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MODELING THE EFFECT OF ETHANOL AND HEXANE ON PERCENTAGE OIL YIELD FROM COCONUT: A COMPARATIVE STUDY

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ABSTRACT

The research was aimed to comparatively study the effects of solvent extractions on three different species of coconut using developed model equations of extraction and experiment conducted. The research was useful for communities in West African countries that are significantly dependent on the financial gain from agrarian enterprise. The study was focused on the comparative performance evaluation of ethanol and hexane solvents on oil recovery from three different species of coconut (tall, dwarf, and hybrid). The effective extraction power was compared based on the quality and efficiency of oil extracted using an equal volume of the respective solvent. The solvent concentration has more effect on increasing oil extraction yield compared to extraction time and extraction temperature. Dwarf coconut species gave more oil than tall and hybrid coconut species with the organic solvents on the different factors affecting the adsorption process of oil from the coconut's species in terms of selectivity, reliability, and economics of the process. Also, looking at the result quantitatively and not economically, hybrid coconut species gave a high yield of the oil with hexane solvent, then tall and dwarf coconut species respectively.

KEYWORDS: comparative study, extraction, coconut, ethanol and hexane, species

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NOMENCLATURE

Symbol	Description	Unit
SVO	Straight Vegetable Oil	-
y	Yield of Oil	%
x	Concentration of Solvent	%
t	Extraction Time	min
T	Extraction Temperature	^{0}C
A, B, C	Coconut Species (tall, dwarf and hybrid respectively	-
hex	Hexane solvent	-
εth	Ethanol solvent	-
n	Stage Number	-
xf	Feed Composition of coconut meal	%
xn-1	(n-1)th composition of the coconut meal	%
yi	Yield of extract at stage i	%
S	Solvent Amount	g/L
A	Amount of solvent present in the coconut meal	%
Shex, Sεth	Slopes of hexane and ethanol solvents respectively	
Chex, Cεth	Intercepts of the hexane and ethanol solvents used respectively	

1. INTRODUCTION

Coconut oil is edible oil extracted from the kernel of mature coconut palm. It is a source of fats in diet of many homes and has various applications in food, medicine and industries. Coconut is extracted by dry and wet process (Ajewole, 2005; Robin, 2000; Richter et al., 2001; William, 2000). In spite of various techniques, wet processing is less viable than dry processing due to a 10-15% lower yield. Conventional coconut oil uses hexane as solvent to extract up to 10% more oil from just using rotary mills and expellers. Many health organizations advice against the consumption of high amounts of coconut oil due to its high level of saturated fat. Coconut oil is commonly used in cooking. It has been tested for use as a feedstock for biodiesel and can also be used as skin moisturizer, helping with dry skin. Increasing the extraction of oil to meet the rising demand for vegetable oils in different industries requires a suitable solvent which is readily available in the country at a relatively cheaper cost to replace Straight-run Naphtha, which is considered hazardous, expensive and occasionally scarce based on demand and cost of petroleum (Applewhite, 2000; Bennion, 2004; Franco et al., 2009; Huddlicky, 2000; Ogbu et al.,2008). This study therefore, sought to provide a fair idea on solvents such as Hexane and Ethanol in the extraction of Coconut oil giving a clear indication as to the best options and requirements for higher optimum oil recoveries from coconut using these two solvents. (Bourke and Harwood, 2009; Berlin, 2015; Bird et al., 2007, Fennema et al.,2006, Oyediji et al., 2006). Generally, an increase in temperature improves the solubility of lipids, as high temperature can disrupt the cohesive and adhesive interactions between oil molecules and oil-matrix molecules respectively, thus increasing the diffusion rate of the lipids. Kondamudi and Rahman (2008) found that the use of dichloromethane resulted in a slightly higher oil yield than hexane with a possible explanation being the drying process, which was carried out at a temperature of 50 °C and may potentially have led to incomplete moisture removal. Johnson et al, (2002) found out that the slightly polar character of dichloromethane may have been responsible for the slight oil yield increase relative to that obtained with hexane, as polar solvents can improve the oil extraction efficiency from wet samples. Caeteno et al, (2006) achieved a higher oil yield with heptane comparing to hexane and ethanol extractions, however, extractions with the various solvents were conducted for different and not specified durations (Depmer, 2003). Chien et al, (2003) concluded that because of the potential risks to human health and the environment associated with hexane use, many research efforts have been focused on finding alternative solvents (Foster et al.,2009). There are different types of mechanical extraction: expeller-pressing extraction is common, though the screw press, ram press, and Ghani (powered mortar and pestle) are also used (Foale, 2003, McCabe, 2001). Oil seed presses are commonly used in developing countries, among people for whom other extraction methods would be prohibitively expensive; the Ghani is primarily used in India (Bredson and Bill, 2003; Chukwuma, 2002; Erham, 2009; Gertz et al., 2006; Nagendra, 2011). However, the most common solvent is petroleum-derived hexane. This technique is used for most of the "newer" industrial oils such as soybean and corn oils. Supercritical carbon dioxide can be used as a non-toxic alternative to other solvents (Brady et al, 2002). Examples of the solvent are benzene, carbon tetrachloride, isopropyl alcohol, ethanol, and acetone (Hamburg, 2014; Gervajio, 2005, Hamid et al., 2011; Sacks et al., 2017; Oliveira et al., 2002; Kurian, 2007). Hexane and ethanol are chosen to be used for this project because; they extract more oil, cheaper and more available compare to others and also have no (lesser) negative health effect (Gunt, 2014). Many researchers did not identify which temperature range will affect extraction process (Ahangari and Sargolzaei, 2013; Brady et al., 2002). Also, the literatures were irrelevant in terms of the solvent best suitable in extraction of the oil from coconut seeds and the time and concentration of the solvent dependent or not for extraction process. (Bussy, 2000). The literatures did not also focus on parameters comparison. This forms the novelty of the present study.

The research is aimed to comparatively study the effects of solvent extractions on three different species of coconut using Hexane and Ethanol as Solvents.

2. MATERIALS AND METHODS

2.1. Experimental Methods

2.1.1. Extraction of vegetable oil from coconut using n-hexane

The experiments were carried out at the Chemical/Petrochemical Engineering Laboratory, of the Rivers State University. The weighing machine was checked for zero error. A clean and dry empty crucible was weighed and weight recorded. The meal was gradually put into the crucible on the weighing machine until its new reading exceeded the initial reading by 100g. At this point the meal was transferred into bags before putting it into the thimble of the Soxhlet apparatus. 150cm3 of hexane was measured in a measuring cylinder and poured into the round bottom flask. Heat was supplied to the round bottom flask by the electric heater which makes the hexane to boil. As it boiled, its vapor ascended through the siphon of Soxhlet into the condenser which condensed it. Timing started when the first condensate appeared and dropped into the extraction thimble. The condensate dissolved the oil contained in the meal. The mixture of the condensate and the dissolved oil dropped back to the round bottom flask where the solvent (hexane) which has lower boiling point kept on boiling and sending vapors to the condenser which condenses it into the extraction thimble again. Different timing period were used. At the expiration of each time, the electric heater was put off. At the end of these different extraction times, the round bottom flask containing the dissolved oil and the solvent was removed for solvent recovery experiment after reweighing. This procedure was repeated for new coconut meal feed also using hexane as the solvent.

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2.1.2. Recovery of solvent (Hexane) from the mixture of solvent and vegetable oil.

The apparatus was set up, then heat was applied to the round bottom flask by the electric heater. When the mixture boils the vapor of the lower boiling fraction (Hexane) ascends up and condenses into the beaker by the help of the condenser. The heating process continued until all the solvent in the mixture was evaporated and condensed into the beaker leaving only the vegetable oil in the round bottom flask. The distillate (Hexane) was noted. The volumes of the vegetable oil extracted was measured and recorded accordingly. This process was used to obtain the volume of vegetable oil in 150cm3 of solvent.

The procedure for extraction of vegetable oil from coconut using ethanol and the recovery of solvent (Ethanol) from the mixture of solvent and vegetable oil is same as the method stated above (see subsection 2.1.1 and 2.1.2).

2.2. Extraction-Model Development

Liquid-Liquid extraction model exist for co-current contract with immiscible solvents and counter current contract with immiscible solvents (McCabe, 2001). For better extraction of the oil from coconut, latter cases will be effectively implemented.

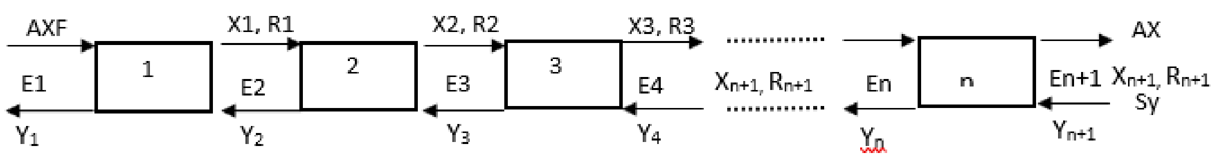

Figure 1. Counter-current contact with immiscible solvent

The material balance for the unit, 2nd, 3rd and nth stage given:

Rate of inflow = Rate of outflow [1]

1st Stage

$$AX_f + Sy_2 = AX_1 + Sy_1 \quad [2]$$

2nd Stage

$AX_1 + Sy_3 = AX_2 + Sy_2$ [3]

From (2): equation (3) becomes:

$AX_f + Sy_3 = AX_2 + Sy_2$ [4]

$A(X_f\text{-}X_{2)} = S(y_1\text{-}y_3)$ [5]

$y_3 = (A/S)\ (X_1\text{-}X_f) + y_1$ [6]

3rd Stage

$AX_2 + Sy_4 = AX_3 + Sy_3$ [7]

The sum of Eq. 4 and 6 gives:

$AX_f + Sy_4 = AX_3 + Sy_1$ [8]

$y4 = (A/S)(X_3\text{-}X_f) + y_1$ [9]

For nth - Stage

$AX_{n\text{-}1} + Sy_{n\text{-}1} = AX_n + Sy_n$ [10]

For the whole unit:

$AX_f + Sy_{n\text{-}1} = AX_n + Sy_1$ [11]

$y_n{=}A/S)(X_{n\text{-}1} - X_f) + y_1$ [12]

Hence, $y_{n\text{-}1} = (A/S)(X_n\text{-}\ X_f) + y_1$ [13]

where y_i= yield of extracts on stage i, X_f= Composition of coconut meal, S = Solvent amount, A = Amount of solvent present in the coconut meal

3. RESULTS AND DISCUSSION

The results obtained from the experiments are as presented and discussed below. The tables below vividly explain the comparative power of extraction of the ethanol and hexane on the three (3) different coconuts species i.e., Fruits from: Tall Coconut species assigned as A; Dwarf coconut species assigned as B and Hybrid coconut species assigned as C. The three factors affecting the extractions process are Temperature (℃), Time (min) and Solvent concentrations (%).

3.1. Effect of temperature, time and solvent concentration on oil yield

Table 1. Effect of temperature on oil yield during extraction from different species of coconut using ethanol and hexane as catalysts

Temp. (℃)	Specie A		Specie B		Specie C	
	Ethanol	Hexane	Ethanol	Hexane	Ethanol	Hexane
0	0	0	0	0	0	0
58	0.15	0.205	0.15	0.19	0.158	0.206
62	0.155	0.212	0.16	0.205	0.161	0.208
68	0.162	0.218	0.165	0.210	0.167	0.212

Table 2. Effect of time on oil yield during extraction from different species of coconut using ethanol and hexane as catalysts

Time (min)	Specie A		Specie B		Specie C	
	Ethanol	Hexane	Ethanol	Hexane	Ethanol	Hexane
0	0	0	0	0	0	0
60	0.20	0.232	0.18	0.20	0.210	0.240
72	0.22	0.25	0.20	0.23	0.225	0.255
80	0.245	0.27	0.22	0.25	0.230	0.265

3.2. Effect of solvent concentration on oil yield: comparing different species

Table 3. Effect of solvent concentration (%) on oil yield during extraction from different species of coconut

Solvent conc. (%)	Specie A		Specie B		Specie C	
	Ethanol	Hexane	Ethanol	Hexane	Ethanol	Hexane
0	0	0	0	0	0	0
0.75	0.19	0.24	0.20	0.23	0.18	0.25
0.90	0.24	0.288	0.25	0.278	0.23	0.30
1.00	0.27	0.33	0.28	0.320	0.26	0.34

In Figure 2, it was observed that %oil yield increases with increase in solvent concentration. However, the variation in %oil yield is due to effect of coconut specie and catalyst. It was revealed that addition of hexane catalyst produced more oil than ethanol (see Figure 2). Therefore, hexane performed better than ethanol interns of oil yield. Again, comparing the effect of coconut species, specie C produced more oil than A and B.

Figure 3A demonstrates the relationship between the yield of oil extract from species A coconut (tall tree) with hexane and ethanol and temperature. The equation of the lines is yεth=0.3342T+0.167 and yhex=0.2462T+0.1023 respectively for ethanol and hexane. The squares of the root mean values for the solvents are Rεth20.9955 and Rhex2=0.9934. This shows that ethanol solvent is more reliable than hexane tree coconut, though both are reliable. The order of the process is one indicating that the data used and obtained are reliable and acceptable. The slope of equations is Shex=0.3342 and Sεth=0.2462. Also, the intercepts for both lines are Chex=0.167 and Cεth=0.1023. Figure 3B depicts the yield of oil extracted from dwarf coconut (species B) varying with temperature using two different solvents (hexane and ethanol). The results indicated that yield increases with temperature for say 0^0 – 8^0C for both solvents usage. The R^2- values for both solvents are more than 50%, hence reliable results were obtained and acceptable data. The performances of the solvents show that ethanol solvent gave relatively high yield of oil from the dwarf coconut.

The equations of the lines for both are: yhex=0.0032T+0.001; Rεyh2=0.9964.

Thus Rεyh2>Rhex2, meaning ethanol solvent is more reliable than hexane solvent for extraction of oil. Both processes are of order one (1) indicating that data are acceptable and reliable. Again, Figure 3C shows that variation of yield of oil extracted from hybrid coconut fruit (species C) using hexane and ethanol and temperature. The variation is proportional at certain range of temperature (0^o – 8°C). Above this range, the yield does not increase, rather becomes quasi steady state. The equations of the lines are respectively; yhex=0.0033T+0.0022; R2=0.9887 and y=0.0026T+0.0013; R2=0.9929. The reliability of the process is such that ethanol solvent is more reliable than hexane solvent since R2=Rhex2, though all of them is reliable. The order of the processes is one (1) meaning that data and results are acceptable and reliable. Figure 3D depicts the variation of the oil yield extracted from tall tree coconut (species A) using ethanol and hexane and time. The results indicate that time is an essential parameter for the yield and the increase in time lead to the increase in the yield for both solvents. yhex=0.3461T+0.4567; R2=0.09884 and y=0.3089T+0.2538 process involving ethanol is more reliable than hexane because R2-0.9947>Rhex2=0.9884. Though both processes are reliable but the process involving ethanol is more reliable than hexane because R2=0.9947>Rhex2=0.9884. The order of both processes is one (1) meaning that the data and results are reliable and acceptable. The slope of the processes is respectively S=0.3089 and the intercepts of the processes are also Chex=0.4567 and C=0.2538. The performance of oil from coconut species A is high and reliable than the other solvent. In Figure 3E demonstrates the relationship between the yield of oil extracted from dwarf coconut using ethanol and hexane solvents and time. Time increases the yield of oil extract from coconut fruits as long as solvent last long on the Soxhlet apparatus for the leaching process. The comparative study for the solvent’s usage in terms of yield in such that ethanol solvent is better and more reliable than hexane solvent due to R2- values as shown in Figure 3E. The equation of the lines for the processes are respectively y=0.0039T+0.0015 and

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yhex=0.0032T+0.0019, where t = time in minutes. The order of the processes is one (1), hence data obtained and collected are reliable and acceptable. In Figure 3F shows the relationship between the oil yield extracts from hybrid coconut species (species C) using hexane and ethanol solvents and time (minutes). For both solvents, yield is a function of time, hence the equations of the lines of best fit shown as: y=0.003T+0.0058; R2=0.9766 and yhex=0.0035T+0.0064; Rhex2=0.9766. The reliability for both processes is the same and highly reliable since R2- values are 50% and above. The data collected and used for generation are highly reliable and acceptable. The order of the processes is one (1) as back-up by the previous statement. Comparatively, ethanol and hexane have same efficiency, hence same reliable. The slopes and intercepts are respectively Sεth=0.0035; Shex=0.003 and Cεth=0064; Chex=0.0058.

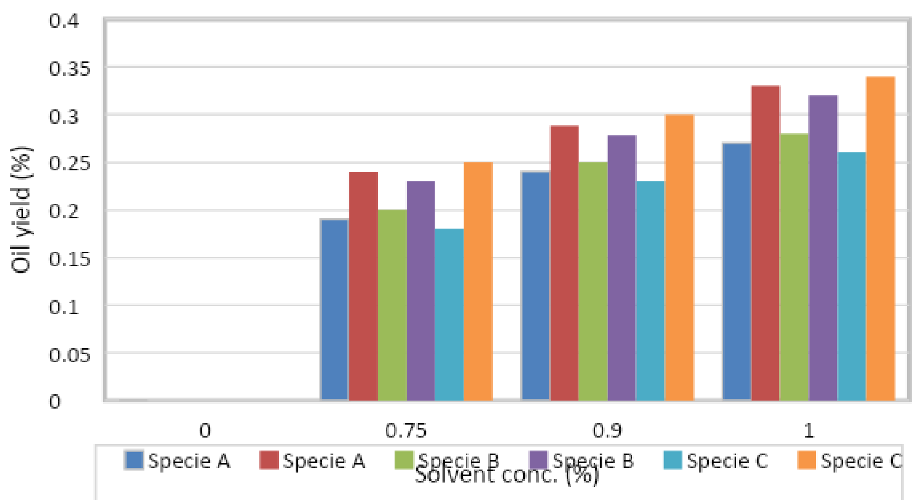

Figure 2. variation in oil yield extracted at different levels of solvent concentration

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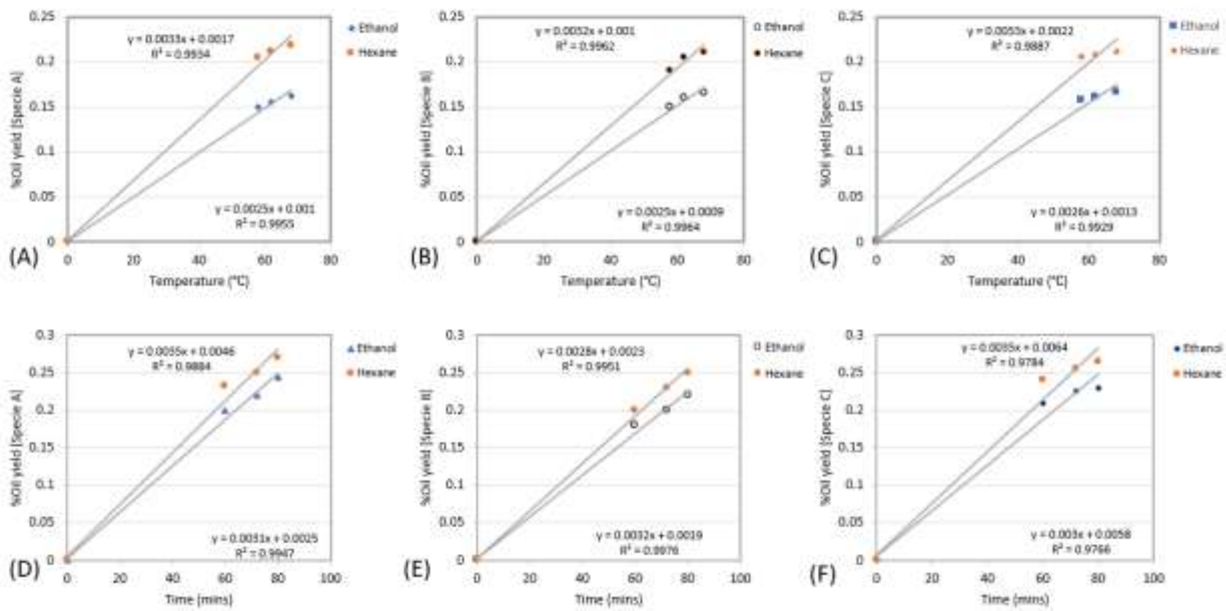

Figure 3: (A – C) effect of temperature on oil yield during extraction from different species of coconut using ethanol and hexane as catalysts, (D – F) Effect of time on oil yield during extraction from different species of coconut using ethanol and hexane as catalysts

Table 4. Summary of regression equations for oil yield prediction using temperature as the independent variable

Specie	Linear Equation		R^2		Remark
	Ethanol	Hexane	Ethanol	Hexane	
A	YTE=0.0033T+0.0017	YTH=0.0025T+0.001	0.99340	0.9955	Significant
B	YTE=0.0032T+0.001	YTH=0.0025T+0.0009	0.99620	0.9964	Significant
C	YTE=0.0033T+0.0022	YTH=0.0026T+0.0013	0.09887	0.9929	Significant

T=temperature, E= ethanol, and H = hexane

Table 5. Summary of regression equations for oil yield prediction using time as the independent variable

Specie	Linear Equation		R^2		Remark
	Ethanol	Hexane	Ethanol	Hexane	
A	YtE=0.0035t+0.0046	YtH=0.0031t+0.0025	0.9884	0.9947	Significant
B	YtE=0.0028t+0.0023	YtH=0.0032t+0.0019	0.9951	0.9976	Significant
C	YtE=0.0035t+0.0064	YtH=0.003t+0.0058	0.9784	0.9766	Significant

t=time, E= ethanol, and H = hexane

The linear regression equations and correlation coefficients showing the relationship between temperature, time and oil yield subjected to different catalysts have been summarized in Table 4 and 5. It was observed all species as well as catalyst effects have very strong relationship between oil yield and temperature and time. Therefore, the linear equations in Table 4 and 5 can be used to predict %oil yield at varying temperature and time using ethanal and hexane as catalysts.

4. CONCLUSION

In the present study, it was revealed that the extraction power of Ethanol is the best when compared to that of Hexane. Hence, Ethanol is a better solvent for extraction of oil from coconut meal when compared to Hexane in large scale process industries. The variation of oil yield with extraction temperature, extraction time and solvent concentration were carefully studied. To obtain the parameter varying with yield, the other parameters were held constant. At such, time and solvent concentration are held constant. While increasing the extraction temperature from 58, 62 and 68; there was an increase in extraction yield from 15, 15.5, and 16.2 %. When the temperature is kept constant at 65°C, and increasing extraction time from 60, 72 and 80 min, extraction yield increasing from 20, 22 and 24.5 % thus, extraction time has more effect in increasing oil extraction yield compared to change in extraction temperature. Similarly, when extraction temperature is kept constant at 65°C with the variation of extraction time and solvent concentration, it was observed that as the extraction time is kept constant at 90 min and also increasing the solvent concentration from 75, 90 and 100 %, there was an increase in extraction yield from 19, 24 and 27%. When solvent concentration is kept constant at 100%, and also increasing the extraction time from 60, 72 and 80 min, extraction yield increased from 20, 22 and 24.5% thus, solvent concentration has more effect in increasing oil extraction yield compared to extraction time and extraction temperature.

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