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Transesterification process optimization for tung oil methyl ester (*Aleurites fordii*) and characterization of fuel as a substitute for diesel

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Abstract
Biodiesel is the best substitute for fossil fuels in this modern era of Renewable energy. This research paper is based on usage of Tung (*Aleurites fordii*) oil for biodiesel production, optimization of transesterification process parameters to produce Tung oil methyl ester (TOME) and its fuel characterization for performance in engines. The various experimental factors like concentration of catalyst, alcohol to oil molar ratio, time for reaction etc. were studied to optimize the process to get maximum recovery of the biodiesel with minimum possible viscosity. In this study, it was found that the tung oil produced maximum ester recovery at optimal experimental conditions of 5:1 methanol to oil molar ratio in presence of 2% concentration of KOH as catalyst, maintaining a temperature of 60 °C during the reaction for a period of 45 minutes. Lowest possible kinematic viscosity 4.54 with ester recovery 94% was obtained at this set of conditions. Various fuel properties of the produced tung oil methyl ester and crude tung oil were also measured. Results show that the methyl ester of tung oil obtained under the optimum condition is an excellent substitute for fossil fuels.

Keywords: biodiesel, fuel characteristics, optimization, methyl transesterification, tung seed oil, Tung Oil Methyl Ester (TOME)

1. Introduction
Tung tree (*Aleurites fordii*) is a deciduous shade tree of the Euphorbiaceae family (spurge) and is found mainly in Central and West China, Vietnam, Argentina, Paraguay, Africa, United States and North-Eastern parts of India. The tree usually bears fruit within 2–4 years and reaches maximum productivity at around 10–12 years of age. The productivity of Tung oil mainly varies from 300 to 450 kg/ha. The oil content of fruit is between 14–20%, in the kernel 53–60% and the in seed 30–40%. Oil can be extracted from various species of Aleurites using expeller. Tung oil has been used in different industrial applications such as ceramics, paint, paper and cloth production. Tung oil is used as a protective coating or drying agent [1, 2]. Recently Tung oil (*Aleutites fordii*) has been regarded as a promising non-edible source of biodiesel production. But this oil cannot be utilized specifically in a Compression Ignition (CI) diesel engine due to its high viscosity. Such high viscosity leads to reduction in fuel atomization and increased fuel spray entrance that results in high engine deposits and thickening of lubricating oil. The utilization of synthetically changed or transesterified vegetable oil, called biodiesel (calorific value of 9500 – 10500 k Cal/ kg), does not require alteration of the engine or fuel-injection system and is straightforwardly conceivable in any CI diesel engine. Because of tung oil has a high acid value (AV), the esterification using solid acid catalyst, KOH, employed to produce biodiesel more efficiently [3, 4].
Increasing world population, declining petroleum fuel reserve, advancing technology and improved standard of living has arisen stress to introduce alternatives of conventional fossil fuels. In this context, biodiesel is a renewable, harmless, eco-friendly and cleaner energy source that ensures energy security with properties similar to diesel. Edible or non-edible oils like sun-flower oil, soybean oil, palm oil, *Jatropha curcas*, *Pongamia pinnata*, animal fats and waste cooking oils are being used for producing biodiesel as substitute for diesel. Tung oil is a good source for producing biodiesel, as tung oil biodiesel does not lead to corrosion on the piston metal and piston liner, while Jatropha curcas has a slight corrosive effect on the piston liner [5-7].

Biodiesel is produced either by the direct use or mixing of vegetable oils with solvents and different physico-chemical techniques, like pyrolysis, transesterification and micro-emulsification [5]. Triglycerides present in vegetable oils undergo transesterification reaction using monohydric alcohols (CH_3OH) in the presence of anhydrous basic (KOH) or acidic (H_2SO_4) catalysts to produce biodiesel. In this process, a temperature of 55-60°C is maintained and allowed to settle by gravity for 24 h, producing a translucent methyl ester of tung oil termed as biodiesel. Any amount of water left in esterified oil is removed by heating of oil. Glycerol is produced as a major by-product of bio-diesel production [8,9]. Depending on the carbon chain length and the number of double bond of the fatty acids of the feedstock oils, biodiesel has different properties [10].

The process of transesterification is affected by various experimental factors like catalyst type, molar ratio of methanol to oil, and catalyst concentration as well as the reaction conditions. These factors are taken into account to increase yields of biodiesel and the response rate. The molar ratio of methanol to oil is one of the most vital parameters influencing the output of biodiesel [11-13].

Studies have shown that excess alcohols move the equilibrium of the reaction in the direction of the product and gives higher yields from transesterification of vegetable oil [8]. However, constant molar ratio gives similar biodiesel yield regardless of the vegetable oil used [14]. The molar ratio is related to the catalyst type and catalyst concentration [15]. Basic catalysts give faster Transesterification than acid catalyst. But the reaction catalyzed by the acid catalyst results in a very high yield of biodiesel [15]. If the vegetable oil has a relatively high free fatty acid content and water content, the use of an acid catalyst is suitable in the trans-esterification [5, 14]. The catalyst concentration is determined by the difference in molar ratio, catalyst type and oil properties considered in the reaction process involved [15]. The reaction temperature is a vital factor affecting the yield of biodiesel and reaction rate. The transesterification is generally carried out at a temperature in the range of 25 °C to 120 °C, depending on the types of catalyst and oil used [5, 14, 15, 16].

Decreasing availability and increasing price of petro-diesel has made it very important to g*et al*ternative sources of energy to harmonize energy conversion, sustainable development, efficiency, management and environmental preservation[17]. Renewable and non-toxic edible or non-edible vegetable oils are good and environment friendly sources of biodiesel with major economic benefits to cope with shortage of petro-diesel [18]. Esterified non-edible tung oil is the future candidate for alternative environment-friendly diesel fuel. In view of the above, this study was conducted to standardize methyl transesterification process parameters of tung oil and its fuel characterization.

2. Materials and Methods

2.1 Materials and experimental setup

The filtered tung oil used in the current research was purchased from Riddhi Chemicals, Mumbai. The commercial diesel fuel was purchased from petrol pump which is nearer to Gurunanak Dev Engineering College, Ludhiana (Punjab). All chemical reagents (Methanol, KOH catalyst and silica gel) for the transesterification reaction were procured from THAMES chemicals near choura bazaar, Ludhiana. The water bath shaker was used for transesterification of filtered tung seed oil. The transesterified ester was allowed to settle using 0.5-L separating funnels. The procured tung fruit, seed and the arrangement of the batch-type transesterification reactor used in the study is shown in Figure 1.

2.2 Transesterification process for Tung oil

Transesterification process is conducted to convert a vegetable oil into biodiesel for using it in internal combustion engines. Figure 2 shows the chemical transesterification process. This biodiesel correlates with energy conversion, sustainability, environment conservation and preservation [18-20, 12]. In the current work, single stage process was used to produce tung oil biodiesel, where the required quantity of Tung oil was placed in the batch reactor and was heated to the required temperature. Different methanol/alcohol ratios (3:1, 4:1, 5:1, 6:1) were prepared and different concentration of alkali catalyst (KOH) 0.5, 1.0, 1.5, 2.0 were taken. The preheated oil was mixed with methoxide solution and was put into shaking water bath for time intervals of 30,45,60,75 minutes at 60 °C. The stirrer started vigorously at 650-700 rpm and then reduced to 450-500 rpm once the temperature of the mixture reached 60 °C. After the specified time period, the mixture was put into a separating flask and settled by keeping it overnight. After settling, biodiesel or methyl ester was obtained as the upper lighter layer and glycerol settled as lower darker layer in the separating flask. Then the washing of the ester layer was done using hot water spray over its surface, 2-3 times to neutralize it. Washed methyl ester was again allowed to settle for overnight. The residual water catalyst was then discarded. Thus, a clear ester layer was obtained, which was dried using silica gel by dropping the ester through the silica bed.

For the purpose of optimization of transesterification process, four different levels of molar ratio (3:1,4:1,5:1,6:1), four different levels of KOH catalyst concentration (0.5, 1.0, 1.5, 2.0%) and four different levels of reaction time (30 min, 45 min, 60 min, and 75 min) were set at constant reaction temperature (60 °C) as given in Table 1. Thus, 64 different sets of ester samples were prepared to optimize the effect of these four levels of molar ratio, catalyst concentration, reaction time etc on recovery of the ester by measuring their kinematic viscosity subsequently. This range of different selected process parameters was chosen on the basis of studies in the past. The lowest viscosity and higher ester recovery was the set standard to get optimized process parameters. The experiment was chosen as +1 0 -1 asymmetrical factorial experiment.

2.3 Composition of Tung oil

Tung oil is mainly composed of fatty acids and their concentration is given in Table 2. The primary constituent is an aliphatic carboxylic acid with a chain of 18 linked carbon atoms or methylene units containing three conjugated double bonds. They are especially sensitive to autoxidation which encourages cross linking of neighboring chains and hence hardening of the base resin.

Properties of Tung oil as fuel

Fuel properties of Tung oil have been studied and compared with those of diesel and according to the specification provided by American Society for Testing and Materials (ASTM) standards. The fuel properties of Tung oils are listed in Table 3 which indicates that the kinematics viscosity of tung oil is 119.67 mm^2/s at 40°C. The calorific value of optimized tung oil was 35.06 MJ/Kg which is lower than diesel fuel. The flash point and fire point of tung seed biodiesel were observed to be higher than of diesel fuel.

2.4 Physico-chemical characterization of TOME

Tung oil methyl ester (TOME) was analyzed for its fuel characteristics along with standard diesel as per standard test procedures. Properties of TOME, mineral diesel and other methyl esters are illustrated in Table 4. Which indicates that the calorific value of TOME was 38.8 MJ/ kg, which is 86.60% of that of diesel (44.8 MJ/kg). TOME's calorific value is slightly lower due to the presence of oxygen in the molecular structure, as determined by elemental analysis. When exposed to air, the tendency of the substance to form a flammable mixture is indicated by its flash point. Flash point of the fuel affects the safety for transport, handling, and storage purpose. A fuel with high flash point may cause carbon deposits in the combustion chamber. The high flash point value in the case of TOME specifies the relative safety of the fuel. Kinematic viscosity affects the operation of fuel injection, blending formation and combustion process. The high viscosity leads to insufficient atomization. The properties of TOME are better than those of other biodiesels in nature, so it is relatively closer to diesel.

3. Results and Discussion

3.1 Determination of optimal experimental conditions:

The yields of TOME, as biodiesel, formed under 64 sets of experimental conditions are shown in Table 5. From these results, set no.46, which had a mean TOME yield of 94%, appeared to have the set of experimental conditions with optimal parameters. The effect of different parameters is discussed here:

3.1.1. Effect of ester recovery

Tables 5 and 6 shows the percent methyl ester recovered by transesterification process carried out at different molar ratios used, catalyst concentration, reaction time and reaction temperature. It was evident from the table that the recoveries of tung methyl esters observed at different process parameters varied between 44 and 94 percent. It was found that the highest recovery of 94% of methyl ester was obtained at 5:1 M ratio when filtered tung oil was reacted with methanol at 60^0C for 45 min in the presence of 2 percent KOH and then allowed to settle for 24 h. The recovery of high quality glycerol as an ester byproduct lowers the cost of ester. When the molar ratio was decreased, it shows low yield. On the other hand, when it was increased, then conversion efficiency of methyl ester was improved. Different experiments for varied reaction time have been conducted to optimize the standardization of transesterification process. 64 experiments were performed for this complete experimentation, out of which some experiments gave low yield with high glycerol content while some experiments show low conversion efficiency of methyl ester. The recoveries of maximum esters (94%, 92%, 91%) were observed at different reaction time (45 min, 60 min, 30 minutes).

3.1.2. Effect of kinematic viscosity

Table 5 shows the kinematic viscosity of methyl esters obtained by transesterification of filtered tung oil at the selected process conditions. It was evident from the table that the methyl esters obtained from transesterification of filtered tung oil at different process conditions ranged from 4.54 cSt to 8.88 cSt. It is seen that lowest viscosity (4.54 cSt) of tung methyl ester was obtained at 5:1 M ratio when the filtered tung oil was reacted with methanol at 60 ^{o}C reaction temperature for 45 min in the presence of 2 percent KOH catalyst and then allowed to settle for 24 h. The lowest viscosities of esters (4.54 cSt, 4.78 cSt, and 4.88 cSt) were observed at different reaction times (45 min, 60 min, 75 min). In some experiments, the viscosity of final product has been observed up to 8.88 cSt. It may be due to the fact that at that set of parameters, the reaction could not be completed which resulted in high viscosity of end product. For better performance in engine, product with lowest viscosity (4.54 cSt) was selected with little compromise in ester yield (94%).

3.1.3. Effect of preheating temperature

The preheating of vegetable oil was used to resolve the fuel filter clogging problem and also to improve engine performance. The higher molecular weight and the chemical structure of vegetable oils contribute to their high viscosity. The high viscosity of vegetable oils deteriorates the atomization, evaporation and air fuel mixture formation characteristics leading to improper combustion and higher smoke emissions. The preheating of tung oil helps to lower the viscosity of tung oil and thus providing smooth fuel flow.

3.1.4. Effect of molar ratio

One of the most important parameters affecting the yield of ester is the molar ratio of alcohol to vegetable oil. The molar ratio is the ratio of number of moles of alcohol to number of moles of triglycerides in the oil. Theoretically, trans-esterification reaction requires 3 mol of alcohol for each mole of oil. However, in practice, the molar ratio should be higher than that of stoichiometric ratio. In present research, methanol was used. Different molar ratios (3:1, 4:1, 5:1 and 6:1) were selected for optimization of ester yield. The Table 5 reveals that the ester recovery increases with increase in molar ratio (5:1 and 6:1) and for low values of molar ratio (3:1), the reduction in ester recovery takes place. The maximum conversion efficiency was achieved at a molar ratio of close to 5:1. Taking lowest viscosity into consideration, molar ratio of 5:1 was selected as optimization ratio.

3.1.5. Effect of catalyst concentration

The effect of KOH concentration was studied in the range of 0.5% to 2.0% (weight of KOH/weight of oil). The results for different catalyst concentration are shown in Table 5. It was found that the ester recovery increases as the amount of catalyst increased from 0.5% to 2.0%. The ester recovery increases drastically as KOH concentration increases above 0.5% whereas ester recovery increases when KOH concentration reduces to almost 1%. The reduced recovery at higher KOH concentration may possibly be due to high soap formation. Regarding viscosity, 2% KOH catalyst gave better results than 1% and 0.5% of KOH catalyst. The viscosity of tung methyl ester was found to be within the ASTM limits. The excess of KOH reduces the recovery and also leads to undesirable extra processing cost because it is necessary to remove it from the reaction products at the end.

3.1.6. Effect of reaction time

Several investigators found that the reaction starts very fast and almost 80% of the conversion takes place in the first 5 min. After 1 h, almost 93-98% conversion of triglycerides into esters takes place. In the present work, the effect of reaction time from 30 min to 75 min on the ester recovery was evaluated. Table 5 indicates that when the reaction time was increased beyond 60minutes, the ester yield was decreased slightly. In order to achieve perfect contact between the reagent and the oil during transesterification, it must be properly stirred at constant rate. The results obtained from the

present experiments with tung oil reveal that about 45 min of reaction time is sufficient to complete the transesterification.

3.2 Characterization of tung oil methyl ester as a substitute to diesel

TOME was characterized for fuel properties like relative density, kinematic viscosity, flash and fire point, cloud and pour point, calorific value and free fatty acid content using ASTM methods. The relative densities of tung oil and tung methyl ester were observed to be 7 and 5% higher than that of diesel respectively. The experimental results indicated that the relative density of tung methyl ester was slightly increased to that of diesel. The kinematic viscosity of diesel, tung oil, and tung methyl ester was found to be 3.18, 119.67, 4.64 cSt at 40ºC. The results indicated that the kinematic viscosity of tung methyl ester was higher than that of diesel and Kinematic viscosity of tung oil was also more than that of diesel. The tung methyl ester was found to have higher flash and fire point than those of diesel. The flash and fire point of tung oil was also higher than those of diesel.The cloud and pour point of tung oil and tung methyl ester was lower than that of diesel. While the calorific value of diesel, tung oil, and tung methyl ester was found to be 44.8, 35.06 and 38.8 MJ/kg respectively. The calorific value of tung oil as well as TOME is lower than that of diesel. For an alkali-catalyzed transesterification, the glycerides and alcohol must be substantially anhydrous because water partially changes the reaction to saponification, which produces soap. The soap lowers the yield of esters and renders the separation of ester and glycerol which makes washing difficult. The glycerides should have an acid value of less than 1 and all the reactants should be substantially anhydrous. When the acid value is greater than 1, more catalyst is required to neutralize FFA. There was a significant drop in ester conversion when the free fatty acids were beyond 2%. The soap formation would exacerbate the problem of phase separation at the stage of product recovery. Researchers have found that ester yields were significantly reduced if the reactants do not meet these requirements. Experiments were performed to find the FFA and acid value. The properties of tung biodiesel were compared with ASTM biodiesel standards. The tested properties of tung methyl ester were found to be in reasonable agreement with ASTM 6751.

4. Conclusion

Based on the observations of the ester recovery and kinematic viscosity, it was found that filtered tung oil at 5:1 M ratio (methanol to oil) preheated at 60 ºC temperature and maintaining 60 ºC reaction temperature for 45 min in the presence of 2 percent KOH and then allowed to settle for 24 h gave lowest kinematic viscosity (4.64 cSt) with ester recovery (94%). The lowest viscosity is considered better for engine performance in internal combustion engine in this research study. The density, flash and fire points of tung methyl ester gave good results but calorific value was slightly less as compared to diesel.

In this experimental investigation, the production, characterization and optimization of critical process parameters influencing the transesterification process of a new biodiesel derived from Tung oil have been studied and reported. Methanol with KOH as catalyst was used for the transesterification process. The molar ratio of methanol to oil, concentration of catalyst, time of reaction were the three influencing parameters considered for the optimization of biodiesel production. The experimentally determined optimum conditions for the production of TOME are: 5:1 methanol-to-oil molar ratio, 2% (w/w) concentration of catalyst, 45 min reaction time and 60 ºC reaction temperatures, and the corresponding yield rate is 94%. Hence, TOME can be considered a potential substitute for fossil diesel, and may address the global con-cerns of energy crisis and environmental degradation. Biodiesel production from the tung oil by alkali-catalyzed transesterification, offers a triple-facet solution: economic, environmental. The viscosity of tung oil reduces substantially after transesterification and is comparable to petro-diesel and the physical and chemical properties of biodiesel produced conform to EN/ASTM standards. Water used as a washing agent increases the purity of the product.

Table 1: Process parameters for standardization of transesterification process

Optimizing parameter	Level selected
Preheating temperature (ºC)	60 ºC
Molar ratio	3:1, 4:1, 5:1 and 6:1
Catalyst concentration (%)	0.5%, 1.0 %, 1.5% and 2.0%
Reaction time (Minutes)	30 min, 45 min, 60 min and 75 min
Reaction temperature (ºC)	60 ºC
Settling time	24 hours
Washing time	24 hours

Table 2: Major fatty acid composition of Tung oil (%)

Major Fatty acid	Percentage
Alpha-eleostearic acid	84.0
Palmitic acid	5.0
Linoleic acid	7.0
Oleic acid	4.0

Table 3: Chemical and physical properties of diesel, raw Tung oil and vegetable oils.

Properties	ASTM D6751	Straight diesel[a]	Tung oil	Mahua oil[c]	Jatropha oil[b]	Rubber seed oil[a]
Density at 15ºC (kg/m^3)	860–900	839	901	955	912	910
Kinematic viscosity at 40ºC, (mm^2/s)	1.9–6.0	3.18	119.67	24.58	8.72	66.2
Calorific value (MJ/kg)	–	44.8	35.06	36	40	37.5
Flash point (^{0}C)	Min. 130	68	314	232	125	198
Carbon residue (%)	–	0.1	–	3.7	–	–
Ash content (%)	< 0.02	0.01	–	0.9	–	–
Acid value (mg KOH)	< 0.8	0.35	10.99	38	10.47	34
Cetane number	–	51	–	–	57	–
Free fatty acid (FFA, wt%)	–		0.98	–	1.26	–

* [a]Ramadhas *et al* [21], [b]Deng.X *et al* [22],[c]Sinha *et al* [23]

Table 4: Comparison of physico-chemical properties of Tung oil methyl ester (TOME) with different methyl esters (ASTM D 6751).

Properties	ASTM D6751	Diesel	Mahua biodiesel	Jatropha biodiesel	TOME
Density at 15°C (kg/m^3)	860–900	839	880	876	883
Kinematic viscosity at 40°C (mm^2/s)	1.9-6.0	3.18	3.98	9.6	4.64
Calorific value (MJ/kg)	–	44.8	37	36.12	38.8
Flash point (°C)	Min: 130	68	208	187	197
Carbon residue (%, w/w)	–	0.1	0.2	0.24	0.021
Ash content (%)	< 0:02	0:01	0:01	0:02	0.01

Table 5: Ester recovery and its respective kinematic viscosity

S. No	Molar ratio (Alcohol : Oil)	Catalyst concentration (%)	Reaction Time (mins.)	Reaction Temperature (ºC)	Pre-heating Temperature (ºC)	Settling Time (Hours)	Kinematic Viscosity (cSt)	Ester Recovery (%)
1	3:1	0.5	30	60	60	24	7.37	62
2	3:1	0.5	45	60	60	24	7.93	86
3	3:1	0.5	60	60	60	24	6.87	80
4	3:1	0.5	75	60	60	24	7.58	79
5	3:1	1.0	30	60	60	24	7.79	76
6	3:1	1.0	45	60	60	24	8.81	81
7	3:1	1.0	60	60	60	24	5.99	73
8	3:1	1.0	75	60	60	24	8.48	86
9	3:1	1.5	30	60	60	24	6.8	66
10	3:1	1.5	45	60	60	24	7.08	79
11	3:1	1.5	60	60	60	24	8.61	70
12	3:1	1.5	75	60	60	24	7.72	74
13	3:1	2.0	30	60	60	24	6.07	71
14	3:1	2.0	45	60	60	24	6.58	65
15	3:1	2.0	60	60	60	24	7.65	71
16	3:1	2.0	75	60	60	24	6.44	67
17	4:1	0.5	30	60	60	24	8.14	56
18	4:1	0.5	45	60	60	24	8.55	75
19	4:1	0.5	60	60	60	24	8.75	51
20	4:1	0.5	75	60	60	24	8.34	74
21	4:1	1.0	30	60	60	24	7.86	68
22	4:1	1.0	45	60	60	24	6.95	72
23	4:1	1.0	60	60	60	24	8.41	44
24	4:1	1.0	75	60	60	24	8.68	75
25	4:1	1.5	30	60	60	24	6.07	89
26	4:1	1.5	45	60	60	24	8.88	52
27	4:1	1.5	60	60	60	24	8.27	61
28	4:1	1.5	75	60	60	24	7.99	70
29	4:1	2.0	30	60	60	24	8.2	50
30	4:1	2.0	45	60	60	24	Not detected	Low yield
31	4:1	2.0	60	60	60	24	8.06	50
32	4:1	2.0	75	60	60	24	7.44	62
33	5:1	0.5	30	60	60	24	7.23	95
34	5:1	0.5	45	60	60	24	6.37	91
35	5:1	0.5	60	60	60	24	6.51	93
36	5:1	0.5	75	60	60	24	5.62	92
37	5:1	1.0	30	60	60	24	5.17	94
38	5:1	1.0	45	60	60	24	6.07	91
39	5:1	1.0	60	60	60	24	6.73	94
40	5:1	1.0	75	60	60	24	5.39	97
41	5:1	1.5	30	60	60	24	5.24	80
42	5:1	1.5	45	60	60	24	5.7	91
43	5:1	1.5	60	60	60	24	7.51	83
44	5:1	1.5	75	60	60	24	5.55	90
45	5:1	2.0	30	60	60	24	5.47	86
46	5:1	2.0	45	60	60	24	4.54	94
47	5:1	2.0	60	60	60	24	4.78	78
48	5:1	2.0	75	60	60	24	4.88	74
49	6:1	0.5	30	60	60	24	4.93	79
50	6:1	0.5	45	60	60	24	5.32	89
51	6:1	0.5	60	60	60	24	5.85	75
52	6:1	0.5	75	60	60	24	5.01	81
53	6:1	1.0	30	60	60	24	7.3	82
54	6:1	1.0	45	60	60	24	5.77	96
55	6:1	1.0	60	60	60	24	5.92	94
56	6:1	1.0	75	60	60	24	6.07	94
57	6:1	1.5	30	60	60	24	5.01	94
58	6:1	1.5	45	60	60	24	5.86	93
59	6:1	1.5	60	60	60	24	7.08	90
60	6:1	1.5	75	60	60	24	7.15	90
61	6:1	2.0	30	60	60	24	5.68	94
62	6:1	2.0	45	60	60	24	6.65	86
63	6:1	2.0	60	60	60	24	5.54	88
64	6:1	2.0	75	60	60	24	5.46	76

Fig 1: Tung fruit, seeds and husk and experimental set up for transesterifictaion

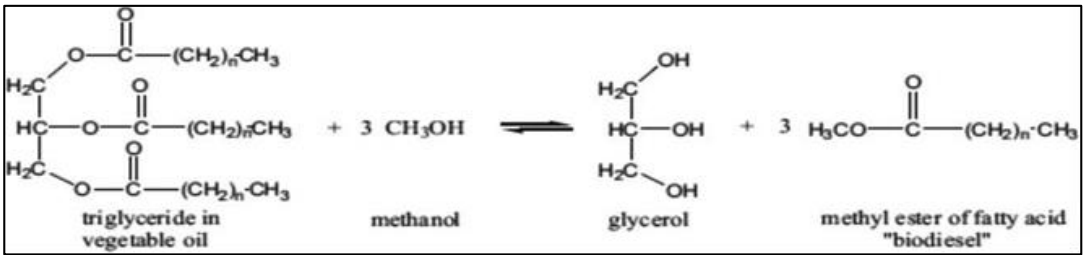

Fig 2: Chemical reaction of transesterification

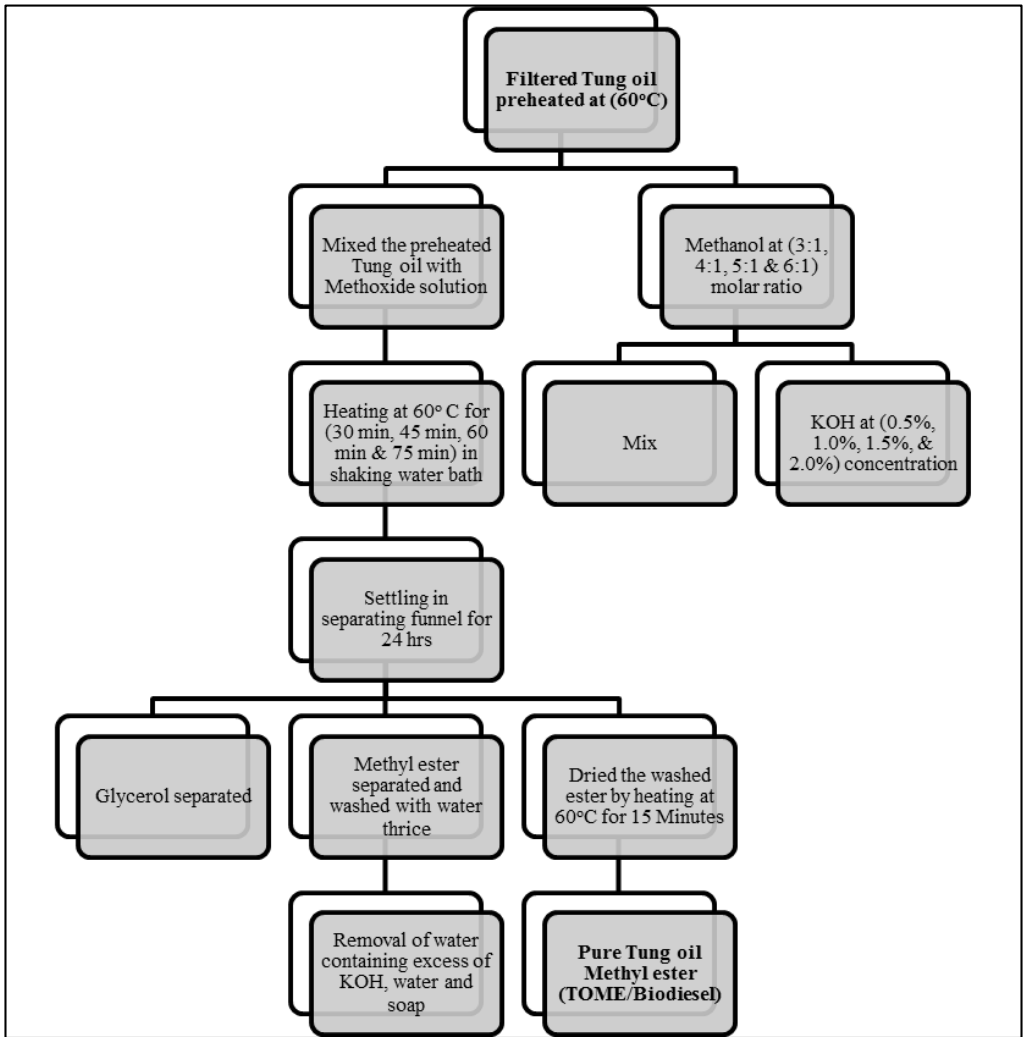

Fig 3: Schematic diagram of simple procedure developed for the production of tung oil methyl ester.

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