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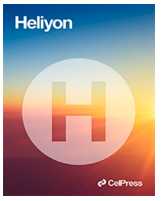

Research article

Kinetics and thermodynamic studies on oil extraction from Ghanaian cashew kernel using hexane

Emmanuel Boafo Baidoo [a], Samuel Kofi Tulashie [a,b,*], Michael Miyittah [c], Enoch Mbawin Alale [a], Kingsley Enoch Adukpoh [d], George Wardu Agyekwaga [a], Philomina Adams Asante [a]

[a] *Industrial Chemistry Section, Department of Chemistry, School of Physical Sciences, College of Agriculture and Natural Sciences, University of Cape Coast, Takoradi - Cape Coast Rd, Cape Coast, Central Region P.M.B. University Post Office, Ghana*
[b] *Department of Chemical and Renewable Energy Engineering, School of Sustainable Engineering, College of Agriculture and Natural Sciences, University of Cape Coast, Takoradi - Cape Coast Rd, Cape Coast, Central Region P.M.B. University Post Office, Ghana*
[c] *Department of Environmental Science, School of Biological Sciences, College of Agriculture and Natural Sciences, University of Cape Coast, Cape Coast, Ghana*
[d] *Department of Chemistry, College of Science, Kwame Nkrumah University of Science and Technology, Kumasi, Ashanti Region, Ghana*

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ABSTRACT

This study underlines all the techniques adopted to extract and define the oil that was extracted from cashew kernels and also to figure out if it fits the bill for applications in industrial operations. Using the solvent extraction method, the oil was obtained at different extraction times and temperatures. At the maximum temperature 333 K, the highest yield of the oil (34.7 %) was obtained at the highest extraction time 130 min adhering to first order kinetics. The mass transfer (k_m) and the regression coefficient (R^2) were 0.0115 and 0.9853 respectively. The activation energy (E_a), the entropy changes (ΔS), the equilibrium constant (K) and the enthalpy change (ΔH) were 59.958 KJmol^{-1}, 228.4 KJmolK^{-1}, 7.54 and 70.29 KJmol^{-1} respectively. The activation enthalpy (ΔH^*), entropy (ΔS^*) and Gibbs free energy (ΔG^*) were 57.2880 KJmol^{-1}, −0.1617 KJ (molK)$^{-1}$ and 114.834 KJ mol^{-1}, respectively, favoring an endothermic, irreversible, and spontaneous extraction. The negative Gibbs free energy range of −2.3342 KJ(molK)$^{-1}$ to −5.7602 KJ (molK)$^{-1}$ indicated the feasibility of oil extraction from cashew kernels. Also, some major fatty acids compositions that were identified in the oil after characterization were oleic acid (71 %) and linoleic acid (32 %). The oil's bond and potential functional groups were identified using the Fourier Transform Infrared analysis (FTIR) which indicated the presence of O–H, C–H, C–N, C═O, C–C and = C–H.

1. Introduction

Globally, the cashew industry has been recognized as the third largest producer of edible nuts, with an estimated value of US$2 billion and a production of roughly 2 million tons of nuts-in-shell in 2000. Both cultivated and wild trees are used to produce cashew nuts, and the four main producing regions are Tanzania, Brazil, India, and Nigeria [1]. The cashew kernel, a constituent of the cashew

* Corresponding author.
E-mail address: stulashie@ucc.edu.gh (S.K. Tulashie).

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seed, can be extracted using various extraction methods. One such product is the versatile cashew kernel oil (CKO), derived from the seed of the cashew fruit, which finds application in diverse industrial processes [2]. Due to the many advantages that cashew kernel oil offers, it is becoming more prevalent. Cashew nut contains a lot of different nutrients such as vitamins, minerals and other antioxidant properties which aid in the prevention of many diseases including cardiovascular and the enhancement of skin hydration and texture [3,4].

Most people discard the cashew seed after eating the edible cashew apple, despite the kernel's high oil content as reported by [5]. Also, comprehensive studies on the influence of the thermodynamics and kinetic parameters on the oil extraction may not have been done by many researchers, owing to the cashew kernel oil's economic importance, increasing the crop's output is required [1]. Oil from cashew kernel can be extracted using several methods including the mechanical process, extraction using solvent, hot oil process, supercritical fluids processes, and vacuum extraction. The technique most frequently employed to extract the oil from the seed is solvent extraction [6]. Enzymatic oil extraction is environmentally friendly, but it takes more time because it extracts oil at a much slower rate than solvent extraction methods [7]. Despite its efficiency, mechanical pressing often produces minimal quantity of oil [8]. Additionally, supercritical fluid extraction yields very high amount of oil in a very short time but at a higher operating and investment cost. Hexane's lower boiling point and relatively easy recovery make it an effective option for extraction [7,9]. Industry standard hexane is typically used because it yields more oil and this is most likely because additional ingredients, including methyl pentane, are present [10].

Several research conducted on various oil types by [11–13] reported that oil yield surges with rising contact time, ratio of solvent to oilseed, and increasing temperature using kinetics and thermodynamic concepts. Comparing their results, the coefficient of mass transfer of the oil was proportional to the rising temperature and extraction period. The thermodynamic studies in these research works highlighted the feasibility and impact of heat on the cashew kernel oil.

Therefore, this study aimed to extract, characterize, and determine the thermodynamic and kinetic processes involved in the process derived from the cashew plant. The oil was extracted by employing the method of solvent extraction to produce the oil at different extraction periods and temperature ranges by applying thermodynamic and kinetic concepts. Moreover, the physicochemical properties of the oil were determined by measuring the oil's iodine value (IV), acid value (AV), peroxide value (PV), and free fatty acid (FFA). The fatty acid composition, and the oxidative stability of the cashew kernel oil were determined by gas chromatography (GC) and Fourier Transform Infrared spectroscopy (FTIR), respectively.

2. Materials and methods

2.1. Experimental materials

The experimental materials used for the process include; cashew nut seeds, hexane, and distilled water. The equipment used for the study include; reflux apparatus, grinder, sample bottle, heater, magnetic stirrer, flasks, beakers, burette, measuring cylinder, G-clamp, flat bottom flask, water bath, weighing balance, pipette, thermometer, and stopwatch. Every reagent used to characterize the oil was of laboratory quality.

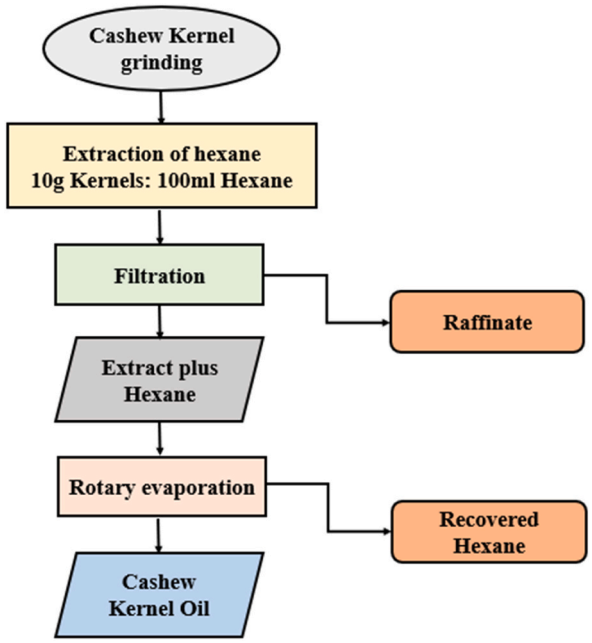


Fig. 1. Simplified flow chart of cashew kernel oil extraction.

2.2. Sample collection and preparations

The source of the cashew kernels was from the western region of Ghana specifically Bibiana, which was then transported and prepared at the chemistry laboratory, University of Cape Coast (UCC). The seeds were washed to remove contaminants and cut open to obtain the cashew kernels. The milled cashew kernels were then sieved to produce a uniform and fine texture, then smaller size of particulate.

2.3. Experimental procedures

2.3.1. Extraction with solvent

Procedures from previous research were applied to the solvent extraction of the powdered cashew kernel [13] at a temperature of 298 K using AOCS (2005) as the protocol. After being weighed, 20 powered samples obtained were divided into five groups, with 10g in each using a sartorius cp3202s and the solvent to volume ratio used for the experiment was 100 ml, that is a ratio of 1:10. The extraction was performed using reflux apparatus and the solvent used was hexane.

2.3.2. Thermodynamics and kinetics studies

During the extraction process, different temperatures of 318 K, 323 K, 328 K, and 333 K were used. 10g of milled cashew kernels were heated along with the hexane at a steady temperature of 318 K for varying extraction time ranges of 50, 70, 90, 110, and 130 min, at 20 min intervals. The steps were repeated for temperatures 323 K, 328 K, and 333 K. Afterward, the use of a rotary evaporator was deployed to recover the extract. The oil yield data was gathered and the kinetics, mass transfer, and thermodynamic parameters were examined. The processes involved in the oil extraction obtained from cashew kernels are simplified in Fig. 1 below.

2.3.3. Physicochemical analysis

Following the requirements of the International Standard Organization (2010), the cashew kernel oil's free fatty acid (FFA) content was determined and expressed as a percentage using the ISO 660:2009. In accordance with the AOCS procedure (AOCS Official Method Cd 8b-90, 2003) using a titrimetric analysis, the recorded peroxide value (PV) values were expressed in $meqkg^{-1}$. The AOCS procedure was followed in the analysis of the iodine value (IV) using (AOCS, 2009), with the findings represented in grammes of iodine per 100 g of oil [13].

2.3.4. Preparation of fatty acid methyl esters

The Slover and Lanza (1979) approach was used to prepare the fatty methyl esters (FAMEs) which were extracted from the cashew kernel oil [14]. Briefly, about 200 mg of CKO extracted was treated with 1 ml of methanolic sodium hydroxide at 100 °C for 15 min in stoppered round glass tubes. After cooling the tubes on ice, 2 ml of boron trifluoride was added and also boiled for another 15 min. Upon cooling the tubes containing the ice, 1 ml of iso-octane and 2 ml of saturated sodium chloride was added. The mixture was shaken vigorously and allowed to stand for layer separation. Analysis by gas chromatography (GC) was later performed on the upper hexane layer obtained comprising of the FAME that was transferred to a small tube stored at −20 °C.

2.3.5. Gas chromatography analysis on Fames

Analysis on fatty acid methyl esters (FAMEs) were carried out by the use of European Method EN14103:2011 [13] and methyl ester of nonadecanoic acid (Sigma Aldrich Chemical Co., Missouri, USA) while maintaining a 250 °C injector temperature. A ratio of 10 parts to 1 was employed for the split mode injection. The flow rate of the carrier gas (99 % of nitrogen gas) was 1 mL per minute. The column's initial temperature was set at 100 °C with no holding time, then increased at a rate of 6 °C/min until reaching 250 °C, where it was held for 25 min within the 50 min program. Throughout the process, the operation of flame ionization detector (FID) operated at a temperature of 260 °C. Identification of fatty acids (FAs) were accomplished by analyzing the holding times against a reference standard (C8 – C24 FAMEs Mixture, SUPELCO, Bellefonte, PA, USA). The FAME's response factor for each in the reference standard was determined using an internal standard [15].

2.3.6. ATR-FTIR analysis

A Bruker Alpha FTIR spectrometer with platinum attenuated total reflectance (ATRFTIR, BRUKER, KARLSRUHE, GERMANY) was employed to carry out FTIR spectra of CKO. In between 4000 cm^{-1} to 400 cm^{-1} throughout the CKO (samples) and background scans, every piece of equipment was thoroughly cleaned under standard laboratory conditions at the KNUST central laboratory (Kumasi, Ghana). All the spectra from the FTIR were collected by the use of OPUS program (BRUKER, KARLSRUHE, GERMANY) with a resolution of 4 cm over 32 scans [16].

2.3.7. Statistical analysis

The samples were triplicated and the results presented as mean ± standard deviation. All statistical data were analyzed with Origin Pro (version 2020, Northampton, MA, USA). The detection of various data obtained was analyzed using the one-way analysis of variance (ANOVA). The significant difference was assessed by the P-values ($P < 0.05$).

2.4. Results and discussion

In various industries, temperature and processing time stand out as the primary operational factors vital for cashew kernel processing. These parameters significantly impact the oxidative stability, physicochemical attributes, and overall quality of the yield obtained post-processing [3]. To comprehensively understand the impact of duration and temperature on the process of extraction, an in-depth exploration of the thermodynamics and kinetic studies governing the process was carried out [12].

2.5. Extraction yield and kinetic analysis of cashew kernel oil (CKO)

Table 1 presents the yield (%) of CKO across various extraction times and temperatures. The extraction process was investigated within a time range of 50–130 min with intervals of 20 min at temperatures of 318 K, 323 K, 328 K, and 333 K. Increasing both the temperatures and times of extraction resulted in higher yields, as indicated in Table 1. For instance, at 318 K, the yield percentage increased from 13.9 % to 28.2 % when the extraction time was extended from 50 to 130 min. Similarly, at temperatures 323 K, 328 K, 333 K, and extraction time range of 50 min to 130 min, the yield percentages increased from (13.9 %-25.3 %), (15.4 %–28.6 %), (18.3 %–32.7 %), and (21.8 %–34.7 %), respectively. The rise in yield obtained with increasing temperature aligns with literature according to other research works conducted by [17,18], as they indicate that the maximum yield was obtained at the maximum time and temperature. To achieve this, the general rate law, which is provided as follows, was used to calculate the extraction yield in minutes (50, 70, 90, 110, and 130);

$$\frac{dY}{dt} = k_a Y^n \tag{1}$$

where k_a is the extraction constant; The percent yield of oil obtained is represented by Y; n is the order of extraction, and the time of extraction is represented by t. The extraction constant (k_a), and the extraction order (n) can be obtained from equation (2) using equation (1). Eq. (1) was simplified into Eq. (2) [17]. as;

$$\mathrm{In}\frac{dy}{dt} = \mathrm{n\ In\ Y} + \mathrm{In\ k_a} \tag{2}$$

Plotting a graph of $ln\frac{dy}{dt}$ as ordinates and lnY as abscissa at the extraction temperatures (318 K, 323 K, 328 K, and 333 K) gives a linear graph as shown in Fig. 2 with a coefficient of substantial regression (R^2) values in Table 2. The extraction order(n) and extraction constant (k_a) from Table 2 were 1 and 0.0079 min^{-1} with increasing temperature. This relationship shows how temperature variations impacts the CKO extraction rate since higher temperatures need faster mass transfer, which increases the extraction rate [15,19].

As the temperature increased, the oil extracted remained unchanged beyond 333 K as shown in Fig. 3. At 110 and 130 min, there was a noticeable difference in the amount of oil extracted based on temperature [17]. This correlation is observable and reported in other investigations in the extraction of oil from oilseeds such as sunflower [6,20]. Also, from Fig. 4 it can be deduced from the graph that as time and temperature increased, there was also an increase in the yield due to the increased solubility of the sample in the solvent at elevated temperatures, allowing the solvent to effectively interact with the sample to produce a higher yield as reported by [17].

Mass transfer via convection and diffusion controls the extraction process due to the oil's concentration variations. In the seed, diffusion is more common than advection in the solvent [17]. It is difficult and complex to determine Fick's second law, but also necessary to analyze and explain the mass transfer using a model diffusion because the solid particles concentration is unknown [17]. The time of extraction in the liquid phase changes with the oil's mass concentration according to equation (3); Also, equation (3) can be integrated and re-written as shown in equation (4).

$$\frac{dC}{dt} = k_m \times \left(C_f - C_t\right) \tag{3}$$

$$-\ln\left(\frac{C_f - C_t}{C_f}\right) = k_m t \tag{4}$$

C_f and C_t represent mass concentrations of CKO at (C_f = 130 min and C_t at time, t) whereas k_m represents the mass transfer coefficient. The mass concentrations of the CKO in equation (4) can also be expressed in terms of yield as shown in equation (5).

Table 1
Oil obtained at various extraction temperature and times.

Time(min)	318K	323K	328K	333K
50	13.9	15.4	18.3	21.8
70	17.2	18.3	22.8	24.5
90	19.7	21.2	26.7	29.3
110	22	25.1	30.4	32.1
130	25.3	28.6	32.7	34.7

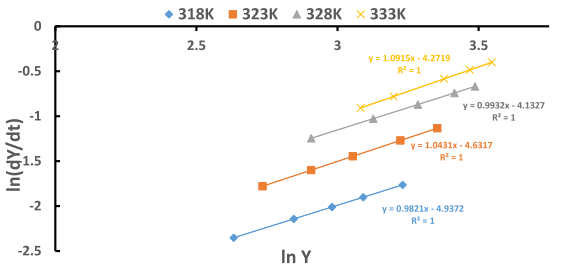


Fig. 2. Kinetics of extraction showing the orders at various temperatures.

Table 2
Values obtained for extraction constant (k_a) from cashew kernel oil.

Temperature/K	In (k_a)	k_a/min^{-1}	R^2	n
318	−4.9372	0.0072	1	0.9821
323	−4.6317	0.0097	1	1.0431
328	−4.1327	0.0160	1	0.9932
333	−4.2719	0.0139	1	1.0915
Mean ± S. D	−4.4933 ± 0.2812	0.0468 ± 0.0143	1 ± 0.0000	1.0275 ± 0.0389

S.D: Standard Deviation; $R^{2;}$ Regression Coefficient; n: Slope

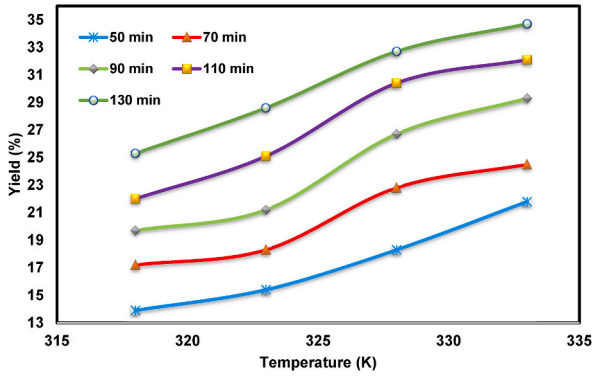


Fig. 3. Yield against temperature at various extraction time.

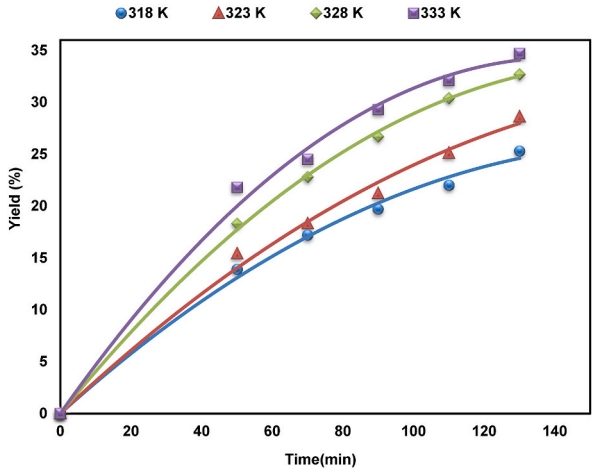


Fig. 4. Yield against time at various extraction temperature.

$$-\ln\left(\frac{Y_f - Y_t}{Y_f}\right) = k_m t \tag{5}$$

where Y_f represents percentage yield at 130 min; Y_t represents yield percentage at a time, *t*.

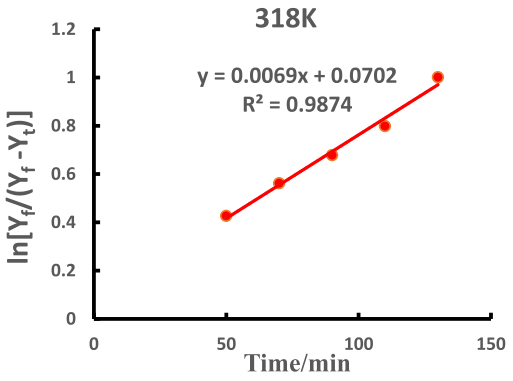
A graph of $\ln\left(\frac{Y_f}{Y_f - Yt}\right)$ against time as shown in Fig. 5 gives a linear graph where k_m is obtained as the slope. From Fig. 5(A, B, C, and D), the values for the regression coefficient obtained were above 0.9728 for all the temperatures 318 K, 323 K,328 K, and 333 K.

The coefficient of mass transfer, k_m rises proportionally as temperature also rises due to the reduced barrier to the mass transfer at the solid-liquid interface, as Table 3 illustrates. Several research works conducted on the extraction of various oils support this relationship. [13,21] discovered that employing ethanol as a solvent and extracting oil from jatropha seeds [22] at temperatures of 303 K, 313 K, 323 K, and 333 K increased the mass transfer coefficient. The capacity of the solid-liquid interface of the CKO is enhanced by the temperature-dependent tendency of the rise in Gibb's free energy.

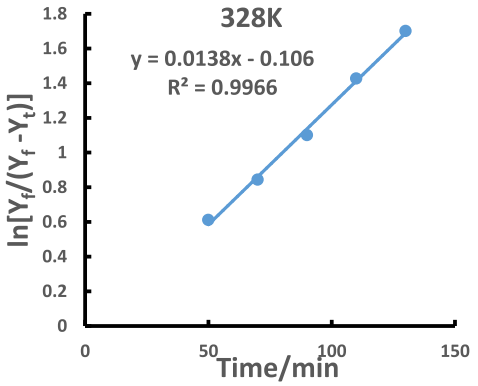
2.6. Thermodynamics study of extracted cashew kernel oil

Activation energy (E_a.) is the minimum amount of energy needed for every process of extraction [23]. Equation (7) is the linearized Arrhenius equation from equation (6). This enabled to establish the relationship between the corresponding temperatures, T, and K_m (extraction mass transfer coefficients).

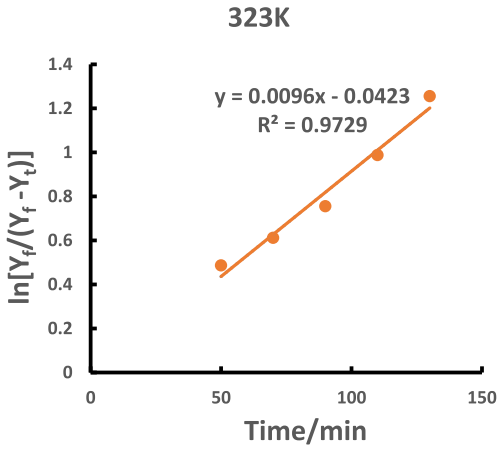
$$k_m = Ae^{-\frac{E_a}{RT}} \tag{6}$$



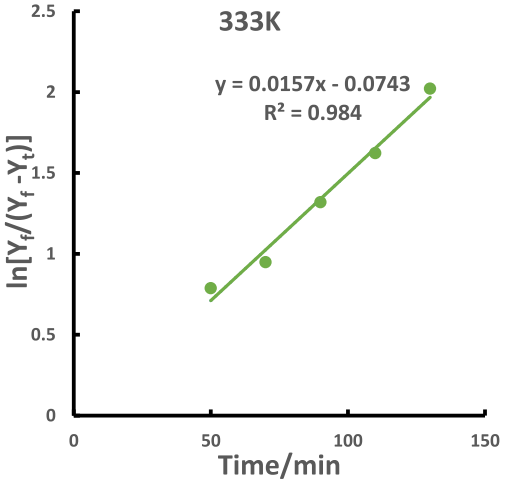
(A). ln [Y_f/(Y_f -Y_t)] against time at 318 K



(B). ln [Y_f/(Y_f -Y_t)] against time at 328 K



(C). ln [Y_f/(Y_f -Y_t)] against time at 323 K



(D). ln [Y_f/(Y_f -Y_t)] against time at 333 K

Fig. 5. (A)ln[Y_f/(Y_f-Y_t)] against time at 318 K. Fig. 5(B) ln[Y_f/(Y_f-Y_t)] against time at 328 K. Fig. 5(C) ln[Y_f/(Y_f-Y_t)] against time at 323 K. Fig. 5(D) ln[Y_f/(Y_f-Y_t)] against time at 333 K.

Table 3
Mass transfer coefficient (k_m) at varied temperatures.

Temperature (K)	k_m (min^{-1})	R^2
318	0.0069	0.9874
323	0.0096	0.9729
328	0.0138	0.9968
333	0.0157	0.9840
Mean ± S. D	0.0115 ± 0.0035	0.9853 ± 0.0085

S.D: Standard Deviation; R^2: Regression Coefficient.

$$\ln k_m = \frac{-E_a}{R}\frac{1}{T} + \ln A \tag{7}$$

where A represents the Arrhenius constant and R denote the universal molar gas constant expressed in kJ mol^{-1} K^{-1}. Plotting $\ln(k_m)$ against $1/T$ (K^{-1}) give a slope of $-\frac{Ea}{R}$ and intercept of $\ln A$ in Fig. 6 using the values obtained in Table 4.

The calculated activation energy was obtained to be 59.958 KJ mol^{-1} and the Arrhenius constant also to be 2.889 s^{-1} using the values obtained in the graph of Fig. 6. This E_a value demonstrates that diffusion through a constrained boundary layer holds the rate restrained [24]. The value of the activation energy (E_a) is relatively in line with earlier published extraction research on different types of oils [17].

The activation parameters of thermodynamics, namely activation enthalpy (ΔH*), activation entropy (ΔS*), and activation Gibb's free energy (ΔG*) were defined for each temperature for the extracted CKO by the use of Equations (8)–(10):

$$A = \frac{RT}{N_A h} e^{\left(\frac{\Delta S^*}{R}\right)} \tag{8}$$

$$\Delta H^* = E_a - RT \tag{9}$$

$$\Delta G^* = \Delta H^* - TAS^* \tag{10}$$

where N_A represents Avogadro's constant and h represents Plank's constant.

Table 5 displays average data for ΔH*, ΔS*, and ΔG* for temperatures 318 K, 323 K, 328 K and 333 K were evaluated to be 57.2880 KJ mol^{-1}, −0.1617 KJ $(mol\ K)^{-1}$ and 114.834 KJ mol^{-1}, respectively. Due to the internal energy level diminishing during the transition, a strongly negative value for ΔS* indicates a more complex transition and a lower extraction rate. Furthermore, the Arrhenius model equation's influence on Ea (59.958 KJ mol^{-1}) is equivalent to the Eyring equation's ΔH* (57.29305 KJ mol^{-1}) as shown in similar works according to [17].

The estimation of [ΔH, ΔS, K] and ΔG are determined using Equation (10). Also, Equation (11) below expresses the ratio of extracted oil to unextracted yield of the oil.

$$\frac{Y}{Y_u} = K = e^{kt} \tag{11}$$

$$\ln K = \frac{-\Delta G}{RT} = \frac{-\Delta H}{RT} + \frac{\Delta S}{R} \tag{12}$$

Where [K, Y_T, Y_u,H, S, G, R, T] are equilibrium constant, percentage oil yield unextracted, the percentage of oil yield extracted, enthalpy, entropy, Gibbs free energy, universal gas constant and absolute temperature respectively [11]. The Van't Hoff equation, sometimes is used in equation (12).

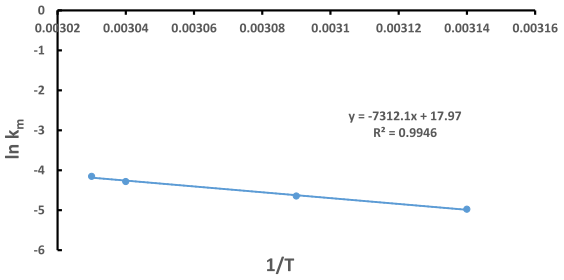


Fig. 6. ln k_m against 1/T.

Table 4
Values obtained for 1/T and ln K_m.

1/T (K)	In k_m
0.00314	−4.9762
0.00309	−4.6459
0.00304	−4.2831
0.00303	−4.1541

ln K_m: natural logarithm of K_m (mass transfer coefficient).

Table 5
Parameters of activation for the extracted cashew kernel oil.

Temperature(K)	ΔH* (KJ/mol)	ΔS* (KJ /mol)	ΔG* (KJ/mol)
318	57.3504	−0.1766	113.509
323	57.3094	−0.1764	114.392
328	57.2684	−0.1769	115.275
333	57.2240	−0.1770	116.158
Mean ± S. D	57.2880 ± 0.0470	−0.1617 ± 0.0002	114.834 ± 0.9872

S.D.: Standard Deviation; ΔH*: Activation enthalpy change; ΔS*: Activation entropy change; ΔG*: Activation Gibbs free energy.

A graph of ln (K) against T^{-1} at 130 min using equation (12) gives - ΔH/R and ΔS/R as the slope and intercept respectively as represented in Fig. 7.

The regression coefficient (R^2) yielded a value of 0.92, while ΔS and ΔH were respectively determined to be 228.4 KJ $(molK)^{-1}$ and 70.29 KJ/mol as illustrated in Fig. 7. Also, the physicochemical properties of the cashew kernel oil's internal energy correspond to the enthalpy in the reaction system. It is therefore necessary to note that the oil extraction process elevate the oil-solid mixture's entropy [13,24]. Reactions that have greater than zero values for both entropy and enthalpy change suggest that they are endothermic and irreversible, respectively.

As shown in Table 6, increased temperature by 5 K showed a significant increase in the equilibrium constant. The highest Gibbs free energy was observed at 333 K having a value of −5.7602 $KJmol^{-1}$. Also, the +K and the -ΔG values indicate the process of extraction was spontaneous and feasible [13].

2.7. Characterization of cashew kernel oil

Using heat to extract oil from oilseeds speeds up the extraction process and produces oil with a high yield and absolute purity. However, some research has shown that using heat during the extraction and processing of oil may cause thermal oxidation and deterioration, which could lower the oil's quality and shorten its life span [25]. To assess the cashew kernel oil's potential for industrial applications, it was required to characterize it following the thermal extraction process.

2.7.1. Fatty acid composition

Table 7 indicates the characterization of cashew kernel oil (CKO) that was utilized to analyze the amount of free fatty acids (FFAs) present. For CKO to be suitable for the best industrial application, processing, storage, and health benefit, its FA profile was essential. Cashew kernel oil is very essential in its applications such as cosmetics, lubricants, oil blends, resins, etc. for example high concentrated Oleic Acid, C18:1 content help in the use of production of numerous foods and products, such as textiles, face creams and lotions, soaps

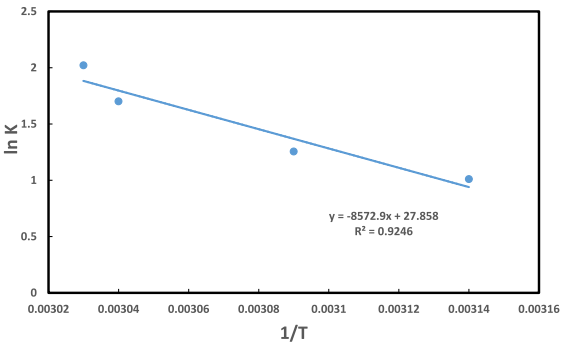


Fig. 7. A graph of ln K against $1/T$.

Table 6
Gibbs free energy and equilibrium constant for CKO at various temperatures.

1/T	K	In K	ΔG (KJ/mol)
0.00314	2.7210	1.0100	−2.3342
0.00309	3.5087	1.2552	−3.4762
0.00304	5.4784	1.7010	−4.6182
0.00303	7.5472	2.0212	−5.7602

ΔG: Gibbs free energy; K: equilibrium constant; ln K: natural logarithm of K.

Table 7
Cashew kernel oil profile showing the composition of free fatty acids.

Fatty acid%	318 K	323 K	328 K	333 K
Lauric acid (C12:0)	0.34 ± 0.04	0.35 ± 0.01	0.36 ± 0.03	0.35 ± 0.01
Palmitic acid (C16:0)	6.95 ± 0.02	6.58 ± 0.01	6.41 ± 0.01	6.85 ± 0.03
Stearic acid (C18:0)	8.08 ± 0.01	7.88 ± 0.03	8.39 ± 0.03	8.61 ± 0.02
Arachidic acid (C20:0)	0.59 ± 0.02	0.69 ± 0.01	0.54 ± 0.01	0.61 ± 0.01
Docosanoic acid (C22:0)	0.26 ± 0.01	0.33 ± 0.02	0.23 ± 0.02	0.28 ± 0.01
Lignoceric acid (C24:0)	0.39 ± 0.03	0.39 ± 0.02	0.48 ± 0.02	0.36 ± 0.01
Total SFAs	16.67 ± 0.01	15.72 ± 0.01	16.26 ± 0.01	16.76 ± 0.01
Palmitoleic acid (C16:1)	0.58 ± 0.01	0.74 ± 0.01	0.56 ± 0.01	0.43 ± 0.02
Oleic acid (C18:1)	70.55 ± 0.02	71.41 ± 0.03	70.03 ± 0.02	70.23 ± 0.01
Total MUFAs	71.13 ± 0.01	72.15 ± 0.01	70.59 ± 0.01	70.66 ± 0.01
Linoleic acid (C18:2)	30.61 ± 0.02	32.26 ± 0.01	31.89 ± 0.01	31.94 ± 0.02
Total PUFAs	30.61 ± 0.02	31.26 ± 0.01	31.89 ± 0.01	31.94 ± 0.02

Data are given as mean ± S.D; n = 3; S.D: Standard Deviation; SFAs (Saturated fatty acids) MUFAs (monounsaturated fatty acids) PUFAs (Polyunsaturated fatty acids).

and detergents, and more according to some published research works [14]. In Table 7, four primary fatty acids were noticed; Oleic Acid, OA (71 %), linoleic Acid, LA (32 %), stearic acid, SA (8 %), Palmitic Acid, PA (6 %) and with some other fatty acids having a concentration less than 2 %. The geographic area corresponding to the many cashew types available in other countries and locations may likely explain the low lauric acid level and other minor fatty acids present in the cashew kernel oil [26]. Saturated fatty acids (SFAs) constitutes 16 % of the composition of the oil, while monounsaturated (MUFAs) and polyunsaturated (PUFAs) made up of 71 % and 30 % respectively as shown in Table 7.

PUFA undergo intramolecular cyclization than other less unsaturated fatty acids [25]. In theory, oils having a higher degree of unsaturation requires a lot less energy to break down than oils with a high saturation level [27]. The latter's chemical structure has more double bonds, which easily break down when heated to a high sufficient temperature and change the composition of fatty acids [28].

2.7.2. FTIR analysis

The FTIR spectrum in Fig. 8 shows extracted cashew kernel oil at 318 K. Fig. 8 below shows a strong band of 2921.88 cm^{-1} and 2852.94 cm^{-1} which indicates that they both show a C–H stretch present in an alkane [29]. Also, the wavelength of 1744.21 cm^{-1} indicates C═O stretch in a carbonyl while the band of 1459.61 cm^{-1} indicates the presence of carbon single bond stretch in-ring which shows that there is a presence of aromatics. There is the presence of C–N stretch showing the presence of an aliphatic amines. The band of 722.16 cm^{-1} shows C–H rocking in an alkane.

Fig. 9 shows the FTIR spectrum of extracted cashew kernel oil at 323 K. This Fig. 9 below show bands at 2932.68 cm^{-1} and 2852.65 cm^{-1}, which is assigned to a C–H stretch in an aromatic compound. Also, a band with wavelength of 1743.82 cm^{-1} shows the presence of C═O stretching in an ester or saturated aliphatic compounds [30]. The band of 1460.51 cm^{-1} is assigned to C–H bending in an alkane. The band of 1377.03 cm^{-1} indicates the presence of C–H rock with an alkane. 1160.55 cm^{-1} band has the presence of C–N stretch with an aliphatic amine. The band of 721.96 cm^{-1} indicates that C–H rock is present in an alkane. Also, the band of 432.86 cm^{-1} indicates the presence of a benzene derivative with a C–H stretch.

Fig. 10 shows the FTIR spectrum of extracted cashew kernel oil at a temperature of 328 K. This Fig. 10 below also show bands of 2921.74 cm^{-1} and 2852.93 cm^{-1} showing the presence of C–H stretch having an alkane. The band at 1745.12 cm^{-1} has a C═O stretch having an ester or saturated aliphatic compound. Also, the band having the wavelength of 1709.70 cm^{-1} represents C═O stretch having an α, β-unsaturated aldehydes or ketones present in them. 1459.95 cm^{-1} is the band having or showing C–H bend in an alkane [29]. The band of 1161.89 cm^{-1} shows C–N stretch having an aliphatic amine. Also, the band at 937.76 cm^{-1} shows the presence of O–H bend in a carboxylic acid. The band at 721.96 cm^{-1} represents C–H rock in an alkane [30].

Fig. 11 shows the FTIR spectrum on the extracted cashew kernel oil at a temperature of 333 K. The band of 2921.83 cm^{-1} and 2852.92 cm^{-1} shows C–H stretch in an alkane. Also, the band at 1744.91 cm^{-1} shows the presence of a C═O stretch having an ester or an unsaturated aliphatic compound. The band at 1708.76 cm^{-1} indicates the presence C═O stretch having an α, β-unsaturated aldehydes or ketones present in them. Again, the band at 1462.96 cm^{-1}has a C–H bend in an alkane. 1282.52 cm^{-1} is a band assigned with a C–N stretch of an aromatic amine. The band at 1163.73 cm^{-1} has a C–N stretch of an aliphatic amine. Also, the band 963.18

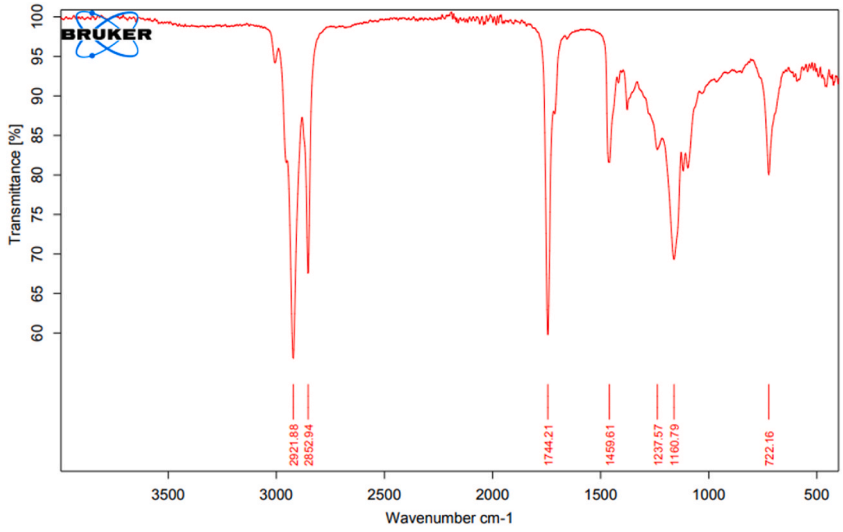


Fig. 8. Transmittance (%) against wavenumber (cm^{-1}) at 318 K

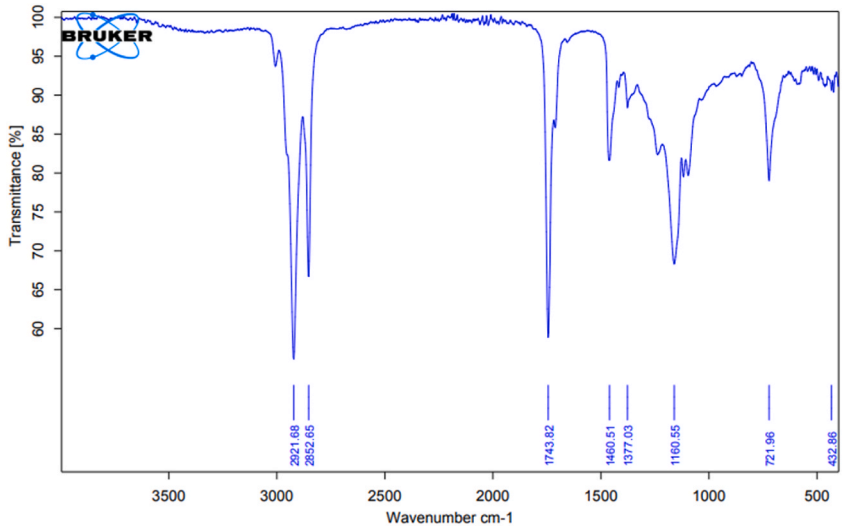


Fig. 9. Transmittance (%) against wavenumber (cm^{-1}) at 323 K

cm^{-1} shows the presence of = C–H bend which represent an alkene. The band 722.05 cm^{-1} has a C–H rock showing in an alkane.

2.8. Physicochemical properties of cashew kernel oil

According to published researches, majority of extracted oils have physicochemical characteristics that improve with storage [18]. Not all oils that is being extracted are good for consumption [31]. Research from [32] indicates that factors including oxidation and thermal deterioration might shorten the life expectancy of the oil when it is extracted, depending on how long and how much heat is used during the process that is why it is very necessary to do characterization on the oil [25]. Therefore, tests were done to determine the iodine value, peroxide value, acid value and FFA (free fatty acid).

The physicochemical properties highlight the importance and utilization of the cashew kernel oil at various temperatures of extraction. This information is very vital for various applications including, industrial processes, food industries, etc. as shown in Table 8.

2.8.1. Iodine value

The iodine test was done to determine amount of unsaturation in the cashew kernel oil. Therefore, higher iodine values are more susceptible to oxidation, which can lead to rancidity and decreased shelf-life. The iodine values for the cashew kernel oil for the

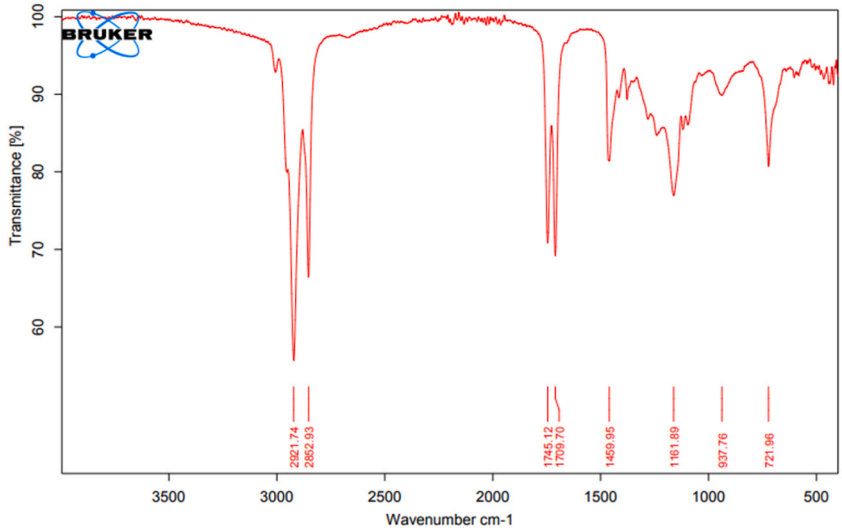


Fig. 10. Transmittance (%) against wavenumber (cm^{-1}) at 328 K

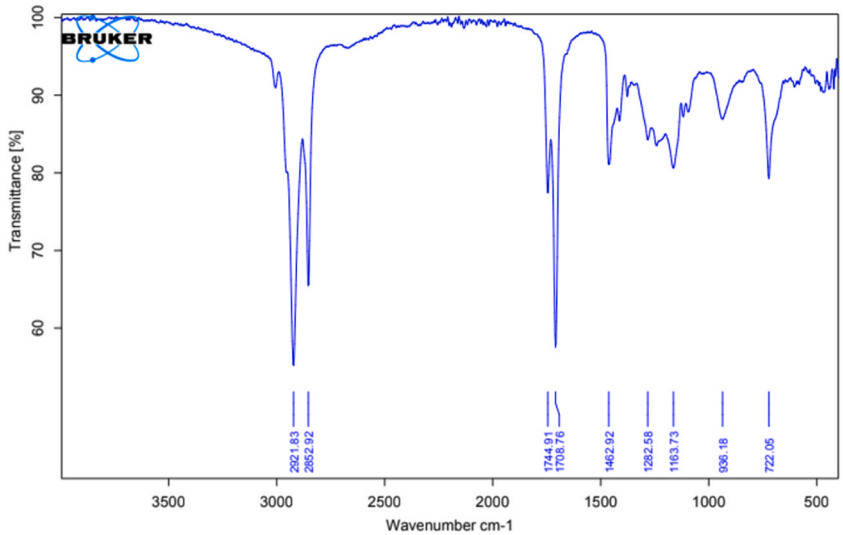


Fig. 11. Transmittance (%) against wavenumber (cm^{-1}) at 333K

Table 8
Physicochemical properties of cashew kernel oil (CKO).

Parameters	318 K	323 K	328 K	333 K
Iodine value (g/100g)	71.62 ± 0.07	76.89 ± 0.04	74.02 ± 0.05	75.31 ± 0.02
Peroxide value (meq/kg)	2.5 ± 0.11	2.6 ± 0.09	2.54 ± 0.13	2.61 ± 0.09
Acid value (mqKOH/g)	4.48 ± 0.12	5.43 ± 0.08	4.29 ± 0.10	4.98 ± 0.08
Free fatty acid (%)	2.24 ± 0.13	2.72 ± 0.11	2.19 ± 0.12	2.49 ± 0.09

Data are given as mean ± S.D; n = 3; S.D: Standard Deviation.

temperatures of 318 K, 323 K, 328 K and 333 K were obtained in Table 8 to be 71.62 mg iodine/100g, 76.89 mg iodine/100g, 74.02 mg iodine/100g and 75.31 mg iodine/100g as it is in relation with literature and researches [32] which was determined to have a range of 60–105 mg iodine/100g.

2.8.2. Peroxide value

Determination of the amount of peroxide present in the cashew kernel oil shows or indicates whether the oil will easily undergo

oxidation or rancid. The test was done on the temperatures of 318 K, 323 K, 328 K and 333 K and the values were obtained to be 2.50 meq/kg, 2.60 meq/kg, 2.54 meq/kg and 2.61meq/kg respectively as shown in Table 8. Therefore, the lower peroxide value in this cashew kernel oil makes it difficult for it to easily undergo oxidation [33].

2.8.3. Acid value

Acid value is the amount of free fatty acid generated by the hydrolytic breakdown of glycerides, which is enhanced by increase in temperature [34]. Determination of the extent of hydrolysis (breakdown by water) of triglycerides present in the oil was done using the acid value test. As oils degrade over time or due to poor storage conditions, free fatty acids are released as result of hydrolysis. The values obtained at each temperature (318 K, 323 K, 328 K and 333 K) after the test were (4.48, 5.43, 4.39 and 4.98) mgKOH/g respectively as shown in Table 8. These values obtained quantifies the amount of potassium hydroxide required to neutralize 1g of the extracted oil free fatty acid. Higher acid numbers in oil can also indicate the deterioration of the oil and since the acid values obtained were smaller, it can be useful for industrial purposes [32].

2.8.4. Free fatty acids

Molecules that have been separated from their parent triglycerides due to hydrolysis are the free fatty acids. This can occur naturally over time, especially if the oil is exposed to heat, light, and moisture. Free acids are undesirable as high FFA contents results in oxidative aging, they become rancid more quickly [14]. From Table 8 the values that were obtained for the free fatty acids at the various temperature were 2.24 %, 2.72 %, 2.19 %, and 2.49 %. This lower value in the FFA shows that the oil is not easily to become rancid [32].

3. Conclusion

This research studied the kinetics and thermodynamic parameters and their influence on the oil extraction. These studies showed that at the maximum temperature 333 K, the highest yield of the oil (34.7 %) was obtained at the highest extraction time at 130 min adhering to first order kinetics. As the temperature rises, there is a greater transfer of oil from the phases between the solid and the liquid because of the increase in the oil's chemical potential within the solid. Also, the parameters in thermodynamics ($+\Delta H$, $-\Delta G$ and $-\Delta S$) indicated that the process was endothermic, spontaneous and irreversible respectively and also having an activation energy of 59.958 KJ/mol. The bonds and functional groups that were present in the oil were O–H, C–H, C–N, C═O, C–C and = C–H. Also, the analysis on the physicochemical properties indicated that the oil was suitable for industrial applications.

CRediT authorship contribution statement

Emmanuel Boafo Baidoo: Writing – original draft, Validation, Software, Methodology, Formal analysis, Data curation. **Samuel Kofi Tulashie:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Conceptualization. **Michael Miyittah:** Writing – review & editing, Resources, Investigation. **Enoch Mbawin Alale:** Writing – original draft, Software, Methodology, Formal analysis. **Kingsley Enoch Adukpoh:** Methodology, Investigation, Formal analysis, Data curation. **George Wardu Agyekwaga:** Software, Formal analysis, Data curation. **Philomina Adams Asante:** Software, Formal analysis, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e32421.

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