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ANALYSIS OF FACTORS THAT INFLUENCE RUBBER SEED OIL - BASED BIODIESEL PRODUCTION USING PRINCIPAL COMPONENT ANALYSIS AND KENDALL'S COEFFICIENT OF CONCORDANCE TECHNIQUES

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Abstract

The inability of oils and hydroelectric sources to meet the ever growing demand experienced in global energy in recent years has generated a lot of concern. The continuous increase in the demand for energy and the dwindling tendency of petroleum resources has steered endless search for alternative renewable and sustainable fuel. This study adopts a novel combination of Principal Component Analysis (PCA) and Kendall's Coefficient of Concordance (KCC) to analyze some factors that affect rubber seed oil-based biodiesel production which has been found to be a good substitute and most advantageous over petrol diesel because of its environmental friendliness. The KCC was used to analyze the data matrix generated by thirteen Judges who were requested to rank the thirty-one variables identified from relevant literature that influence biodiesel production in descending order of importance upon which basis an index of concordance in ranking among the judges was computed as W = 0.84. PCA was used to analyze the outcomes of the questionnaires crafted with thirty-one of the well-ordered variables, purposively selected, using statistiXL software. The results obtained by KCC provide basic insight into how consistent the Judges were in ranking the variables. The results by PCA shows that significant parsimony was achieved in factor reduction from thirty one variables to mere seven factors creatively labeled Chemical Process Dynamics, Reaction Circumstance, Factors Affecting Mixing, Miscellany and Rancidity which represent the principal factors that influence rubber seed oil-based biodiesel production. It is believed that the results of this study will be helpful and insightful in understanding the dynamics of interplay among the identified factors with respect to the quality of rubber seed oil-based biodiesel produced.

Keywords: Rubber seed oil, Biodiesel, Principal component analysis, Parsimony, Kendall's Coefficient of Concordance.

1. Introduction

Some concern has been raised over the inability of oils and hydroelectric sources to meet the ever growing demand experienced in global energy in recent decade. This dramatic growth can solely be traced to the continued requirements of transport and industry. Meanwhile, the International Energy Agency (IEA) has reported that the global energy demand in 2020 would be 14,896 million tons of oil equivalent (Mtoe) and up to

18,048 M toe by 2035.The finite supply and depletion of fossil energy reserves, coupled with increased energy consumption is placing higher demands on energy production [1]. According to [2] renewable energy technology was introduced as an alternative energy to fulfill these needs. He further stated that the renewable energy contributes only 20% to the global energy demand and the other 80% is still supplied by fossil fuels.

The use of fossil energy also has adverse effects on the environment, including global warming and climate change [3-4]. These anxieties have drawn the attention of researchers to the potential of biofuels [5-6]. Because they are extensively available in tropical zone and that they result from classic and simple process, vegetable oils have been considered for exploitation as biofuel. [7] defined biodiesel as a liquid fuel produced from edible or non-edible vegetable oil or animal fats while according to [8] it is an environmental friendly alternative energy, renewable, energy efficient, substitution fuel that does not sacrifice an engine's operational performance. Biodiesel has many environmentally beneficial properties. The main benefit of biodiesel is that it can be described as 'carbon neutral'. This means that the fuel produces no net output of carbon in the form of carbon dioxide (CO_2). This effect occurs because when the oil crop grows it absorbs the same amount of CO_2 as is released when the fuel is combusted. In fact this is not completely accurate as CO_2 is released during the production of the fertilizer required to fertilize the fields in which the oil crops are grown. Fertilizer production is not the only source of pollution associated with the production of biodiesel, other sources include the esterification process, the solvent extraction of the oil, refining, drying and transporting. Biodiesel can be produced from straight vegetable oil, animal oil/fats, tallow and waste oils. There are three basic routes to biodiesel production from oils and fats: Base catalyzed transesterification of the oil, Direct acid catalyzed transesterification of the oil and Conversion of the oil to its fatty acids and then to biodiesel. Almost all biodiesel is produced using base catalyzed transesterification as it is the most economical process requiring only low temperatures and pressures and producing a 98% conversion yield. Rubber seed, the agriculture residues considered as waste in the rubber industry has the potential to be a non-edible biodiesel production source. The oil content in rubber seed is high, between 40 and 50% [9], so it has attracted attention as a biodiesel raw material.

Researchers over the world have carried out research in various aspects relating to the use of rubber seed oil in biodiesel production using different methods and techniques. Notable among include [10] who carried out a comprehensive review of the biodiesel production methods of rubber seed oil. The article was written to be a reference in the selection of methods and the further development of biodiesel production from rubber seed oil. Abdul Shokib *et al*. [11] investigated the effect of reaction temperature, reaction time and molar ratio between methanol and oil on the yield of biodiesel product using rubber seed oil by Supercritical Methanol Method. Rismawati *et al*. [12] produced biodiesel from a traditional coconut oil using $NaOH/\gamma\text{-}Al_2O_3$ heterogeneous catalyst. The study involves producing biodiesel using base catalysts for a transesterification process with the variation of catalyst concentration and the time. In [13] biodiesel produced from rubber seed oil in the homogeneous transesterification is studied using a Plackett-Burman experimental design, a full factorial design, a central composite design and an Artificial Neural Network (ANN) coupled with a Genetic Algorithm (GA).Variables such as temperature, stirring speed, reaction time, type of alcohol, and type of catalyst were studied to obtain the best specific gravity and kinematic viscosity. [14] produced rubber seed biodiesel via the transesterification process under subcritical methanol conditions with nanomagnetic catalysts. The experimental results indicated that the KF/CaO-Fe3O4-Al nanomagnetic catalyst produced the highest FAME yield of 86.79%. [15] reviewed the production of biodiesel from waste cooking oil and factors affecting its formation while [16] reviewed various reaction parameters and other factors which affect the production of chicken fat based biodiesel. Widayat and Suherman [17] in 2012 studied biodiesel production from rubber seed oil via esterification process. The Parameters used in the study are the ratio of catalyst and temperature and its influence on the characteristics of the resulting biodiesel product. Similar studies in this area include: [18-21].

It is evident from the foregoing survey of literature that there exists paucity of research on the use of array of some relevant factors considered influential in the production of rubber seed oil based biodiesel using Principal Component Analysis (PCA) and kendall's coefficient of concordance (KCC). The major advantage of PCA approach adopted is that it provides a correlation matrix that relativizes the interplay among the identified factors.

The aim of this study therefore is to identify some factors that affect or influence the production of rubber seed oil-based biodiesel using Principal Component Analysis and Kendall's Coefficient of Concordance with a view to understanding the inter correlation among the identified variables.

2. Materials and Methods

2.1. Raw Material and Chemicals

The crude rubber seed oil used in this study was extracted from rubber seeds collected from Rubber Research Institute of Nigeria, Iyanomo, Benin City, Edo State, Nigeria. The seeds were dried, crushed, and the oil extracted using Soxhlet extraction method shown in Figure 1. All chemicals and reagents used in this study were analytical grade from Sigma Aldrich and were used without any further purification.

Figure 1: A Typical Soxhlet Extraction Set-Up

2.2 Methods
2.2.1 Kendall's coefficient of concordance (KCC)

Thirty one variables (scale items) were identified through wide literature survey. These variables were used to craft questionnaire administered to eighteen (18) knowledgeable respondents (the number of experts that were available at that time the questionnaires were administered) where only thirteen (13) were retrieved. These knowledgeable respondents otherwise known as expert Judges then ranked the variables in descending order of importance. The respondents' scores were collated into data matrix having a dimension of 13 by 31. The measure of agreement among the thirteen judges who ranked the scale items was computed. The consistency in the Judges ranking is represented by Kendall's coefficient of concordance. A test statistic called chi square (χ^2) was used to evaluate how consistent the judges were in ranking the scale items. The

χ^2 - test guided the application of hypotheses:

H_0 : Judges ranking are discordant

H_1 : Judges ranking are consistent

Decision Rule: if $\chi^2_{cal} > \chi^2_{tab}$, we then conclude that we do not have sufficient evidence to accept the null hypothesis, H_0 .

The Kendall coefficient of concordance is given by

$$W = \frac{S}{\frac{1}{12}K^2\left(N^3 - N\right)} \tag{1}$$

where,

$$S = \sum\left(R_j - \frac{\sum R_j}{N}\right)^2 \tag{2}$$

R_j = Column sum of ranks
N = Total number of Variables (Scale items)
S = Variance
K = Number of Judges

2.2.2 Principal Component Analysis (PCA)

Under this regime, the questionnaire that contained the thirty - one critical variables (scale items) was administered to 110 respondents (the number of experts that were available at the time the questionnaires were administered) for their expert evaluation where only 100 were retrieved. The respondents' scores were collated as data matrix that was fed into StatistiXL software which generated the following outputs namely: descriptive Statistic, correlation matrix, eigenvalues, eigenvector, unrotated factor loading, case-wise factor scores, varimax rotated factor loadings, explained variance and factor plot, among others. On the basis of this statistiXL outputs, factor matrix interpretation was rendered and results discussed.

3. Results and Discussion
3.1 Result of Kendall Coefficient of concordance (KCC)

The Kendall's coefficient of concordance *(W)*, can be calculated using equation 1.

i.e. $$W = \frac{S}{\frac{1}{12}K^2\left(N^3 - N\right)}$$

where,

$$S = \sum\left(R_j - \frac{\sum R_j}{N}\right)^2$$

From the Factor Ranking Matrix

$$\sum R_j = 7418$$

$$\frac{\sum R_j}{N} = \frac{7418}{31} = 239.29$$

$$S = \sum \left(R_j - \frac{\sum R_j}{N} \right)^2 = 352050.40 \text{ Therefore}$$

$$W = \frac{352050.40}{\frac{1}{12} \times 13^2 \left(31^3 - 31\right)} = \frac{352050.40}{419120} = 0.84$$

Also, $\chi^2_{cal} = K\,(N - 1)\,W$ (3)

where,
K = 13, N = 31, W = 0.84

$$\therefore\ \chi^2 = 13(31-1)0.84 = 327.60$$

Test of Hypothesis:

H_0 : The ranking of the thirteen (13) judges are discordant.

H_1 : The ranking of the thirteen (13) judges are consistent.

Since $\chi^2_{cal} = 327.60 > \chi^2_{tab} = 43.77$, we reject the null hypothesis (H_0) and conclude that the judges ranking of the 31 scale items were consistent.

Table 1 shows the merit order sequentiality of the thirty-one scale items ranked by the thirteen Judges. The R_js determine the ranking order.

Table 1: Merit order sequentiality of 31 variables for rubber seed oil based biodiesel production

S/N	Rj	Variables	S/N	Rj	Variables
1	70	Reaction temperature	17	265	Amount of reagents
2	71	Reaction time	18	272	Induction time
3	86	Catalyst concentration	19	276	Oxidative stability
4	87	Trans esterification	20	296	Type of reagents
5	99	Agitation speed	21	311	Environmental conditions
6	125	Type of catalyst	22	315	Reaction rate
7	134	Mixing intensity	23	325	Oil price
8	134	Purity of reactants	24	344	Oil availability
9	143	Oil molar ratio	25	348	Geographical location
10	165	Moisture content	26	353	Storage time
11	178	Alcohol molar ratio	27	369	Production method
12	181	Physicochemical properties	28	370	Oil type
13	213	Free fatty acid	29	395	Storage conditions
14	219	Thermal cracking (pyrolysis)	30	396	Moisture level
15	236	Density	31	405	Order of reaction
16	237	Kinematic viscosity			

3.2 Result of Principal Component Analysis (PCA)

The questionnaire that contained the thirty - one critical variables (scale items) was administered to 110 respondents for their expert evaluation where only 100 were retrieved. The data obtained from the questionnaire were arranged in matrix form based on the 5–point Resis-Likert scale. The scree plot showing the elbow at (7, 1) is depicted in Figure 2. It is obvious from the scree plot that at eigenvalue of 1, and component number 7, the curvity tends to flatten out, suggesting that seven factors extracted are adequate.

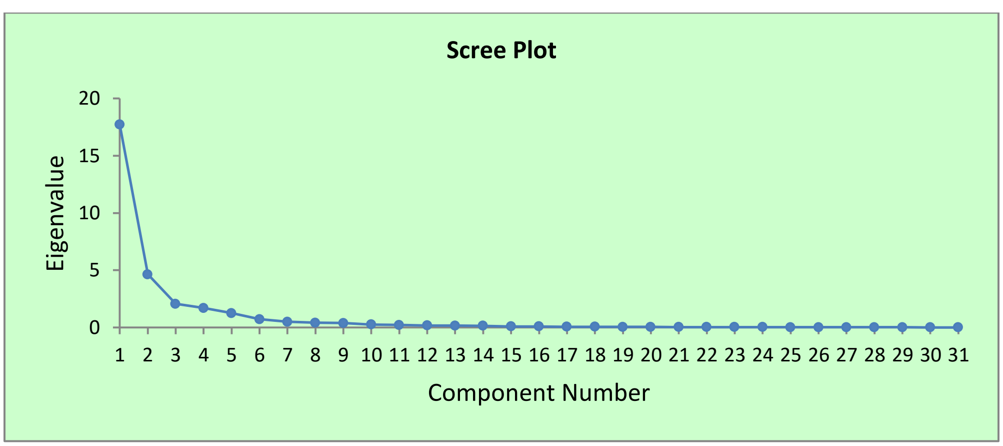

Figure 2: Scree Plot

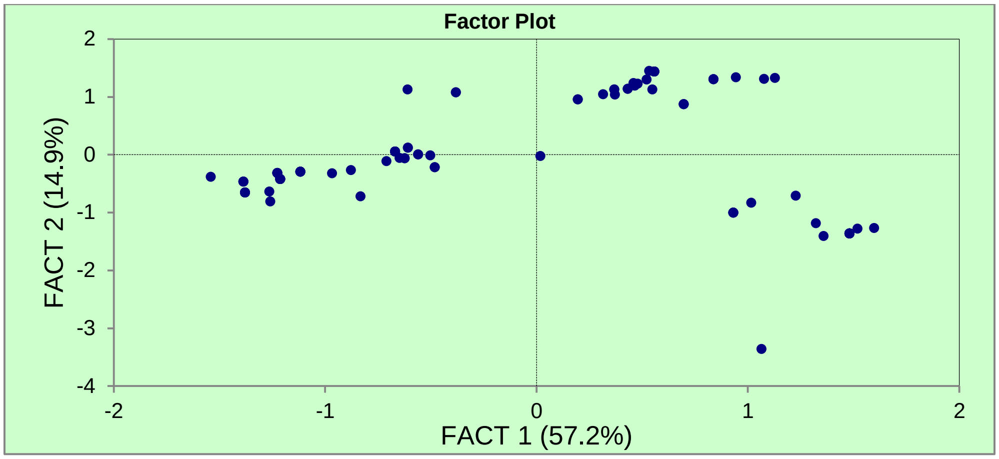

Figure 3: Factor Plot

This actually shows that there is significant parsimony in factor reduction from 31 to mere 7 unique factors. Figure 3 represent the factor plot of the 31 variables that influence the rubber seed oil- based biodiesel production process.

The result of the varimax rotated factor matrix is depicted in Table 2. The highest factor loadings are the ones in bold face. The varimax rotation was normalized and completed in 21 iterations.

Table 2: Varimax Rotated Factor Loadings matrix of 31 variables for Biodiesel Production

S/N	Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7
1	Reaction time	0.493	0.166	0.292	0.078	0.293	0.128	**0.721**
2	Reaction temperature	**0.886**	0.152	0.178	0.221	0.081	0.013	0.013
3	Agitation speed	0.455	0.095	**0.728**	0.227	0.113	-0.173	0.015
4	Catalyst concentration	**0.826**	-0.180	0.265	0.118	0.166	-0.241	0.240
5	Transesterification	**0.698**	-0.028	0.342	0.375	0.039	0.165	0.017
6	Type of catalyst	0.473	0.016	0.270	**0.822**	0.003	0.091	0.084
7	Mixing intensity	**0.917**	0.200	0.217	0.092	0.066	-0.015	0.038
8	Oil molar ratio	**0.642**	-0.005	0.338	0.458	0.123	0.247	0.048
9	Alcohol molar ratio	**0.602**	0.207	0.235	0.277	0.353	-0.048	0.465
10	Purity of reactants	**0.784**	0.040	0.403	0.120	0.086	-0.102	0.253
11	Moisture content	0.315	**0.907**	0.165	0.074	0.084	0.084	0.090
12	Physicochemical properties	**0.641**	0.048	0.077	0.219	**0.668**	0.117	0.174
13	Thermal cracking (pyrolysis)	-0.014	0.514	**0.539**	-0.067	0.353	0.190	0.114
14	Free fatty acid	**0.659**	-0.146	**0.631**	0.260	0.032	0.010	0.080
15	Density	**0.528**	-0.024	0.475	0.154	0.002	0.134	0.021
16	Kinematic viscosity	**0.872**	0.253	0.218	0.089	0.213	-0.044	0.114
17	Oxidative stability	**0.784**	0.384	0.341	0.101	-0.100	-0.106	0.084
18	Induction time	0.312	0.143	**0.908**	0.051	0.056	-0.024	0.116
19	Amount of reagents	0.306	**0.698**	0.297	-0.126	0.097	0.092	-0.002
20	Type of reagents	0.392	**0.677**	0.375	-0.094	0.120	0.074	0.030
21	Environmental conditions	-0.225	**0.912**	-0.016	0.105	0.171	0.227	0.023
22	Oil price	0.272	0.336	**0.640**	0.297	0.119	0.228	0.022
23	Reaction rate	0.430	0.246	**0.576**	0.242	0.206	-0.001	0.199
24	Oil availability	**0.792**	0.291	0.424	-0.081	0.037	-0.126	0.078
25	Geographical location	-0.168	0.358	-0.021	0.104	0.195	**0.886**	0.055
26	Storage time	0.050	0.492	0.108	-0.031	**0.795**	0.252	0.145
27	Oil type	0.426	0.315	**0.495**	0.356	0.167	0.025	0.197
28	Production method	0.277	0.182	**0.915**	0.050	0.070	-0.025	0.093
29	Storage conditions	0.195	**0.639**	0.299	-0.076	**0.595**	-0.039	0.071
30	Moisture level	**0.715**	-0.057	0.504	0.255	0.092	0.006	0.138
31	Order of reaction	0.345	0.287	**0.791**	0.161	0.116	0.077	0.089
	Rotation completed in 21 iterations Rotation was normalised							

Factor Interpretation

From the scree plot, the 31 factors were reduced to 7 unique factors as shown in the tables below with their respective factor loadings. The variable clusters (Factors) are discussed in what follows:

Factor 1: Chemical Process Dynamics

Table 3: Clusters 1(Factor 1): Chemical Process Dynamics

Factor 1: Chemical Process Dynamics		
Variable Number	**Variable Description**	**Factor Loading**
2	Reaction temperature	0.886
4	Catalyst Concentration	0.826
5	Transesterification	0.698
7	Mixing intensity	0.917
8	Oil molar ratio	0.642
9	Alcohol molar ratio	0.602
10	Purity of reactants	0.784
12	Physiochemical properties	0.641
13	Free fatty acid	0.659
15	Density	0.528
16	Kinematic viscosity	0.872
17	Oxidative stability	0.784
24	Oil availability	0.792
30	Moisture level	0.715

Under this regime, 14 variables clustered. It is therefore a stocky, sturdy factor being that all the variables wield positive factor loadings which provide relevant information about the chemical process dynamics of rubber seed oil- based biodiesel production. The most influential variable, based on its factor loading of 0.917, is mixing intensity. This could be attributed to the fact that the rate at which the reagent and oil reacts together may help to achieve perfect miscibility and homogeneity during transesterification. The next high factor loading of 0.886 which is reaction temperature shows its industrial importance in which substances act mutually on each other and are changed into different substances or one substance changes into other substances as a result of temperature change. Following reaction temperature is Kinematic viscosity which wielded a positive factor loading of 0.872. Viscosity is one of the most important physical properties or key factor of biodiesel fuel that can affect an engine's performance. It is often one of the first parameters measured to determine if the biodiesel produced can be used. Catalyst concentration with a factor loading of 0.826 is the fourth highest in this regime. It is instructive to note that catalyst plays an importance role in the chemical process dynamics of rubber seed oil-based biodiesel production. It typically speeds up a reaction by reducing the activation energy and changing the reaction mechanism that affect the reaction efficiency. The rest variables under this regime indicate their importance under the factor chemical process dynamics.

Factor 2: Reaction Circumstance

Table 4: Clusters 2 (Factor 2): Reaction Circumstance

Factor 2: Reaction Circumstance		
Variable Number	**Variable Description**	**Factor Loading**
11	Moisture Content	0.907
19	Amount of Reagents	0.698
20	Type of Reagents	0.677
21	Environmental Conditions	0.912
29	Storage Conditions	0.639

Cluster 2 is creatively labeled reaction circumstance. The top two variables include: Environmental conditions and Moisture content with positive factor loading of 0.912 and 0.907 respectively. These variables are very critical under this regime. The implication is that both environmental conditions and moisture content individually and conjointly influence the reaction process of rubber seed oil-based biodiesel. Next to these dual variables is amount of reagents with factor loading of 0.698. This suggests that the amount of reagent used during any reaction plays a significant role under the reaction circumstance. However, other variables under this factor do exercise significant influence according to the level of the factor loading they wielded.

Factor 3: Factors Affecting Mixing

Table 5: Clusters 3 (Factor 3): Factors Affecting Mixing

Factor 2: Factors Affecting Mixing		
Variable Number	**Variable Description**	**Factor Loading**
3	Agitation speed	0.728
13	Thermal cracking (pyrolysis)	0.539
14	Free fatty acid	0.908
18	Induction time	0.908
22	Oil price	0.640
23	Reaction rate	0.576
27	Oil type	0.495
28	Production method	0.915
31	Order of reaction	0.791

The third Cluster creatively labeled Factors affecting mixing is a sturdy cocktail (mixed bag or assortments) of factor loading ratings. This regime has the variable - Production method - with the highest factor loading of 0.915 followed by free fatty acid (0.908) and induction time (0.908) suggesting that the period of time necessary to initiate a reaction or time interval needed to start a reaction coupled with the free fatty acid composition of the oil plays a role to influence mixing during the production process.

Factor 4, 6, 7: Miscellany

Table 6: Clusters 4 (Factor 4, 6 and 7): Miscellany

Factor 4, 6 and 7: Miscellany		
Variable Number	**Variable Description**	**Factor Loading**
6	Type of catalyst	0.822
25	Geographical location	0.886
1	Reaction time	0.721

The fourth cluster that comprises factor 4, factor 6 and factor 7 is creatively labeled Miscellany. This is a triad of miscellany of lone factors with substantial factor loading of 0.822, 0.886 and 0.721 that are stocky factors providing information on the time it takes for a reaction to occur which depends on the type of catalyst employed.

Factor 5: Rancidity

Table 7: Clusters 5 (Factor 5): Rancidity

Factor 5: Reaction Circumstance		
Variable Number	**Variable Description**	**Factor Loading**
12	Physicochemical properties	0.668
26	Storage time	0.795
29	Storage conditions	0.595

Finally, the last cluster which is under factor 5 creatively labeled Rancidity has a total of 3 variables which are physicochemical properties, storage time and storage conditions respectively. This proposes that a product can be kept under a certain storage condition without losing its specifications of performance depending on the physicochemical properties of the product and the time of storage.

4. Conclusion

This study has successfully employed the use of principal component analysis (PCA) and Kendall's coefficient of concordance (KCC) to analyze some factors that plays a critical role in the production process of rubber seed oil based biodiesel. The PCA model adopted was effective in achieving parsimony in factor reduction from thirty one variables to seven factors. The results show that seven principal factors, namely clusters: 1, 2, 3, 4, 5 creatively labeled: Chemical Process Dynamics, Reaction Circumstance, Factors Affecting Mixing, Miscellany and Rancidity respectively, because factor 4, 6 and 7 are lone factors under Miscellany, represent the principal factors that influence rubber seed oil-based biodiesel production. The KCC model also helped to provide basic understanding into how consistent the Judges were in ranking the variables (scale items) that influence rubber seed oil-based biodiesel production in descending order of importance and the way the variables interplay.

References

1. Martchamadol, J. and Kumar, S. Thailand's energy security indicators. Renew. Sustain. Energy Rev., **2012**, 16, 6103–6122.
2. Abas, N.; Kalair, A.; Khan, N. Review of fossil fuels and future energy technologies. Futures, **2015**, 69, 31–49.
3. Hasheminejad, M.; Tabatabaei, M.; Mansourpanah, Y.; Javani, A. Upstream and Downstream Strategies to Economize Biodiesel Production. Bioresource Technology, **2011**, 102, 461-468.
4. Ayhan, D. Progress and Recent Trends in Biodiesel Fuels: A Demirbas. Energy Conversion and Management, **2009**, 50, 14-34. https://doi.org/10.1016/j.enconman.2008.09.001 .
5. Felizardo, P.; Machado, J.; Vergneiro, D. Study on the Glycerolysis Reaction of High Free Fatty Acid Oils for Use as Biodiesel Feedstock. Fuel Processing Technology, **2011**, 92, 1225-1229. https://doi.org/10.1016/j.fuproc.2011.01.020.
6. Balat, M. and Balat, H. Progress in Biodiesel Processing. Applied Energy, **2010**, 87, 1815-1835. https://doi.org/10.1016/j.apenergy.2010.01.012
7. Siriwardhana, M.; Opathella, G.K.C.; Jha, M.K. Bio-diesel: Initiatives, potential and prospects in Thailand: A review. Energy Policy**, 2009**, 37, 554–559.
8. Takase, M.; Zhao, T.; Zhang, M.; Chen, Y.; Liu, H.; Yang, L.; Wu, X. An expatiate review of neem, jatropha, rubber and karanja as multipurpose non-edible biodiesel resources and comparison of their fuel, engine and emission properties. Renew. Sustain. Energy Rev. **2015**, 43, 495–520.
9. Mukherjee, I. and Sovacool, B.K. Palm oil-based biofuels and sustainability in Southeast Asia: A review of Indonesia, Malaysia, and Thailand. Renew. Sustain. Energy Rev. **2014**, 37, 1–12.
10. Ulfah, M.; Mulyazmi, Burmawi, E.; Praputri, E.; Sundari and Firdaus. Biodiesel production methods of rubber seed oil: a review. 3rd ICChESA 2017, IOP Conf. Series: Materials Science and Engineering, **2018**, 334, 012006 doi:10.1088/1757-899X/334/1/012006. Pp. 1-7.
11. Abdul Shokib, Gumanti, P. and Rachimoellah, M. Biodiesel Production from Rubber Seed Oil by Supercritical Methanol Method. The Journal for Technology and Science, **2010**, Vol. 21, No. 2.
12. Rismawati, R.; Zakir, S.; Ainun, P.H.; Rasdin, J.; Rahmania, M. Production of Biodiesel from a Traditional Coconut Oil Using NaOH/γ -Al_2O_3 Heterogeneous Catalyst. IOP Conf. Series: Earth and Environmental Science 175, **2018**, 012025 doi :10.1088/1755-1315/175/1/012025.
13. Kouassi, K.E.; Abolle, A.; Benjamin Yao, K.; Boa, D.; Adouby, K.; Drogui, P.; Tyagi, R.D. Optimization of Rubber Seed Oil Transesterification to Biodiesel Using Experimental Designs and Artificial Neural Networks. Green and Sustainable Chemistry, **2018**, 8, 39-61. https://doi.org/10.4236/gsc.2018.81004
14. Winoto, V. and Yoswathana, N. Optimization of Biodiesel Production Using Nanomagnetic CaO-Based Catalysts with Subcritical Methanol Transesterification of Rubber Seed Oil. Energies, **2019**, 12, 230; doi:10.3390/en12020230
15. Gashaw, A.; Teshita, A. Production of Biodiesel from Waste Cooking Oil and Factors Affecting Its Formation: A Review. International Journal of Renewable and Sustainable Energy. **2014**, Vol. 3, No. 5, pp. 92-98. doi: 10.11648/j.ijrse.20140305.12.
16. Jagadale, SS. and Jugulkar, LM. Review of Various Reaction Parameters and Other Factors Affecting on Production of Chicken Fat Based Biodiesel. International Journal of Modern Engineering Research (IJMER), **2012**, Vol.2, Issue.2, pp-407-411.
17. Widayat, W. and Suherman, S. Biodiesel Production from Rubber Seed Oil via Esterification Process. Int. Journal of Renewable Energy Development. DOI: 10.14710/ijred.1 **2012**, (2): 57-60.
18. Meena Devi, R.; Subadevi, R.; Raj, SP.; Sivakumar, M. Comparative Studies on Biodiesel From Rubber Seed Oil Using 7b Homogeneous and Heterogeneous Catalysts, International Journal of Green Energy, **2015**, 12:12,1215-1221, DOI: 0.1080/15435075.2014.893879.
19. Widayat, W.; Wibowo, ADK.; Hadiyanto. Study on Production Process of Biodiesel from Rubber Seed (Hevea Brasiliensis) by in Situ (Trans) Esterification Method with Acid Catalyst. Energy Procedia, **2013**, Volume 32, Pages 64-73.
20. Mathiyazhagan, M. and Ganapathi, A. Factors Affecting Biodiesel Production. Research in Plant Biology, **2011**, 1(2): 01-05.
21. Atadashi, I.M.; Aroua, M.K.; Abdul Aziz, A. High quality biodiesel and its diesel engine application: A review. Renewable and Sustainable Energy Reviews, **2010**, 14:1999–2008.