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ORIGINAL CONTRIBUTION

Different Feed Stocks for the Production of Biodiesel through Transesterification

Siddhartha Sankar Boxi*, Suraj Rana, Smriti Mandal, Smritikana Phadikar, Soumen Pal

Department of Chemical Engineering, Haldia Institute of Technology, Haldia 721657, West Bengal, India

ABSTRACT

In this modern century the whole world is facing the crisis of renewable fossil fuels, such as crude oil, coal, etc for its large number of consumption in energy production. So we are focusing on alternative resources which are environmentally suitable and economically feasible. Petroleum fuels are mainly produced by hydrogenation process from petroleum refineries and it contains more sulfur, wax and aromatic components which are not eco-friendly so it's a cause of pollution and greenhouse effect. Biodiesel is a good substitute of petroleum fuels and it has some similarity with petroleum-diesel. It contains low sulfur and aromatic components. Biodiesel mainly produced from natural feedstocks. It looks like yellow amber in color, mono alkyl ester and long chain fatty acid. It is non-toxic, sustainable, biodegradable, and more lubricant. Biodiesel invention or production process was started from 90's century by using vegetable oil. Nowadays biodiesel not only produced from edible oil such as palm oil, musterd oil, soybean oil, sunflower oil but also from non-edible oil such as pongamia oil, jatropha oil, sewage sludge, lamp meat, etc. Biodiesel is mainly produced by a common and very well-known chemical reaction that is transestrification. In this process vegetable oil or animal fat reacted with methanol or ethanol in the presence of alkali or acid catalyst and formed ester to biodiesel. By other process like blending, micro-emulsion, thermal cracking, Biox process biodiesel also produced. At the first generation homogeneous catalyst was used for biodiesel production, where high amount of soap is also formed and the separation is highly expensive. In second generation heterogeneous catalyst is used for biodiesel production, where less amount of soap is formed. In that two generation the useable feedstocks are highly expensive. Recently use of non-edible oil is in high demand for the biodiesel production.

KEY WORDS: Biodiesel, Feedstocks, Transesterification, Catalyst dose, Palm oil, Yield

*Corresponding Address: ssboxich@gmail.com

1. INTRODUCTION

In this era our world is facing a big problem of uncertainties for future energy sources. In this modern days energy is most important to run our daily life. We use energy in every footsteps of our life like domestic purpose to transportation or in industries. In this world likely 80% energy is produced from fossil fuel [1, 2]. Biodiesel is an alternative substitute for energy production. Nowadays use of biodiesel is increasing for its biodegradability, low toxicity and high lubricity nature. Lubricity of biodiesel is superior compared to convectional diesel. The lubricity of biodiesel is imparted to blends at level above 20 vol% [3]. In 19^{th} century the diesel engine inventor Rudolph Diesel used vegetable oil as a fuel in diesel engine. In 70's when the price of petroleum fuel increase rapidly that time some alternative fuels being used as a substitute of petroleum fuel [4]. At present time the population of world increasing rapidly as a result the demand of energy is bound to increase. So many developing countries trying to manufacture liquid alternative fuels from renewable energy like biomass. Among them oil-seed crops are the big source of energy generation [5]. Biodiesel is the monoalkyl ester of vegetable oils or animals fats. It is burnt like petroleum fuel but it is eco-friendly. It has better efficiency than gasoline. The high heating values of biodiesel are higher than coal (32-37 MJ/Kg) but slightly lower than gasoline (46 MJ/Kg), petroleum (42 MJ/Kg) and petrolium diesel (43 MJ/Kg) [6].

During petroleum crisis time biodiesel is produced by the process of alcoholysis of triglycerides or esterification of fatty acids and their derivatives. Many countries like Brazil startup their bio-fuel program with economical feasibility [7]. Biodiesel and ethanol are the most common bio-fuel. Bio-fuel production policy support rural economical development and sustainable agriculture [8]. Biodiesel used as blending component or substitute of diesel fuel. It comprises with lower alkyl fatty acid (C14-C22), short chain esters (Ethanol, Methanol). Transesterification is a well-known method of Biodiesel production. It is done for lower the viscosity of the oil. Biodiesel are sulfur and aromatic free. It can use in any type of diesel engine without any improvement [9]. Enzymatic transesterification is the new method for the production of biodiesel. It is done by using lipase [10]. Biodiesel properties are determined by structure of fatty acids including quantity, lubricity, ignition quantity, heat of combustion, cold flow, etc [11].

Selection of feed stock for biodiesel production is still a challenging job. In this paper we discussed different feed stocks, such as edible and non-edible oil. Different kinds of edible and non-edible oils are also discussed in this paper. Along with feed stock the process trans-esterification is also discussed. Different parameter of transesterification, such as time, temperature, catalyst dose, methanol to oil ratio (MO ratio) has been discussed in details.

2. DIFFERENT FEEDSTOCKS

Biodiesel is produced from natural resources by transesterification process [12]. Vegetable oil is a massive resource for biodiesel production. It is environmentally acceptable and economically competitive. Mainly vegetable oils are classified into two types- I) Edible oil and II) Non Edible oil [13]. Biodiesel also produced from animal's fat, free fatty acids and triglycerides contained substances [14]. For biodiesel production waste cooking oil, restaurant grease those are also used as a potential feedstock's [15].

2.1 EDIBLE OIL

If we go hundred years back, the alternative fuel exits as a vegetable oils. Due to presence of low sulphur and 10% O_2 by weight, the emission of toxic compounds like CO, SO_2, and unburned hydrocarbon are reduced simultaneously, that's why it is an environmentally favorable [16]. The drawback properties of vegetable oils are high viscosity and low volatility which results engine deposits, injector coking, piston ring sticking, and thickening of the lubricating oil occur frequently [16]. Edible oil used as a substitute fuel for diesel engine and it's also depends on the climate and edaphic factors of a country [17]. In our daily life we get a various kinds of edible oils on the market as for example soybean oil, sunflower oil, corn, olive and coconut oil from plant sources [18].

2.1.1 SOYBEAN OIL

In soybean oil contains five types of fatty acids; those are as follows- palmitic acid (approx 11%), oleic acid (approx 24%), linolenic acid (approx 53%), linoleate acid (approx 8%), density 917.0 kg/m^3 and molecular weight 890 g/mol [19]. In the beginning of twenty century in India the production of soybean oil was 1242 metric tons and now it can be increases consequently. In the U.S, among the vegetable oils only soybean oil is available in the market [20]. The properties of soybean oils are- Kinematic viscosity at 38°C- 4.5 mm^2/s, Cetane no- 45°C, Flash point- 178°C, Lower heating value- 33.5 MJ/Kg, Cloud point- 1°C, Density- 0.885 Kg/l, Pour point- -7°C [21].

2.1.2 SUNFLOWER OIL

Nowadays it is very necessary to use as an alternative fuel because a shortage of crude oil. In last few years the biodiesel gets importance instead of diesel for diesel engine [22]. Biodiesel production is very easy and eco-friendly. The Sunflower oil used for the study was of the commercial edible grade obtained from china oil & Foodstuffs Corporation with acid value (AV) less 0.4 mg KOH/g [23]. India is main production source of it. As estimated annual potential of about 20 million per year. About 175 million hectares are classified as waste and degraded land. Thus it's given a demand- based market. So that India cans easily potential and produce biodiesel in a large scale [24]. The properties of sunflower oils are- Density- 918 Kg/m^2, Kinematic viscosity- 39.6 C.Stokes, Flash point- 267°C, Fire point- 296 °C, Heating value- 36220 KJ/Kg, Specific gravity- 0.9180 [25]. Sunflower is a key member of the composite family, an important oil seed crop worldwide, accounting for about 45-50% of oil (dehulled seed mass basis). An unconventional oil seed crop usually grows in both spring and summer. In the wide climatic conditions of Pakistan, the sunflower crop fits well with the local intercropping system and successfully thrives in spring and in this way two crop yields can be born in 1 year [26]. A huge potential exists to increase the domestic production of sunflower in Pakistan. Recently, serious efforts have been made to encourage the local production of this crop. As a result, the sunflower acreage has increased from 107717 ha in 2002–03 to 379204 ha in 2006–07. The current sunflower seed and oil production in Pakistan is 656000 and 249000 tons respectively [27]. While sunflower oil is widely used in food for cooking and frying, it is also attracting attention as a feedstock for biodiesel production [28]. The sunflower oil was provided from Iranian Nazgol Company. The sunflower oil characterization parameters are the Cannon–Fenske Routine viscometer (Cole- Parmer Co., US) in a glycerine bath fixed at specified temperature ± 1K the sunflower which can be used for high viscosity measurements was employed to measure kinematic viscosity variation of samples according to ASTM D445 (Standard test method, 2012) and EN 14214 standard test method.

2.1.3 PALM OIL

Nowadays the demand of palm oil gradually increases. Malaysia is a main production sources of it, approximately 47% palm oil produced in Malaysia [29]. Especially in Southeast Asia and Indonesia the global land area increased 3.5 Mha to 18.7 Mha in between nineteenth to twenty century [30]. Palm oil are grows mostly in tropical moist region [31]. Palm oil is the cheaper feedstock for biodiesel production. By homogeneous base catalyst and enzymatic supercritical technologies biodiesel can be produced [32]. Mainly palm oil methyl ester are blended with diesel for make substitute fuel for diesel engine. After blending palm oil with diesel the fuel properties are very close to the diesel oil and only 30% other properties are in the limits [33]. For low cost and availability of palm oil it is used as feedstock in Malaysia. Life cycle assessment (LAC) done for show the people that palm oil is green and sustainable fuel. Palm oil biodiesel yield ratio is 3.53 which are more than double from any other oils like rapeseed oil. Palm biodiesel reduced 38%/lit CO_2 emission in combustion [34]. Biodiesel production process from palm oil is done by three steps- I) Oil palm plantation /cultivation II) Palm oil production III) Transesterification [35].

2.2 NON EDIBLE OIL

In the list of Non edible oil we can consider Pongamia oil, Neem oil, Mahua oil, Rubber seed oil, Algae oil, Jatropha oil, Jojoba oil, etc [13].

2.2.1 PONGAMIA OIL (KARANJA OIL)

Pongamia oil is non-edible oil. It is a good feedstock resource for biodiesel production. Pongamia oil is extracted from the seeds of Pongamia pinnata tree [36]. Pongamia oil not only a good substitute of diesel but also a good substitute of kerosene [37]. The trees are mainly noticed in the region of South and Southeast Asia. Indonesia pongamia oil is extracted in two steps -I) Fabricant Mechanical screw expeller II) Solvent extraction press [38]. Karanja oil is a thick yellow or orange to brown in colour which is extracted from karanja seed. In India Karanja oil is used as a fuel or lightening lamps. Pongamia or karanja oil is used for biodiesel production because it's yield potential like 900-9000 Kg/hectare [39]. In India karanja trees are mainly founded in estern India and Western Ghats. Karanja seeds contain 1-2 kidney shaped kernals. It contains 27.5% oil and 19% moisture, approx 17.4% protein [40]. Biodiesel are made from pongamia oil through some steps those are- I) Purification of Pongamia oil. II) Separation of Pongamia oil. III) Transesterification of Pongamia oil. In this process pongamia oil is taken to a container flask with hot water for 30 min. By this process all the impurities are settles down. The mixture of pongamia oil and hot water collected into a separating funnel for settle down the high and low density impurities. After some time pongamia oil are separated from the funnel and collected into a jar [13]. For Diesel engine the best optimized bled is made by blending 20% karanja oil methyl ester [KOME] with diesel B20 [41]. Pogamia/ karanja oil have some properties those are -the flash point for 75 ml sample is approximate 243°C , fire point is 255°C, pour point for 20-25 ml oil is approx. 9°C, specific gravity and density is 0.9413 [13].

2.2.2 JATROPHA OIL

Jatropha oil is basically non-edible oil. It is extracted from Jatropha seeds. The scientific name of Jatropha tree is Jatropha Curcas Linnaeus. It is a cheap feedstock for biodiesel production [42]. Jatropha is a family member of Euphorbiaceous. Actually its origin is from Mexico [43, 44]. Jatropha seeds contain approximate 30-40% oil, crude protein- 24.60, fat and moisture- 47.25, 5.54% [45-47]. Jatropha oil is extracted from jatropha seed by these process- I) Transesterification II) Pyrolysis. Transesterifiation is done in two steps from first step decreases fatty acid level approx 1% and second step gives 90% methyl ester yield [48]. The seeds and leaf of jatropha tree are toxic for human and animal beings [42]. The properties of jatropha oils are density- 940 $kg.m^3$, viscosity- 24.5 mm^2sec^{-1}, flash point- 225°C, pour point- 4°C, acid value- 28 mg KOH g^{-1}, water content- 1.4, calorific value- 38.65 $MJkg^{-1}$, ash content- 0.8%, and carbon residue- 1% [49-51]. Yield point- 97% [52]. Jatropha has its six genotypes like – JC5, JC6, JC7, JC18, IP3A and IP3P. Among of them JC7 contains approx 47.58 % oil [53]. Bangladesh also produces a vast no of biodiesel from jatropha oil. For its high saponification value, soap also made from jatropha oil and it is ecofriendly [54].

2.2.3 NEEM OIL

Neem Tree is a family member of 'maliaceae'. Its scientific name is 'Azadirachta Indica' [55]. Neem oil is dull-dark coloured or greenish darker. It is bitter in test [56]. Neem oil is hydrophobic in nature [57]. It is not consumed by human beings because it is non-edible oil [58]. Its seed contains 30- 40% oil [55]. Neem oil contains saturated and polysaturated fatty acids like- palmitic acid, two stearic acid, oleic acid and linoleic acid [59]. Neem tree is originated from India. It's all part like leaf to roots is used for commercial purpose [60-63]. By two stages of transesterification biodiesel is produced from neem oil. At first stage it decreases acid value of neem oil and in second stage is methanolysis process [64]. Neem seeds oil yield point is approximately 400ml/kg. The properties of neem oils are- flash point- 234°C, fire point- 249°C, pour point- 5°C, density- 947.4 kg/m^3, kinematic viscosity- 36.7 mm^2sec at 40°C [56].

3. TRANSESTERIFICATION

Transesterification is a well-known process for the production of biodiesel from renewable resources with the help of critical mechanism. To complete this synthesis the relative components are involved as: methanol (99.5%,

Merck), potassium hydroxide (85% pellets, Merck), hydrochloric acid (37%, Merck), normal hexane (GC grade, >99%, Merck) [18]. In this synthesis methanol is the most important solvent as well as catalyst for desired production (Biodiesel) and the catalyst activity is a parameter which defines the how many amount of water is present in the oil. Therefore water less from vegetable oil is the benefits for biodiesel production. In transesterification reaction methanol and potassium hydroxide are used as a homogeneous catalyst. For the use of homogeneous catalyst in reaction medium huge amount of soap is formed and it is highly expensive to remove. Therefore to solving this problem we can used heterogeneous catalyst for biodiesel production which is cheap, easy preparation, no soap formation and easily removed after the reaction as for example KF/ZnO [65]. In this synthesis we can use different kinds of molar ratio between methanol and oil are 4:1 [66], 6:1 [16], 7.2:1 [67], 8:2 [68], 9:1 [18], 10:1 [69], 12:1 [70], 14:1 [71], 20:1 [72] and 40:1 [73]. The mechanism is carried out at several temperatures such as 25 [67], 45 [66], 55 [74], 60 [18], 95 [73], 100 [75], 180 [76] and 350°C [77]. The mechanism is followed by various times such as 1.5 [66], 2 [78], 3 [79], 4 [80], 6 [72], 8 [81], 12 [82] and 24 [83] hour. The reaction is going to forward with the help of several catalyst as H_2SO_4, KOH, Montmorillonite KSF, Cu-TiO_2, Dodecylbenzenesulfonic acid, La/Mn oxide, KF/ZnO, NaOH etc and catalyst doses are as follows 0.6 [19], 1.2 [71], 3 [83], 5 [81], 7 wt% [84].

3.1 Effect of temperature

In transesterification reaction the important parameter is temperature such as 25 [67], 45 [66], 55 [74], 60 [18], 95 [73], 100 [75], 180 [76] and 350°C [77]. As temperature increases the production of biodiesel from vegetable oils also increases up to 40°C and it is applicable for certain temperature ranges. When the temperature increases consequently and overcome the optimum stage, it's arrived to the less production of biodiesel. If we compare the two temperature ranges where the yield value are approximately same then consider higher temperature (above 90°C), the yield value of biodiesel is near about 96.51% by the help of several parameters are contact time 90 min of the reactant, M: O ratio 18:1, catalyst dose 8 wt% and the reaction procedure is completed in CSTR [85]. In another case we get same yield value approx 97.25% at lower temperature (approx 60°C) but here the parameters are used in different manner such as lower contact time 18 min, higher M: O ratio 25:1, low catalyst dose 7 wt% and the reaction procedure is completed in micro reactor device at constant temperature and atmospheric pressure with the presence of co-solvent as hexane-chloroform mixture [84] and in both cases dodecylbenzenesulfonic acid used as a catalyst. In another case temperature needed 180°C for the production of 99% biodiesel by different parameter as collision time 90 min, M: O ratio 12:1, La/Mn oxide catalyst and catalyst dose 3 wt% [76]. In another case if we not used catalyst in reaction medium then high temperature (350-500°C) is needed for this reaction then we get 98% biodiesel in 1 min [77].

3.2 Effect of time

In transesterification reaction another essential parameter is time which is in great impact for this process and it may forward at different time as 1.5 [66], 2 [78], 3 [79], 4 [80], 6 [72], 8 [81], 12 [82] and 24 [83] hour. In reaction, time is proportional to the yield value of biodiesel at certain stages, and further increases of time the yield percentage of biodiesel gradually decreases. If we compare two time ranges where yield of biodiesel approximately same but reaction complete in different time, then one reaction is completed in 180 second with several parameters as M: O ratio 9:1, KOH used as a catalyst and catalyst dose 1.2 wt% [18] and in another case reaction is completed in 100 min by involving in different parameters as M: O ratio 1:6, NaOH used as a catalyst and catalyst dose 0.5% [86] and both reaction is completed at 60°C. In another case the reaction is completed in 1 min for the production of 98% biodiesel at high temperature (350-500°C) [77]. If we want complete the reaction in 15 min with 99.4% production of biodiesel where parameters used as at 40°C, M:O ratio 6:1, KOH used as a catalyst and catalyst dose 1.5% Kg/L but the key point here is reaction conducted in ultrasonic mixing [16].

3.3 Effect of catalyst dose

Catalyst dose is an important parameter for the transesterification reaction. As increases of catalyst dose, the production of biodiesel also increases an efficient manner (catalyst doses are as follows 0.6 [19], 1.2 [71], 3 [83], 5 [81], 7 wt% [84]. As we get higher conversion of biodiesel as 90%, the catalyst doses also high as 7wt% with variable parameter as temperature 100°C, time 5h, M:O ratio 10:1 and [$mimC_4SO_3H$][SO_3CF_3] used as a catalyst [75]. In another case as we get almost same conversion as 90.93% but in presence of different catalyst as Cu-TiO_2 with doses as TiO_2- 3 %, Cu- 2 % [87]. In such case where catalyst dose is very low as 0.5% which gives high production 99.1% but here reaction time is very high as 100 min at 60°C and NaOH used as a catalyst [86]. In another case we see that lower production as 79.6% with 3wt% catalyst dose but here montmorillonite KSF used as a catalyst and reaction is completed in batch reactor [88].

3.4 Effect of methanol to oil ratio

The molar ratio of methanol to oil is a significant variable that outcome a better production of fatty acid methyl ester. In this synthesis we can use different kinds of molar ratio between methanol and oil are 4:1 [66], 6:1 [16], 7.2:1 [67], 8:2 [68], 9:1 [18], 10:1 [69], 12:1 [70], 14:1 [71], 20:1 [72] and 40:1 [73]. As increases of methanol to oil ratio, the yield value of FAME also increases. Due to higher M: O ratio as 40:1 we get higher conversion as 96.7% with H_2SO_4 used as a catalyst at 95°C with 5 vol% catalyst dose and reaction time 9h [73]. In another case where M: O ratio is very low as 6:1 although we get 99.4% conversion of biodiesel and here several parameters are reaction time 15 min, temperature 40, KOH used as a catalyst with catalyst dose 1.5% Kg/L [16]. Table 1 represents different feed stocks along with different parameters of transesterification as already reported by different researchers.

Table 1. Different feedstock used in transesterification reaction for biodiesel production by different researchers.

Feed stock	**Catalyst used**	**Reaction temp**	**Time**	**Solvent quantity**	**Solvent used**	**Catalyst dose**	**Biodiesel yield**	**Ref.**
Sewage Sludge	KOH and Activated carbon	60°C	8 hr	10:1(w/w)	Methanol	3 wt%	6.8%	[89]
Sewage sludge	H_2SO_4	39°C	99 min	4.41%	Methanol	1wt%	16.23%	[90]
Sewage sludge	[$mimC_4SO_3H$] [SO_3CF_3]	100°C	5 hr	10:1	Methanol	7 wt%	90%	[75]
Primary sewage sludge	H_2SO_4	40°C	24 hr		Cholorform	3%	48 wt% & 18.7 wt%	[83]
sludge	H_2SO_4	75°C	>8 hr	12:1	Methanol	5% (v/v)	14.5 wt	[81]
sewage sludge	H_2SO_4	55°C	12 hr	6:1	Methanol	1 vol%		[74]
Sewage sludge	H_2SO_4	55°C	8 hr	250 ml & 100 ml	Methanol	5 vol%		[91]
Palm Oil	Cu-TiO_2	45°C	45 min	20:1	Methanol	TiO_2- 3% Cu- 2%	90.93%	[87]
Palm Oil	Montmorilloni	(50–190)	180min	8:1	Methanol	3 wt%	79.6%	[88]

	te KSF	°C						
Palm oil	KOH	50°C	2 hr	10:1	Methanol			[78]
Crude palm oil	H_2SO_4	95°C	9 hr	40:1	Methanol	5% (vol/wt)	96.7 %	[73]
Palm oil	NaOH	60°C	70 min	10:1	Methanol		99%	[69]
Palm oil	Activated dolomite	65°C	6 hr	20:1	Methanol	1 wt%	98%	[72]
Palm oil	H_2SO_4	90°C	3 hr	100%	Ethanol	2.25 M		[79]
Palm oil	Acid catalysed	100°C	5 min	300-5000 $mol.m^{-3}$	Methanol			[92]
Crude Palm oil	NaOH	60°C	1 hr	12:1	Methanol	0.6%		[70]
Soybean oil	KOH	60°C	180 s	9:1	Methanol	1.2 wt%	98%	[18]
Soybean oil	KOH	40°C	15 min	6:1	Methanol	1.5 and 2.2% kg/L oil	99.4%	[16]
Soybean oil	NaOH	60°C	100 min	1:6	Methanol	0.5%	99.1%	[86]
Soybean oil	NaOH	60°C	30 min	2.5 ml	Methanol	0.1 gm	97%	[93]
Soybean oil	NaOH	25°C	0.41 - 10.36 min	7.2:1	Methanol	I wt%	86%	[67]
Soybean oil	La/Mn oxide	180°C	90 min	12:1	Methanol	3 wt%	99%	[76]
Soybean oil	NaOH	23°C	10 min	14:1	Methanol	1.2 wt%	95%	[71]
Soybean oil	NaOH	29°C	30 min	9:1	Methanol	0.2-0.6 w/w	98%	[19]
Soybean oil	KF/ZnO		9 hr	10:1	Methanol	3 wt%	87%	[65]
Algae	NaOH	60°C	25 min	8:2	Methanol	0.3 to 0.5%	95%	[68]
Algae	NaOH		3 hr	24 mL	Methanol	0.25 g		[94]
Jatropha oil	Lipase	40°C	8 hr	1:4	Ethanol	0.05 g	98%	[95]
Jatropha oil	H_2SO_4	45°C	1.5 hr	4:1	methanol	1.0 wt%	95.2%	[66]

Jatropha curcas L. oil	KOH	64°C	20 min	6:1	Methanol	1.3%	98%	[96]
Lamb meat	SC-CO_2	45- 50°C	24 hr	methanol: fat of 10:1	Methanol		53.5%	[97]

4. CONCLUSIONS

In the present day a maximum part of energy consumption is supported from fossil fuels. For this reason the world is facing the decaying of fossil fuels. So we are focusing on biodiesel production from different natural feedstocks. The feedstocks are soybean oil, sunflower oil, palm oil, karanja oil, jatropha oil, neem oil, sewage sludge, lamb meat, etc. But here the vegetables oils are not economically feasible because of its high cost. So an alternative way we can use sewage sludge as a feedstock where we get low cost of feedstock material. The formation of biodiesel via transesterification reaction is one step and the reaction medium is depends upon several parameters such as catalyst dose, reaction temperature, reaction time, solvent, and methanol to oil ratio. From the overall literature review we have seen that for optimum biodiesel production (90-99%) the needed parameter ranges are catalysts (H_2SO_4, KOH, NaOH, Cu-TiO_2, SC-CO_2, KF/ZnO, La/Mn oxide and activated dolomite), catalyst dose (0.6, 1.2, 3 and 7 wt%), reaction temperature (25, 45, 55, 60, 95, 180 and 350°C), reaction time (1.5, 2, 3, 4, 6, 8, 12 and 24 hr) and methanol to oil ratio (4:1, 6:1, 7.2:1, 8:2, 9:1, 10:1, 12:1, 14:1, 20:1 and 40:1).

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