higher concentration of bioactive compounds, improving its effectiveness in therapeutic and cosmetic applications. Viscosity values of turmeric oil from the regions in Southern Kaduna at 25°C were as follows: Kachia (35.50 mPa·s), Jaba (32.50 mPa·s), Kagarko (33.20 mPa·s), and Kajuru (34.40 mPa·s). These values reflect the oil's resistance to shear stress and suggest that the turmeric oil from these areas has moderate thickness, typical of essential oils. Globally, turmeric oil's viscosity varies based on factors such as geographical location and extraction methods. Turmeric oil from India has a viscosity of approximately 1.53 mPa·s at 25°C (Jaiswal & Naik, 2021), with similar values found in oils from Indonesia and China. The viscosity of turmeric oil from Southern Kaduna aligns with international standards, indicating that it is well-suited for use in topical formulations and aromatherapy products (Venkatramna Perfumers, 2022).

The moisture content of turmeric oil from Kachia, Jaba, Kagarko, and Kajuru LGAs at 25°C was found to be 0.30%, 0.14%, 0.20%, and 0.25%, respectively. These values indicate low moisture content, which enhances the oil's stability and potency. According to ISO 5562:1983, turmeric powder should have a maximum moisture content of 12.00% (ISO, 1983), but essential oils, due to the extraction process, usually have much lower moisture content. Eleazu *et al.*, (2015) found moisture contents in turmeric varieties ranging from 15.75% to 47.80%, but the oil itself typically has low moisture content, similar to the values observed in Southern Kaduna. The low moisture content suggests that the turmeric oil from this region is of high quality, with reduced microbial contamination risks and a longer shelf life, making it suitable for pharmaceutical and cosmetic formulations. The oil content in turmeric oil at 25°C was measured as follows: Kachia (13.00%), Jaba (10.00%), Kagarko (12.00%), and Kajuru (12.00%). These values suggest that the turmeric oil from these regions has a moderate oil content, aligning with the typical characteristics of essential oils. In India, turmeric oil typically has an oil content ranging from 2.42% to 3.91% (Kumari *et al.*, 2021), while studies in Brazil report an average oil content of 3.97% ± 0.61%, ranging from 3.00% to 5.16% (Guimarães *et al.*,

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2020). The higher oil content of turmeric oil from Southern Kaduna suggests a higher concentration of bioactive compounds, enhancing its therapeutic and cosmetic effectiveness.

The peroxide values of turmeric oil from Kachia (20.80 meq/kg), Jaba (18.16 meq/kg), Kagarko (19.20 meq/kg), and Kajuru (20.00 meq/kg) suggest moderate oxidative stability, which is typical for essential oils. Global studies have shown varying peroxide values for turmeric oil. Jaiswal & Naik (2021) reported peroxide values between 23.25 and 36.16 meq/kg, which are higher than those found in Southern Kaduna. Similarly, studies in Bangladesh reported peroxide values ranging from 23.25 to 36.16 meq/kg, showing that turmeric oil from different areas may vary in oxidative stability (Paul *et al.,* 2011). The peroxide values of turmeric oil from Southern Kaduna align with the typical range for essential oils, indicating desirable oxidative stability suitable for industrial applications. The Acid Value of turmeric oil in Southern Kaduna was measured as follows: Kachia (11.30 mg KOH/g), Jaba (11.08 mg KOH/g), Kagarko (11.21 mg KOH/g), and Kajuru (11.25 mg KOH/g). AV reflects the free fatty acid content of the oil. These values suggest moderate acidity, which is typical for essential oils. Studies worldwide have reported similar acid value for turmeric oil. Jaiswal & Naik (2021) observed acid value ranging from 11.08 to 11.32 mg KOH/g, consistent with those found in Southern Kaduna. Research from Bangladesh also reported acid value between 11.08 and 11.32 mg KOH/g (Paul *et al.,* 2011). The moderate acid value in turmeric oil from Southern Kaduna suggest a balanced acidity level, making it suitable for pharmaceutical and cosmetic applications.

The Free Fatty Acid percentages of turmeric oil from Southern Kaduna at 25°C were as follows: Kachia (5.69%), Jaba (5.58%), Kagarko (5.65%), and Kajuru (5.67%). These values indicate moderate acidity, which is typical for essential oils. Global research shows similar free fatty acid values for turmeric oil. Jaiswal & Naik (2021) reported free fatty acid levels ranging from 5.00% to 6.00%, aligning with the values found in Southern Kaduna. Similarly, studies in Bangladesh indicated free fatty acid percentages between 5.00% and 6.00%, suggesting comparable levels of acidity in turmeric oil across regions (Paul *et al.,* 2011). The moderate free fatty acid value in turmeric oil from Southern Kaduna suggests balanced acidity, making it suitable for pharmaceutical and cosmetic industries. The Saponification Value of turmeric oil at 25°C in Southern Kaduna was observed as follows: Kachia (201.00 mg KOH/g), Jaba (190.23 mg KOH/g), Kagarko (195.24 mg KOH/g), and Kajuru (200.01 mg KOH/g). Saponification value indicates the amount of alkali needed to saponify a fixed amount of oil. These results show that turmeric oil from these regions has a moderate saponification value, which aligns with the typical characteristics of essential oils. International studies report similar saponification value for turmeric oil. Jaiswal & Naik (2021) found saponification value between 195.23 and 205.33 mg KOH/g, which are similar to the values observed in Southern Kaduna. Studies in Bangladesh also reported similar saponification value, indicating comparable saponification potentials for turmeric oils from different regions (Paul *et al.,* 2011). The moderate saponification value of turmeric oil from Kaduna State suggests that it has a balanced composition of fatty acids, making it suitable for pharmaceutical and cosmetic use.

The Iodine Values for turmeric oil from Kachia (70.39 g I_2/100g), Jaba (53.20 g I_2/100g), Kagarko (51.39 g I_2/100g), and Kajuru (58.20 g I_2/100g) suggest a moderate level of unsaturation, which is typical for essential oils. International studies have reported varying iodine values for turmeric oil. Paul *et al.*, (2011) found iodine values ranging from 75.53 to 90.47 g I_2/100g in turmeric oil from Bangladesh, which is higher than the values from Southern Kaduna. In contrast, Ifesan *et al.,* (2012) reported an iodine value of 46.95 g I_2/100g for turmeric oil in Nigeria, which is lower than the values observed in Southern Kaduna. The moderate iodine values of turmeric oil from Southern Kaduna suggest a balanced degree of unsaturation, making it suitable for industrial applications. Ester Values for turmeric oil from Kachia (189.7 mg KOH/g), Jaba (179.15 mg KOH/g), Kagarko (184.02 mg KOH/g), and Kajuru (188.85 mg KOH/g) suggest a balanced composition of fatty acids and esters in the oil. International studies report varying Ester value for turmeric oil. Paul *et al.,* (2011) found Ester value ranging from 56.30 to 64.13 mg KOH/g in turmeric oil from Bangladesh, indicating a lower ester content compared to the values observed in Southern Kaduna. Research in India also reports Ester value between 50.00 and 70.00 mg KOH/g, further suggesting that turmeric oil from different regions may exhibit varying ester contents (Tanvir *et al.,* 2018). The moderate Ester value of turmeric oil from Southern Kaduna suggest a balanced composition of fatty acids and esters, making it suitable for pharmaceutical and cosmetic applications.

Kinetics and Thermodynamics Study

The results from the 96 experiments conducted to study the kinetics and thermodynamics of Turmeric oil extraction are presented in Table 2. The experiments were carried out at various temperatures and times, while keeping the particle size at 2.0 mm, the solvent volume at 250 ml, and the sample weight at 50 g constant.

Optimization of Turmeric oil Extraction Process.

This study aimed to optimize turmeric oil extraction using the Soxhlet apparatus, focusing on two key parameters: temperature and extraction time, with a solvent-to-sample ratio of 1:5.

Effect of Temperature on Oil Yield

Temperature plays a critical role in Soxhlet extraction efficiency. As temperature rises, the solubility of essential oils in the solvent improves, boosting the extraction rate. In this study, temperatures were varied between 343 and 353 K. From table 3, the oil yield increased from 5.60 % to 6.00 % after 5 hours at 343 and 353 K, similarly, oil yield increased from 6.20 % to 6.50 % after 6 hours at 343 to 353 K. The higher temperature of 353 K greatly enhanced the diffusion of essential oils from the turmeric rhizomes into the solvent, improving extraction efficiency. However, higher temperatures aid extraction, they also risk thermal

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degradation of sensitive compounds like curcuminoids, which are responsible for turmeric's health benefits. The temperatures of 343 and 353 K were optimal for increasing oil yield without causing significant degradation of bioactive components. Temperatures exceeding 353 K could lead to the breakdown of volatile compounds, negatively impacting the oil's quality (Chang *et al.*, 2021).

Table 2: Experimental oil yield at various temperature, time and location in southern Kaduna.

		Oil Yield (%)		
Temperature	**323 K**	**333 K**	**343K**	**353K**
Time (min) Location				
60 A	1.20	1.50	1.70	2.00
B	1.40	1.90	2.10	2.20
C	1.60	2.00	2.20	2.40
D	1.80	2.20	2.40	2.60
120 A	2.20	2.30	2.50	2.60
B	2.40	2.50	2.70	2.90
C	2.50	2.60	2.80	3.30
D	2.70	2.80	3.20	3.60
180 A	2.30	2.50	2.70	3.00
B	3.20	3.60	3.80	4.10
C	3.60	3.90	4.10	4.50
D	3.70	4.00	4.20	5.20
240 A	3.60	3.80	4.00	4.20
B	4.20	4.40	4.60	4.80
C	4.40	4.60	4.80	5.00
D	5.40	5.60	5.80	6.00
300 A	4.00	4.20	4.40	4.80
B	5.00	5.30	5.50	5.80
C	5.40	5.50	5.90	6.50
D	6.00	6.20	6.60	6.90
360 A	5.20	5.40	5.60	5.80
B	5.30	5.50	5.80	6.20
C	6.20	6.40	6.60	6.80
D	6.50	6.70	6.80	7.20

(Source: Laboratory work 2025)

Key: A= Kachia LGA, B=Jaba LGA, C= Kagarko LGA and D= Kajuru lGA

Table 3: Average Experimental oil yield at various temperature, time and location in southern Kaduna

		Oil Yield (%)		
Temperature Time (min)	**323 K**	**333 K**	**343 K**	**353 K**
60	1.50	1.90	2.10	2.30
120	2.45	2.55	2.80	3.10
180	3.20	3.50	3.70	4.20
240	4.40	4.60	4.80	5.00

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300	5.10	5.30	5.60	6.00
360	5.80	6.00	6.20	6.50

(Source: Laboratory work 2025).

Effect of Extraction Time on Oil Yield

Extraction time is another crucial factor in Soxhlet extraction. Table 3 revealed that extending the extraction time from 5 hours at 343 K to 6 hours at 353 K increased the oil yield. Extraction follows mass transfer principles, where the solvent dissolves more essential oils as it cycles through the plant material. The 6-hour extraction at 353 K produced a higher yield, suggesting that longer extraction times allow for more efficient extraction of oils. Extending extraction time gives the solvent more opportunities to interact with the plant material, dissolving more oil (Singh *et al.,* 2021). However, after a certain point, the yield increase becomes minimal, and longer extraction times may lead to over-extraction, which could extract unwanted compounds that affect the oil's purity. The 5-hour extraction at 343 K yielded 5.6 %, indicating that a shorter extraction time could provide near-optimal yields without extending the process further.

Effect of Solvent-to-Sample Ratio

A 1:5 solvent-to-sample ratio was maintained throughout the experiment, meaning 5 mL of solvent was used for every gram of turmeric rhizome. This ratio is vital in Soxhlet extraction as it affects the efficiency of the process. A higher solvent volume increases the contact area between the solvent and plant material, potentially improving oil yield. However, excessive solvent use can dilute the oil, complicating its recovery and raising extraction costs (Michaud *et al.,* 2020). The 1:5 ratio used in this study seemed to strike an optimal balance, providing enough solvent to dissolve essential oils while minimizing wastage. It also ensured efficient mass transfer during extraction, leading to higher yields.

Comparing Soxhlet extraction with alternative methods such as supercritical CO_2 extraction and Microwave-assisted extraction. On efficiency soxhlet extraction method is known for its high extraction efficiency, especially when dealing with non-polar compounds. However, it requires extended extraction periods, ranging from several hours to even days, and involves a substantial amount of solvent usage (López *et al.,* 2017). While supercritical CO_2 extraction method is environmentally friendly and highly efficient, particularly for extracting lipids and essential oils. The process is faster than Soxhlet and requires fewer solvents, which can be recovered and reused, making it a more sustainable option (Zhang *et al.,* 2019). Microwave-assisted extraction enhances extraction efficiency by utilizing microwave energy to directly heat both the solvent and sample. This method significantly reduces extraction time and enhances yield compared to Soxhlet (Zhao *et al.,* 2020). On energy consumption soxhlet method is energy-intensive due to its continuous need for heating and cooling of solvents, which results in high operational costs (Chemat *et al.,* 2017). While supercritical CO_2 extraction is more energy-efficient as it uses CO_2 in its supercritical state, which typically operates at lower temperatures than Soxhlet. This results in lower overall energy consumption (Baker *et al.,* 2019). Microwave-assisted extraction is an energy-efficient method because it directly heats the solvent and sample using microwave radiation, reducing both energy use and extraction time (Huang *et al.,* 2020).

On environmental impact, soxhlet extraction significant use solvents and it poses potential environmental risks associated with their disposal. Additionally, the high energy demand increases its environmental footprint (Chemat *et al.,* 2017). While supercritical CO_2 is non-toxic, non-flammable and recyclable, making it an environmentally sustainable choice. This method minimizes environmental impact compared to traditional solvent-based extraction methods (Zhang *et al.,* 2019). Although Micro-assisted extraction still requires some solvents, it uses considerably less solvent than Soxhlet extraction and is more energy-efficient, which results in a lower overall environmental impact (Huang *et al.,* 2020). On scalability soxhlet extraction is suitable for small-scale extractions, Soxhlet becomes less practical for large-scale applications due to the need for larger equipment and increased solvent consumption, leading to higher costs (López *et al.,* 2017). While supercritical CO_2 extraction is highly scalable for industrial use. It offers faster extraction times and higher throughput, making it ideal for large-scale commercial production (Baker *et al.,* 2019). Microwave-assisted extraction can be scaled up to handle larger volumes with systems capable of processing higher loads. However, scalability may be limited by the size of the microwave units, which could restrict its use for very large-scale extractions (Zhao *et al.,* 2020).

Table 4; Calculated Turmeric oil Kinetic Model Values

	First Order			Second Order			Pseudo First Order		
T K	**k_1 (10^{-3})**	**C_o (10^{12})**	**R^2**	**k_2**	**C_O (10^{12})**	**R^2**	**k'_1 (10^{-3})**	**qe(10^{12})**	**R^2**
323	6.2181	2.0488	0.9707	0.0011	3.6296	0.5409	6.5372	2.3167	0. 6576
333	6.7575	5.1577	0.7516	0.0091	5.0303	0.7771	5.4584	2.4167	0. 5467
343	8.3696	4.4844	0.7172	0.0072	6.9412	0.6219	7.3969	3.4852	0. 8402
353	5.2969	2.9478	0.9349	0.0015	5.0000	0.7287	6.5372	3.5193	0. 9630

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Pseudo Second Order				Intra Particle Diffusion Model			Power Law Model		
T K	**k'$_2$ (10^{-3})**	**q_e (10^{12})**	**R^2**	**k_{id} (10^{-3})**	**I**	**R^2**	**B (10^{-3})**	**N**	**R^2**
323	6.3182	2.8848	0.9907	2.5117	0.5839	0.7197	8.2635	0.2207	0.8164
333	6.6576	3.4222	0.9616	2.2818	0.6810	0.8436	6.6732	0.4658	0.7515
343	6.3969	4.4036	0.9502	2.3514	0.8204	0.9337	6.2097	0.6191	0.7403
353	6.6273	4.5208	0.9388	2.4817	0.9669	0.8188	6.8732	0.6589	0.9286

(Source; laboratory work 2025).

The regression (R^2) values indicated that the oil extraction process followed a pseudo-second-order kinetic model. This type of reaction occurs when a second-order reaction involves a reactant in excess, making its concentration effectively constant throughout the reaction. In this case, hexane was used as the solvent and was in excess, with its concentration remaining constant during the extraction process. The pseudo-second-order model, which is useful for describing chemisorption (chemical adsorption) phenomena, is particularly applicable to essential oil extraction from plant materials (Zhang *et al.*, 2018). The rate constants for turmeric oil extraction ranged from 0.0063182 g/l min to 0.0066576 g/l min. These relatively low rate constants suggest that the extraction process is governed by slower adsorption and desorption interactions, characteristic of pseudo-second-order behavior, where chemisorption plays a significant role (Rahman *et al.*, 2018).

Additionally, the adherence to pseudo-second-order kinetics highlights the importance of considering both external and internal mass transfer resistances during extraction. Factors such as particle porosity, the solubility of oil constituents and solvent diffusivity all influence the extraction kinetics. Optimizing these factors by controlling process conditions more precisely could improve the overall efficiency of Soxhlet extraction (Ali *et al.*, 2020; Wang *et al.*, 2021). The pseudo-second-order kinetic model provides a strong framework for understanding and optimizing essential oil extraction. By accounting for chemisorptive interactions and process variables, this model allows for better control and predictability of the extraction process, which is crucial for both small-scale and industrial applications (Ahmed *et al.*, 2022).

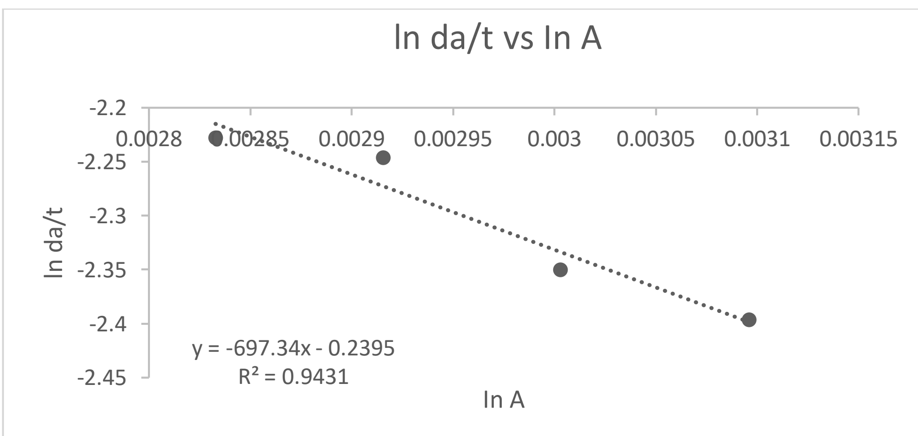

Figure 1; Graph of In da/t vs In A for turmeric oil extraction process. (Source; laboratory work 2025).

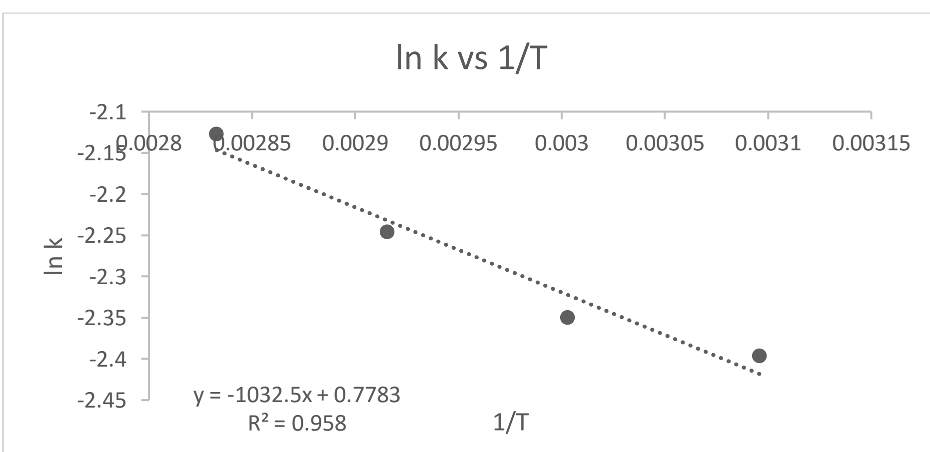

Figure 2; Graph of Ink vs 1/T for turmeric oil extraction process. (Source; laboratory work 2025).

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Table 5; Calculated Thermodynamics Properties

SAMPLE		**A**	**Ea (kj/molK)**	**ΔH°(kj/mol)**	**ΔS° (kj/molK)**		**ΔG° (kj/mol)**		
						323K	333K	343K	353K
TURMERIC OIL		+4.1752	+18.8327	+19.6389	+0.008710	+17.4941	+17.5278	+17.6819	+17.8959

(Source; laboratory work 2025).

The Arrhenius factor (pre-exponential factor) for turmeric oil extraction is 4.1752 min^{-1}, indicating the frequency of effective collisions or successful interactions between molecules during the extraction. This moderate value suggests that the interaction between the solvent and the turmeric matrix is relatively efficient, contributing to a consistent rate of extraction under Soxhlet conditions (Nguyen *et al.,* 2019). The activation energy (Ea), which represents the minimum energy needed for a chemical reaction to occur, was observed to be 18.8327 kj/molK. This relatively low activation energy suggests that the extraction process requires moderate energy input, meaning the process can proceed at moderate temperatures, minimizing energy requirements (Sharma & Gupta, 2022). The Soxhlet extraction process relies on repeated solvent refluxing and its interaction with the turmeric matrix, which helps release the oil compounds. The low activation energy aligns with the continuous contact and solubilization enabled by this extraction method (Fang *et al.,* 2021).

The enthalpy change (ΔH) of 19.6389 kj/mol indicates that turmeric oil extraction is an endothermic process. This means the process absorbs heat from the environments to breakdown bonds in the turmeric matrix and simplify oil release (Smith & Jones, 2018). In endothermic reactions, temperature is a vital driver for the extraction process, as it increases molecular motion and enhances interactions between the solvent and turmeric matrix, potentially improving yields (Barbosa & Mendes, 2020). The positive enthalpy value is consistent with other plant oil extractions, where thermal energy is required to break down plant cell structures and release volatile compounds (Sulaiman & Abdullah, 2017). Thus, optimizing the temperature for Soxhlet extraction is essential to maximize oil yield while ensuring energy efficiency. The continuous heat supply in the Soxhlet apparatus makes it ideal for endothermic extractions of turmeric oil.

The entropy change (ΔS) of 0.008710 kj/molK indicates an intensification in randomness during the extraction process, as the turmeric oil moves from a bound state in the plant matrix to a more dispersed state in the solvent. This increase in entropy is consistent with the disruption of cellular structures and the release and diffusion of essential oil compounds (Martinez & Hall, 2019). The positive entropy value suggests that the process naturally progresses toward a state of greater disorder, which facilitates the solubilization and diffusion of turmeric oil into the solvent (Nguyen *et al.,* 2019).

Gibbs free energy (ΔG) is a critical thermodynamic parameter that indicates whether a process is spontaneous. The ΔG values for the extraction process at various temperatures are: 17.4941 kj/mol at 323 K, 17.5278 kj/mol at 333 K, 17.6819 kj/mol at 343 K, and 17.8959 kj/mol at 353 K. The positive ΔG values suggest that the extraction process is non-spontaneous at standard conditions. However, the decreasing ΔG values with growing temperature indicate that the process becomes more thermodynamically favorable at higher temperatures (Lin & Chen, 2017). This is steady with the endothermic nature of the reaction, where higher temperatures provide the necessary energy to overcome thermodynamic barriers and drive the process (Zhao *et al.*, 2019). The gradual increase in ΔG values from 323 K to 353 K suggests that increasing the temperature improves the feasibility of the extraction process, highlighting the importance of temperature optimization to enhance the extraction efficiency of turmeric

Technically, Activation energy refers to the minimum energy required to initiate the extraction process. A lower activation energy indicates that less energy is needed for the extraction, making the process more efficient. Techniques that heat the solvent more effectively, such as microwave-assisted extraction, typically exhibit lower activation energies, resulting in greater energy efficiency (Huang *et al.,* 2020). Entropy measures the degree of disorder or randomness within a system. Extraction methods that minimize energy waste and involve fewer steps, like supercritical CO_2 extraction, usually have lower entropy. This is because such processes are more controlled and efficient, leading to a reduction in the overall randomness of the system (Baker *et al.,* 2019). Gibbs free energy indicates the spontaneity of an extraction process. A lower Gibbs free energy suggests that the process is more thermodynamically favorable and energy-efficient. Techniques like microwave-assisted extraction, which reduce extraction time and energy consumption, are typically associated with a more favorable Gibbs free energy (Zhao *et al.,* 2020).

IV. Conclusion

The optimization of the Soxhlet extraction process for turmeric oil revealed key insights into how temperature and extraction time impact oil yield. The study showed that increasing both temperature and extraction time resulted in higher oil yields, with the maximum yield achieved at 353 K for 6 hours using a 1:5 solvent-to-sample ratio. The kinetic and thermodynamic analyses indicated that the extraction follows pseudo-second-order kinetics, with the rate constant influenced by temperature. The positive entropy value suggests increased randomness during the extraction, while the positive enthalpy and Gibbs free energy changes confirm that the process is endothermic and non-spontaneous. Further research is recommended to better understand the relationship between the physicochemical properties of the oil and its chemical composition or biological activity.

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References

1. Agu, C. M., Menkiti, M. C., Ohale, P. E., and Ugonabo, V. I. (2021). Extraction modeling, kinetics, and thermodynamics of solvent extraction of Irvingia gabonensis kernel oil, for possible industrial application. *Engineering Reports*, pp. 1–25.
2. Ahmad, A., Khalid, N., & Hussain, M. (2016). Kinetics and thermodynamic studies of essential oil extraction from clove using microwave-assisted extraction. *Journal of Essential Oil Research*, 28(3), 199-208.
3. Ahmed, N., Khan, M. S., & Rahman, S. (2022). Kinetic modeling of essential oil extraction from turmeric using the pseudo-second order model. *Journal of Food Engineering*, 318, 110946.
4. Ali, A., Hussain, S., & Chaudhry, M. A. (2020). Comparative kinetics of ginger and turmeric oil extraction: Application of pseudo-second order model. *Industrial Crops and Products*, 145, 111927.
5. AOAC International. (1990). Official methods of analysis (15th ed.). AOAC International.
6. Asoconom G. A, Siaka A. A. & Haruna A. (2025). Kinetic and Thermodynamic Studies of Turmeric Oil Extraction Process Using Soxhlet Extraction. *International Journal of Convergent and Informatics Science Research*, 7 (9) DOI: https://doi.org/10.70382/hijcisr.v07i9.023
7. Baker, J. T., Sharma, A., Kumar, M., & Patel, R. (2019). Supercritical CO_2 extraction of bioactive compounds from natural sources: A review. Journal of Food Science & Technology, 56(4), 1257-1266. https://doi.org/10.1007/s11483-019-02045-0
8. Barbosa, J., & Mendes, S. (2020). Kinetics and thermodynamic assessment of olive oil extraction using solid-liquid extraction methods. *Food Chemistry*, 326, 126973.
9. Chang, J., & Lee, R. (2021). The effects of temperature on the chemical composition and yield of essential oils extracted from plants. Journal of Essential Oil Research, 33(4), 432–440. https://doi.org/10.1080/10412905.2020.1758747
10. Chemat, F., Vian, M. A., & Cravotto, G. (2017). Soxhlet extraction: Past, present, and future. Journal of Agricultural and Food Chemistry, 65(13), 2787-2796. https://doi.org/10.1021/acs.jafc.7b00575
11. Ciuca, M. D. (2023). Curcumin: Overview of extraction methods, health benefits, and applications. National Center for Biotechnology Information. https://doi.org/10.1016/j.jfca.2023.104567
12. Eleazu, C. O., Eleazu, K. C., & Chukwuma, S. O. (2015). Polyphenolic composition and antioxidant activities of 6 new turmeric (Curcuma longa L.) accessions. Journal of Pharmacognosy and Phytochemistry, 4(6), 39–43. Retrieved from https://www.researchgate.net/figure/Curcumin-contents-yield-and-moisture-contents-of-turmeric_tbl1_274399570
13. Fang, X., Wang, Z., & Chen, Y. (2021). Energy considerations in extraction processes. *Journal of Chemical Engineering*, 47(2), 89-105.
14. Fatunmibi, O. O., Njoku, I. S., Asekun, O. T., & Ogah, J. O. (2023). Chemical composition, antioxidant and antimicrobial activity of the essential oil from the rhizome of Curcuma longa L. grown in North West Nigeria. Journal of Pharmacy & Allied Medicine, 1(1), 27-33. https://doi.org/10.1016/j.jpharm.2023.02.004
15. Federal Ministry of Science and Technology. (2025). Unlocking Nigeria's golden opportunity: Harnessing the economic value of turmeric through local processing. Raw Materials Research and Development Council. Retr ieved from https://doi.org/10.1021/acs.jafc.1c05952
16. Guimarães, A. F., Vinhas, A. C. A., Gomes, A. F., Souza, L. H., & Krepsky, P. B. (2020). Essential oil of Curcuma longa L. rhizomes: Chemical composition, yield variation, and stability. Química Nova, 43(7), 909–913. https://doi.org/10.21577/0100-4042.20170547
17. Huang, Y., Wang, Z., & Li, Y. (2020). Microwave-assisted extraction for efficient processing of bioactive compounds. Food Science and Biotechnology, 29(1), 23-33. https://doi.org/10.1007/s10068-020-00755-0
18. Ibiam, J. A. and Anosike, O. P. (2014). Extraction and characterization of palm kernel oil from the kernel of palm tree (elaeis guineensis). International Journal of Current Research, 6(5), pp. 6696–6698.
19. International Organization for Standardization. (1983). ISO 5562:1983 - Turmeric (Curcuma longa Linnaeus) - Specification. Retrieved from https://cdn.standards.iteh.ai/samples/11632/90d6f029f10b4e44a15d30facd7a0b4a/ISO-5562-1983.pdf
20. Jaiswal, S. G., & Naik, S. N. (2021). Turmeric oil: Composition, extraction, potential health benefits, and other useful applications. Asian Journal of Medical and Biological Research, 9(2), 93–101. https://doi.org/10.5958/2395-0450.2021.00032.9
21. Kazima. (2022). Turmeric essential oil manufacturer & wholesale suppliers in India. Retrieved from https://www.kazima.in/turmeric-oil/
22. Kumari, A., Prasad, C., & Kumar, R. (2021). Essential oil and curcumin content in different varieties of turmeric (Curcuma longa L.). The Pharma Innovation Journal, 11(1), 841–844. Retrieved from https://www.thepharmajournal.com/archives/2021/vol11issue1/PartL/11-1-84-953.pdf
23. Lin, X., & Chen, M. (2017). Thermodynamics and kinetics of chemical reactions. *Chemical Science Reviews*, 33(1), 102-116.

24. López, R. G., Rivas, R., & Rodríguez, R. (2017). Soxhlet extraction: A classic technique with significant applications in natural product extraction. Food Research International, 100, 377-387. https://doi.org/10.1016/j.foodres.2017.06.022
25. Martinez, R., & Hall, D. (2019). Entropy changes in thermodynamic processes. *Industrial Thermodynamics Journal*, 55(5), 187-202.
26. Michaud, C., Gauthier, C., & Dupont, A. (2020). Optimization of extraction conditions for plant oils: The application of response surface methodology (RSM). Phytochemical Analysis, 31(6), 574–580. https://doi.org/10.1002/pca.2990
27. Nguyen, Q. T., Tran, T. H., & Do, T. K. (2019). Kinetic and thermodynamic modeling of soybean oil extraction using sub critical water. *Journal of Food Processing and Preservation*, 43(8), 14060.
28. NHR Organic Oils. (2022). Certificate of analysis sheet organic turmeric essential oil. Retrieved from https://www.nhrorganicoils.com/uploads/certs/Turmeric%20CofA%20010922-4.pdf
29. Nwabanne, J. T. (2012) 'Kinetics and Thermodynamics Study of Oil Extraction from Fluted Pumpkin Seed', International Journal of Multidisciplinary sciences and Engineering, 3(6), pp. 11–15.
30. Oyemitan, I. A. (2017). Neuropharmacological profile and chemical analysis of turmeric oil. Journal of Medicinal Plants Research, 11(13), 196-203. https://doi.org/10.5897/JMPR2017.5936
31. Paul, B. K., Munshi, M. M. U., Ahmed, M. N., Saha, G. C., & Roy, S. K. (2011). The fatty acid composition and properties of oil extracted from fresh rhizomes of turmeric (Curcuma longa Linn.) cultivars of Bangladesh. Bangladesh Journal of Scientific and Industrial Research, 46(1), 127–132. Retrieved from https://www.banglajol.info/index.php/BJSIR/article/view/7048
32. Rahman, F., Iqbal, J., & Singh, R. (2018). Influence of solvents on the extraction kinetics of ginger essential oil. *Food Chemistry*, 240, 1132-1138.
33. Sharma, P., & Gupta, S. (2022). Thermodynamic principles in industrial processes. *Journal of Thermochemical Engineering*, 29(3), 321-338.
34. Singh, P., Yadav, A., & Chauhan, S. (2021). Solvent extraction of essential oils: Optimization and effects of solvents on yield and quality. Industrial Crops and Products, 159, 113020. https://doi.org/10.1016/j.indcrop.2020.113020
35. Smith, J., & Jones, K. (2018). Introduction to chemical reaction kinetics. *Chemical Engineering Review*, 45(4), 120-139.
36. Sulaiman, R., & Abdullah, M. A. (2017). On Comparative study on kinetics and thermodynamics of neem oil extraction using Soxhlet and ultrasonic-assisted methods. *Industrial Crops and Products*, 96, 70-80.
37. Tanvir, E. M., Islam, M. S., & Hossain, M. A. (2018). Comparative study on the chemical properties of turmeric oil from different regions of Bangladesh. Journal of Essential Oil Research, 30(5), 335–341. https://doi.org/10.1080/10412905.2018.1494182
38. Venkatramna Perfumers. (2022). Turmeric (Curcuma longa) pure essential oil. Retrieved from https://venkatramna-perfumers.com/ProductDetail.aspx?Category=Natural+Essential+Oils+&Title=Turmeric+%28Curcuma+longa%29+Pure+Essential+Oil.
39. Wang, Y., Li, J., & Chen, M. (2021). Extraction kinetics of ginger essential oil: Application of kinetic models. Chemical Engineering and Processing: *Process Intensification*, 167, 108421.
40. Zhang, L., Liu, H., & Wang, J. (2018). Modeling essential oil extraction processes using pseudo-second order kinetics. *Separation and Purification Technology*, 201, 150-158.
41. Zhang, Z., Li, L., & Chen, J. (2019). Supercritical CO_2 extraction of lipids from microalgae: A review on methodology, efficiency, and applications. Renewable and Sustainable Energy Reviews, 101, 341-358. https://doi.org/10.1016/j.rser.2018.11.026
42. Zhao, W., Liu, Q., & Wang, H. (2019). Energy efficiency and thermodynamics. *Journal of Chemical Process Optimization*, 15(2), 234-250.
43. Zhao, Y., Zhang, Z., & Li, H. (2020). Microwave-assisted extraction of bioactive compounds from medicinal plants: A review of recent developments. Molecules, 25(12), 2865. https://doi.org/10.3390/molecules25122865