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Design and Simulation of a Counter Current Extraction Column for The Production of 1,000kg/h of Coconut Oil.

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Abstract
This research focuses on the simulation, design, and kinetic modeling of coconut oil extraction from coconut seeds for pharmaceutical applications. The study aims to develop a scientifically sound and industrially scalable extraction process that ensures maximum oil yield while preserving the bioactive compounds essential for pharmaceutical formulations. Coconut oil, derived from Cocos nucifera, has been used for centuries in food and medicine due to its high content of medium-chain fatty acids such as lauric, capric, and caprylic acids, which possess antimicrobial, antioxidant, and anti-inflammatory properties. In recent years, renewed interest in natural oils and plant-based therapeutics has emphasized the need for efficient extraction methods capable of producing high-purity, pharmaceutical-grade coconut oil. The experimental work involved Soxhlet extraction using ethanol as solvent under controlled laboratory conditions. Process parameters such as temperature (55–80 °C), time (15–35 min), and initial concentration (20–40 g/mL) were systematically varied to evaluate their effect on extraction yield. The coconut seeds were cleaned, dried, ground to 150 µm particle size, and extracted at constant solvent volume (300 mL). The resulting oil was characterized for its physicochemical properties including refractive index, density, flash point, pour point, and cloud point. Data obtained from the experiments were analyzed using kinetic and mass-transfer models derived from Fick's law, and model parameters were computed using MATLAB and SIMULINK. Four kinetic models—zero-order, first-order, second-order, and power-law—were developed to describe the extraction behavior. The results indicated that temperature, extraction time, and initial concentration significantly influence the yield of coconut oil. Optimal conditions were obtained at 55 °C, 15 minutes, and 30 g/mL concentration, producing a yield of approximately 23.05 g/mL. At higher temperatures or prolonged extraction time, the yield decreased due to solvent saturation and loss of volatiles. The kinetic analysis revealed that the power-law model best represented the extraction at varying temperatures with a coefficient of determination ($R^2 = 0.9908$), while the zero-order model provided the best fit for conditions of constant temperature or concentration ($R^2 = 0.9915$ and 0.9316, respectively). These models accurately predicted the rate constants and mass-transfer behavior, validating their use in extraction process design. Using the validated models, a counter-current extraction column was designed and simulated in MATLAB for three cases—constant weight (Case A), constant temperature (Case B), and combined constant weight and temperature (Case C). Each configuration required 30 theoretical stages, with column heights fixed at 9 m and diameters of 1.3969 m, 1.4402 m, and 1.1178 m, respectively. Corresponding residence times ranged between 3.5 and 6.1 minutes, with efficiencies of 85 %. The column designs ensured sufficient residence time, controlled superficial velocity ($4.08 \times 10^{-4} – 7.06 \times 10^{-4}$ m/s), and safe mechanical limits (design pressure = 3×10^5 Pa; shell thickness = 6 mm; allowable stress = 1.2×10^8 Pa).

Keywords: *Coconut oil extraction, Mass transfer, Ficks law, Soxhlet extraction, Counter-current extraction colum, Kinetic modelling, MATLAB simulation, Chemical process design.*

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I. INTRODUCTION

Coconut oil, a versatile edible oil derived from the kernel or meat of mature coconuts harvested from the coconut palm (*Cocos nucifera*), has been an integral part of tropical diets and traditional medicine for centuries. Its usage dates back thousands of years in tropical regions, especially in Southeast Asia and the Pacific Islands, where it serves not only as a staple food source but also as a foundational element in traditional healing systems. The oil is valued for its long shelf life, high stability, and melting point of approximately 76°F (24°C), making it ideal for both cooking and industrial applications. (Dayrit, 2015).

Historically, coconut oil was widely utilized in the baking and food processing industries due to its oxidative stability. However, during the late 20th century, a widespread campaign against saturated fats, particularly tropical oils like coconut and palm oils, led to a significant decline in its popularity in Western

countries. Food manufacturers replaced coconut oil with hydrogenated polyunsaturated vegetable oils, particularly soybean oil, which unfortunately introduced trans fatty acids—now known to be detrimental to human health. (Hejazi & Amiji, 2003).

Recent scientific studies have led to a reassessment of coconut oil, particularly virgin coconut oil (VCO), highlighting its unique fatty acid profile—more than 90% saturated fatty acids, predominantly in the form of medium-chain fatty acids (MCFAs) such as lauric acid, caprylic acid, and capric acid. These MCFAs differ from long-chain fatty acids in that they are rapidly metabolized by the liver for immediate energy and are less likely to be stored as adipose tissue. As such, they bypass the carnitine transport system and enter the mitochondria directly for oxidation. (Gumilar *et al*., 2019).

Coconut oil's high lauric acid content (about 45–52%) has been shown to increase both high-density lipoprotein (HDL) and low-density lipoprotein (LDL) cholesterol levels. This dual effect creates a more balanced lipid profile, though the long-term cardiovascular implications are still a matter of scientific debate. Some studies suggest that regular consumption of coconut oil may raise cholesterol levels without necessarily increasing cardiovascular disease risk, due to the increase in protective HDL cholesterol (Eyres et al., 2016).

Moreover, coconut oil exhibits multiple therapeutic properties. Lauric acid and its monoglyceride derivative, monolaurin, possess potent antimicrobial, antiviral, and antifungal activities. Butyric acid found in small amounts has anticancer potential, while capric and caprylic acids exhibit antifungal effects. These health-promoting attributes have led to renewed interest in the potential pharmaceutical applications of coconut oil, including its role in drug delivery systems, antimicrobial agents, wound healing formulations, and anti-inflammatory therapies. (Isaacs *et al*., 2011).

The increasing global burden of fat-related disorders such as obesity, diabetes, cardiovascular disease, and cancer has led to an urgent need for natural alternatives with functional health benefits. Coconut oil, particularly when extracted using methods that preserve its bioactive components, presents a promising candidate for inclusion in pharmaceutical formulations

II. EXTENT OF PAST WORKS

Coconut oil has, over time, become one of the most researched tropical plant oils due to its unique fatty acid composition, wide range of applications, and potential health benefits. Extracted from the mature kernel or copra of the coconut fruit (*Cocos nucifera*), coconut oil is highly valued not only for its culinary and cosmetic uses but also for its medicinal and pharmaceutical potentials. Over the past few decades, coconut oil has moved from being vilified due to its high saturated fat content to being embraced by many researchers and health practitioners for its bioactive properties. (Megrab *et al*., 2017). Unlike most plant-based oils that are rich in long-chain unsaturated fatty acids, coconut oil is unique for its high content of medium-chain fatty acids (MCFAs), particularly lauric acid. These MCFAs are easily metabolized by the human body, making coconut oil a quick energy source and less likely to be stored as fat. Beyond its nutritional role, coconut oil possesses a variety of therapeutic properties, including antimicrobial, antioxidant, and anti-inflammatory activities. These attributes make it highly relevant in the pharmaceutical industry, especially for use in formulations such as ointments, creams, oral supplements, and drug delivery systems.

The coconut palm (Cocos nucifera), family Arecaceae, thrives in tropical littorals and is colloquially termed the "tree of life" due to its comprehensive utility (Gunn, 1991). The fruit comprises the fibrous exocarp, the lignified endocarp, and the endosperm (copra), which holds 60–70% oil by dry weight (Marina *et al*., 2009). Genetic diversity and geographic variation influence oil yield and composition, with some cultivars yielding up to 70% oil under optimal conditions (Perera, 2011).

Coconut oil's fatty acid distribution is predominantly saturated (90–92%), with lauric acid (C12:0) constituting 45–52% of total lipids, followed by myristic (C14:0), palmitic (C16:0), caprylic (C8:0), and capric (C10:0) acids (Marina et al., 2009; Eyres et al., 2016). Minor components include tocopherols, phytosterols, and phenolic compounds, which confer antioxidant capacity and oxidative stability (Onsaard, 2013). The high lauric acid content underlies antimicrobial efficacy via membrane disruption in pathogens (Kabara et al., 1972; Ogbolu et al., 2007).

Lauric acid and its monoglyceride, monolaurin, exert broad-spectrum antimicrobial effects, disrupting bacterial and fungal cell membranes (Kabara et al., 1972). In vitro studies report minimum inhibitory concentrations (MICs) of 0.05–0.1% against *Staphylococcus aureus* and *Escherichia coli* (Ogbolu et al., 2007). Its antioxidant action, measured via DPPH scavenging, reaches up to 65% inhibition at 1 mg/mL concentration (Onsaard, 2013). Topical application accelerates wound healing and reduces inflammation markers (IL-6, TNF-α) in rodent models (Nevin & Rajamohan, 2010).

III. MATERIALS AND METHOD

2.1 Materials Used

The materials used in this study includes grinded Allanblackia seed, thimble, sample bottles, and cellotape. The equipment employed comprised a clamp/retort stand, oven, weighing balance, Soxhlet extractor, heating mantle, condenser, mechanical grinder, and a gas chromatography–mass spectrometry (GC–MS) detector.

In addition, the apparatus used for the experimental procedures included a distillation apparatus, electrical heating mantle, stopwatch, beakers, round-bottom flask (500 mL), conical flask (250 mL), pipette, thermometer, and measuring cylinder.

The reagents utilized in the study were distilled water, 95% ethanol, anhydrous sodium sulfate, and an internal standard plant chemical

2.2 Method Used

2.2.1 Sample Collection and Preparation

Coconut samples were obtained from Calabar Market in Port Harcourt, Rivers State, Nigeria. The fruit and seed were thoroughly washed with distilled water and was cut in piecemeal, oven dried in a conventional oven at 50-60^{o}C for 48 hours to remove adherent moistures. The dried fruits and seeds were cooled in a dessicator after which was grinded using a mechanical grinding machine to a particle size and sieved thoroughly different Types of screens sizes to get the particles size 150µm.The samples was stored in air tight containers and labeled adequately.

2.2.2 Soxhlet Extraction Experiment

The experiment was carried out in a Soxhlet extractor using ethanol as solvents. The sample was weighed in 10g, 15g, 20g, 25g and 30g respectively and was charged each time in the Soxhlet extractor. The heating mantle was set at a specified temperature which varied from 60, 65, 70, 75 and 80^{oc} respectively at a different extraction time of 15, 20, 25, 30 and 35 minutes. The condenser was ensure that the solvent vapour cools and condenses it back to the thimble of Soxhlet extractor and in each gram charged into Soxhlet extractor or in each phase of the experiment, the temperature was varied between 60-80^{o}C and time 15-35minutes.

Firstly, the weighed sample was charged into the thimble and inserted into Soxhlet extractor and 300ml of ethanol was charged into 500ml round bottom flask of Soxhlet extractor. The flak was heated via electrical heating mantle at a set temperature. The solvent was vaporized and the solvent vapor started rising through the siphon tube in Soxhlet extractor into the condenser (cooled with running water). The condenser condensed the rising solvent vapor, causing it to return and percolate through the sample in the thimble of the Soxhlet extractor where it may permeate into the sample matrix and dissolve the target analytes. When the condensed solvent reaches the top of the siphon tube, the solvent-solute mixture (the extract), was siphoned.The mass transfer, thermodynamics and kinetic parameters of coconut seed was studied in each phase of the experiment, while the temperature was varied between 60-80^{0}C and time 15-35minutes in each stage of the experiment.The extracted oil + solvent was collected and distilled at 60-80^{o}C to separate the solvent from extracted oil (Wami and Ezen Wankwo, 2022), Ethanol with lower boiling temperature was distilled out leaving only the oil in the distillation flask. The recovered oil was weighed and the yield was determined.The percentage of oil yield, percentage solvent recovered and solvent lost and efficiency of the oil was determined.

2 .2.3 Analysis of Physio-Chemical Properties of the Extracted Oil

The physical and chemical properties of the produced oil is characterized as,

2.2.3.1 Refractive Index

Abbe's Refractometer (ASTMD 1218) Refractive index shows the ratio of the velocity of light in a vacuum to the velocity of light in the oil. It is generally expressed as the ratio between the sine of the angle of refraction when ray of light of a known wavelength (usually 589.3.mu the mean of d-lines of sodium) passes from air into the oil. It's useful for identification of sample, for establishment of purity and for observing the progress of reaction.

Procedures

i. A shinny light (lamb) standing behind the refractometer was switched on.
ii. The prison box was opened by releasing toggle on the right hand side, swung on the left and cleaned with acetone and wool.
iii. Drops of oil was placed on the fixed prison and closed, with the eye on the upper telescope, the lower control knob was turned anti-clockwise until the field is divided into two equal parts, light and dark field.
iv. The border line between the field may occur due to dispersion from the lamb.
v. The scale reading was observed in the lower telescope and the number behind the point was interpolated.

2.2.3.2 Flash Point (Pensky-Martens ASTND93)

Flash point is a lowest temperature at which the application of the ignition source causes the vapors above the liquid to ignite.

2.2.3.3 Pour point (ASTMD 97-96)

Pour point is the temperature at which the fluid refused to flow.

2.2.3.4 Cloud point (ASTM D97-96)

The test ascertains the temperature at which the wax crystals that causes oil to be cloudy forms.

2.2.3.5 Determination of Density

A picnometer of 25ml volume was used for the density determination the empty picnometer was weighed on weighting balance and recorded as W_1.

The weighed picnometer was filled with the extracted coconut seed oil and allowed to spill through the cover of picnometer, the spilled oil was cleaned with a dried cloth and re-weighed recorded as W_2.

Equation 1: Shows the mathematical expression

Density (q) = $\frac{mass}{volume} = \frac{m}{v}$

Where m = $W_2 - W_1$

V = volume of the picnometer

2.3 Development of Predictive Extraction Rate Models

The extraction models and the diffusivity model are developed from mass transfer balance in the leaching process/extraction process, adopted from Fick's law (Coulson and Richardson, 2006).

From Fick's law, the molar flux of the leaching process is defined as,

$$N_A = \frac{D_{AL}}{b}(C_s - C) = K_L(C_s - C) \quad (1)$$

Where, N_A = Molar flux for the oil (Kmol/sm^2)

D_{AL} = Diffusivity coefficient (m^2/s)

b = Thickness of the oil film surrounding the particle (m)

C_s = Concentration of the saturated solution in contact with the particle (kg/m^3)

C = Concentration of solution in the bulk of the solution with time (kg/m^3)

K_L = Overall mass transfer coefficient of the liquid (mol/s)

The average molar flux is defined in term of the overall mass transfer coefficient as;

$$\overline{N_A} = K_L A\,(C_s - C) \quad (2)$$

Where, $\overline{N_A}$ = Average molar flux (kmol/s.m^2)

A = Area of seed-oil interface (m^2)

But, $\overline{N_A}$ is defined as;

$$\overline{N_A} = \frac{dm}{dt} = \frac{d\,(VC)}{dt} \quad (3)$$

Where, M is the mass of the solute (kg)

V is the volume of the vessel (m^3)

Thus, substituting equations (1), (2) into (3) gives

$$\frac{d(VC)}{dt} = D_{AL}\,\frac{A}{b}\,(C_s - C) \quad (4)$$

Where, M = VC

For a batch extractor Soxhlet, equation (4) becomes,

$$\frac{V\,dc}{dt} = D_{AL}\frac{A}{b}\,(C_s - C) \quad (5a)$$

$$\frac{dC}{dt} = D_{AL}\,\frac{A}{bV}\,(C_s - C) \quad (5b)$$

Defining Diffusivity in terms of rate constant,

then,

$$k = D_{AL}\frac{A}{b} \quad (6)$$

Diffusivity can be obtained as;

$$D_{AL} = \frac{kb}{A} \quad (7)$$

Where, k = rate constant for extraction process. Also, the mass transfer coefficient is defined in terms of Diffusivity coefficient as;

$$K_L = \frac{D_{AL}}{b} \quad (8)$$

Substituting equation (6) into equation (5) and integrate gives;

$$\frac{dC}{dt} = k(C_s - C) \quad (9)$$

Equation (3.9) is the rate of extraction of oil from seed in a batch (Soxhlet extractor)

$$\int_{C_0}^{C} \frac{dC}{C_s - C} = k\int_0^t dt$$

$$\ln\left[\frac{1}{C_s - C}\right]_{C_0}^{C} = kt \quad (10)$$

Substituting BC (bounding conditions) gives

$$\ln\left[\frac{C_S - C_o}{C_s - C}\right] = kt \quad (11)$$

If pure solvent is used, $C_o = 0$

IV. RESULTS AND DISCUSSION

3.1.1 Extraction Data from the Experiment

Table 1 indicates the yield of oil from the seed due to variation of temperature at constant time and initial concentration. The amount of oil recovered from the seed is dependent on the temperature at constant time and initial concentration. However, in the oil yield extraction experiment, the coconut seeds were subjected to a constant crushing time, while the temperature was systematically varied to assess its effect on oil yield.

Table 1: Yield of Oil from the Seed at constant Initial Concentration but varying Temperature

Temperature (^{0}C)	Time (min)	Initial Conc(g/ml)	Volume of Solvent Recovered (mL)	Volume of Oil Recovered (ml)	Final Conc(g/ml)
55	15	30	190	6.1	22.30
60	20	30	155	7.8	20.50
65	25	30	149	8.1	18.96
70	30	30	143	10.2	18.10
75	35	30	142	12.5	16.39

The concentration of the extracted coconut oil was optimized at a lower extraction temperature of 55°C, where a solvent extract concentration of 22.30 g/ml was obtained, as indicated in Table 2. This would enable more production of oil from the *coconut* seed and the extraction process would be favoured. The density of seed cakes still remains 693 kg/m^3 and volume of the solvent used was 300 ml and total weight of the seed was 455g.
During the experiment for oil extraction from coconut seed, the crushed seed and temperature were monitored using varying initial concentrations of seed. As the initial concentration increased, the final oil yield also increased while the temperature remained constant. This observation is consistent with the findings of Sam et al. (2024), who reported that varying temperatures at constant time and steady-state initial concentration influenced oil extraction from cotton seeds.

Table 2: Yield of Oil from Seed at constant Temperature but varying Concentration.

Temperature (^{0}C)	Time (min)	Initial Conc, Co (g/ml)	Volume of Solvent Recovered (mL)	Volume of Oil Recovered (g)	Final Conc, C(g/ml)
75	15	20	200	6.50	18.89
75	20	25	197	7.90	16.65
75	25	30	195	9.10	14.79
75	30	35	189	10.61	15.84
75	35	40	187	13.70	19.30

An increase in the initial seed concentration to 40 ml resulted in an improved final oil concentration of 19.30 g/ml, as shown in Table 4.2, indicating that higher initial concentrations promote greater oil recovery and favor the extraction process. The physical properties of the residue remained unchanged, with the seed cake density recorded at 693 kg/m^3, the solvent volume maintained at 300 ml, and the total seed weight measured at 455 g. In a complementary experiment, the coconut seeds were processed at a constant extraction temperature while the extraction time was varied. Under these controlled conditions, and with initial concentration kept constant, the final oil yield exhibited a decreasing trend with increasing extraction time.

Table 3: Yield of Oil from Seed at constant Concentration and Temperature

Temperature (^{0}C)	Time (min)	Initial Concentration, Co (g)	Volume of solvent Recovered (mL)	Volume of Oil Recovered, Y(g/ml)	Final Concentration (g/ml)
75	15	30	203	6.7	23.05

75	20	30	198	8.0	20.33
75	25	30	191	8.9	19.00
75	30	30	183	10.8	18.02
75	35	30	181	11.9	16.86

Also, the concentration of the final yield of oil from the *coconut* seed would be better if the time is minimal at 15 minutes and final concentration of 23.05g/ ml was produced as yield of oil. This would enable more production of oil from the *coconut* seed and the extraction process would be favored. The density of seed cakes still remain 693 kg/m^3 and volume of the solvent used was 300 ml at total weight of the seed was 455g.
Table 3 displays the rate constants values for the extraction of oils from the seed at varying concentrations. The rate of extractions affects the yield of oils from the seed. However, the rate constant for the extraction of oil from *coconut* seed was high enough at initial concentration and decreases to 0.1568 at concentration of 40 ml. This means that as the initial concentration increases then the rate constant would decrease to the nearest minimal.
Also, for the yield of oil from *coconut* seed to be enough for use in large and industrial quantity, hence the final concentration of the *coconut* seed would be high say 31.5 ml. This would enable the high yield of oil from *coconut* seed and the extraction process would be favoured for the process.

3.2 Determination of Model Kinetic Parameters for Yield of Oil from Seed at Constant Initial Concentration but Varying Temperature

The kinetic parameters for zero order, first order, second order and power law models are shown in table 4 with their respective values of coefficient of determination

Table 4: Model Kinetic Parameters for Yield of Oil at Constant Initial Concentration and Varying Temperature

Model	**Zero Order**	**First Order**	**2nd Order**	**Power Law**
Model Equation	$y = -kt + y_o$	$y = y_o e^{-kt}$	$\frac{1}{y} = kt + \frac{1}{y_o}$	$y = kt^n$
Model Parameters				
K	-0.3552	-0.0446	-0.0059	0.27085
N	--------	---------	---------	1.0741
y_o	-0.262	2.6923	3.6088	----------
R^2	0.9888	0.9529	0.8908	0.9908

Table 4 shows the determination of kinetic parameters for zero order, first order, second order, and power law model for yield of oil from the seed at constant initial concentration but with varying temperature. A careful examination of table 4.4 shows that if we are to judge the model that fits the experimental results closely, it would be power law followed by zero order, followed by first order and then finally second order. This conclusion is due to the fact that the value of the coefficient of determination (R^2) tells us how close a model best fits an experimental data, hence in this case power law model outperformed the other models because it has the highest value of coefficient of determination (R^2) of 0.9908 which technically means that it can account for 99.08% of the variability in the experimental results.

V.

Table 5: Model Kinetic Parameters for Yield of Oil at Constant Temperature but Varying Initial Concentration

Model	**Zero Order**	**First Order**	**2nd Order**	**Power Law**
Model Equation	$y = -kt + y_o$	$y = y_o e^{-kt}$	$\frac{1}{y} = kt + \frac{1}{y_o}$	$y = kt^n$
Model Parameters				
K	-0.2864	-0.0561	-0.0125	1.3785
N	--------	---------	---------	1.0741
y_o	-0.1.178	1.3557	1.94667	----------
R^2	0.9316	0.8406	0.7229	0.9079

Table 5 shows the determination of kinetic parameters for zero order, first order, second order, and power law model for yield of oil from the seed at constant initial concentration but with varying temperature. A careful examination of table 5 shows that if we are to judge the model that fits the experimental results closely, it would be zero order followed by power law, followed by first order and then finally second order. This conclusion is due to the fact that the value of the coefficient of determination (R^2) tells us how close a model best fits an experimental data, hence in this case zero order model outperformed the other models because it has the highest value of coefficient of determination (R^2) of 0.9316 which technically means that it can account for 93.16% of the variability in the experimental results.

Table 6: Model Kinetic Parameters for Yield of Oil at Constant Temperature and Initial Concentration

Model	**Zero Order**	**First Order**	**2nd Order**	**Power Law**
Model Equation	$y = -kt + y_o$	$y = y_o e^{-kt}$	$\frac{1}{y} = kt + \frac{1}{y_o}$	$y = kt^n$
Model Parameters				
K	-0.6336	-0.0811	-0.0127	0.01591
N	--------	---------	---------	1.9530
y_o	-0.6.688	1.0352	2.1231	----------
R^2	0.9915	0.9507	0.819	0.9877

Table 6 shows the determination of kinetic parameters for zero order, first order, second order, and power law model for yield of oil from the seed at constant initial concentration and temperature. A careful examination of table 4.6 shows that if we are to judge the model that fits the experimental results closely, it would be zero order followed by power law, followed by first order and then finally second order. This conclusion is due to the fact that the value of the coefficient of determination (R^2) tells us how close a model best fits an experimental data, hence in this case zero order model outperformed the other models because it has the highest value of coefficient of determination (R^2) of 0.9915 which technically means that it can account for 99.15% of the variability in the experimental results.

IV. CONCLUSION

The study focused on the evaluation of process conditions that affect the extraction of oil from coconut seed. The objectives of this study were carefully followed. The coconut seed was purchased, washed and sundried. The dried sample was then grinded. A determined quantity of n-hexane was then transferred and immersed into the Soxhlet extractor. A known quantity of the coconut seed was placed on the thimble of the Soxhlet extractor. The temperature and time of the extraction experiment was noted and recorded. The initial and final concentration was recorded and the volume of solvent recovered was also recorded with set time ranges from 15 – 35 minutes and the Soxhlet extractor operation temperature ranged of 55 – 75ºC.

The primary objective of examining the effects of temperature, time, and initial concentration on oil yield was successfully achieved. Results showed that these parameters significantly impact the efficiency of oil recovery, with higher temperatures of 60, 65, 70 and 75ºC, generally improving yield up to an optimal point of 40.3%, 52.90%, 55.6% and 60.69% respectively, at time of extraction of 15 to 35 min.

The study also met the objective of developing and applying kinetic models. Zero-order, first-order, and second-order and power law models were used to describe the extraction behavior in the following cases: when initial concentration was constant and temperature was varied, when temperature was constant and initial concentration was varied and when both were held constant. In the first case the kinetic parameter (k and yo) and coefficient of determination values were -0.3352, -0.262 and 0.9888, in the second case -0.2864, -0.1178 and 0.9316 while in the third case -0.6336, -0.0688 and 0.9915.

The study provides the following contributions to knowledge:

i. The study quantitatively demonstrated how extraction temperature, time, and initial concentration affect oil yield from coconut seed. This provides a framework for optimizing these variables to improve oil recovery in practice.
ii. Developed and Validated Kinetic Models Zero-order, first-order, and second-order and power law kinetic models were applied to the extraction process. Rate constants were calculated, and the best-fitting kinetic model was identified for the predictive yields at maximum temperature and time of 75ºC and 35 minutes. This contributes to the growing body of knowledge on modeling plant-based oil extraction

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