A Review on Potential Source of Biodiesel Production from Non-Edible Oil Seeds of Indian Origin

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Abstract:

Biodiesel has also been paid greater attention in recent years because fossil fuel sources are limited and there is a need to look for alternatives to fossil fuels to ensure environmental protection and energy security. Biodiesel is non-toxic, renewable and biodegradable and is considered as one of the most alternative fuels for diesel engines. Biodiesel is prepared from various sources including edible oils, non-edible oils, animal fats, legume plants, etc. There are more than 350 oil bearing crops identified [10], among which only sunflower, palm, soybean, jatropha oils are considered as potential alternative fuels for diesel engine. Edible vegetable oils and animal fats for biodiesel production have become more expensive as they compete with food materials. In recent years there is an increased demand for vegetable oils since they are edible and hence they are not preferred much for biodiesel production [5]. MM GuiK et.al [18] mentioned currently, more than 95% of the world biodiesel is produced from edible oil which is easily available on large scale from the agricultural industry. However, continuous and large-scale production of biodiesel from edible oil without proper planning may cause negative impact to the world, such as depletion of food supply leading to economic imbalance. A possible solution to overcome this problem is to use non-edible oil or waste edible oil (WEO) as a feedstock. Trans-esterification is a chemical reaction to produce biodiesel (fatty acid methyl ester) by involving triglycerides and an alcohol as reactants in presence of suitable catalysts such as strong alkali, a strong acid and an enzyme. The main factors affecting transesterification are free fatty acid(FFA) content, the molar ratio of glycerides to alcohol, catalyst, reaction temperature and pressure, reaction time and the contents of free fatty acids and trace water content in oil. The commonly accepted molar ratio of alcohol to to glycerides are 6:1-30:1, temperature 40-70C, time period 30-120 minutes and mixing rate is 400-900 rpm.

In this paper an attempt has been made on review of potential source of non-edible oil of Indian origin for production of biodiesel and the researches done by various researchers in this field and their finding on biodiesel production technologies, potential catalysts and effect of reaction parameters on biodiesel yield potentials. This review paper covers the works of researcher published during 2000 to 2018.

Keywords: Biodiesel, Transesterification, FFA, FAME, Ester, Non-edible oil, Catalyst

1.0 Introduction:

The need of alternatives of fossil fuel is pressing hard for several reasons especially to the countries like India with vibrant economy, which consumes large amount of fossil fuels and rely heavily on import for the same. Bio-fuels are renewable liquid fuels extracted from biological raw material and have proven to be good substitutes for oil in the energy sector.About 150 non-edible tree borne oilseeds (TBOs) exist in India. Some of the important TBOs used in India are Neem (*Azadirachta indica*), Karanj (*Pongamia pinnata*), Mahua (*Madhuca indica*), Jatropha (*Jatropha curcas*), Kusum (*Schleichera)*, Pilu *(Salvadora oleoides)*, Bhikal (*Prinsepia utilis)*, Undi (*Calophyllum inophyllum*), Thumba (*Citrullus colocynanthis*), Sal (*Shorea robusta)* and Jojoba (*Simmondsia chinensis)*. The oil content varies between 21 to 73% in these species. All these species have multipurpose uses like domestic and industrial utility such as agriculture, cosmetic, pharmaceutical, diesel and its substitute, *etc.* Most of these TBOs are abundantly found in forest and non-forest areas but are scattered and are not properly collected, what so ever collected is of poor quality due to the lack of awareness of their uses. Among the various Tree Borne Oilseeds (TBOs), *Jatropha curcas* and *Pongamia pinnata* have been found most suitable for biodiesel production [21]

Biofuels are derived from renewable bio-mass resources and, therefore, provide a strategic advantage to promote sustainable development and to supplement conventional energy sources in meeting the rapidly increasing requirements for transportation fuels associated with high economic growth, as well as in meeting the energy needs of India's vast rural population. Biofuels can increasingly satisfy these energy needs in an environmentally benign and costeffective manner while reducing dependence on import of fossil fuels and thereby providing a higher degree of National Energy Security. India is the world's fifth largest consumer of energy, and by 2030 it is expected to become the third largest, overtaking Japan and Russia. India has only 0.4 percent of the world's proven oil reserves. India's energy demand is expected to double to 1901 metric tonne by 2040 from 897metrictonne in 2016 and India's share in global energy demand will be almost double to 11% by 2040 [20]

India is one of the fastest growing economies in the world. The Development Objectives focus on economic growth, equity and human well being. Energy is a critical input for socio-economic development. The energy strategy of a country aims at efficiency and security and to provide access which being environment friendly and achievement of an optimum mix of primary resources for energy generation. Fossil fuels will continue to play a dominant role in the energy scenario in our country in the next few decades. However, conventional or fossil fuel resources are limited, non-renewable, polluting and, therefore, need to be used prudently. On the other hand, renewable energy resources are indigenous, non-polluting and virtually inexhaustible. India is endowed with abundant renewable energy resources. Therefore, their use should be encouraged in every possible way.

The crude oil price has been fluctuating in the world market. Such fluctuations are straining various economies the world over, particularly those of the developing countries. Road transport sector accounts for 6.7% of India's Gross Domestic Product (GDP). Currently, diesel alone meets an estimated 72% of transportation fuel demand followed by petrol at 23% and balance by other fuels such as CNG, LPG etc. for which the demand has been steadily rising. Provisional estimates have indicated that crude oil required for indigenous consumption of petroleum products in FY 2017-18 is about 210 MMT. The domestic crude oil production is able to meet only about 17.9% of the demand, while the rest is met from imported crude. India's energy security will remain vulnerable until alternative fuels to substitute/supplement petro-based fuels are developed based on indigenously produced renewable feedstock. To address these concerns, Government of India has set a target to reduce the import dependency by 10 per cent by 2022 [3].

Biofuels in India is of strategic importance as it augers well with the ongoing initiatives of the Government such as Make in India & Swachh Bharat Abhiyan and offers great opportunity to integrate with the ambitious targets of doubling of Farmers Income, Import Reduction, Employment Generation, Waste to Wealth Creation. Simultaneously, the existing biodiversity of the Country can be put to optimum use by utilizing drylands for generating wealth for the local populous and in turn contribute to the sustainable development. Village Panchayat and communities will play crucial role in augmenting indigenous feedstock supplies for biofuel production. In cases relating to usage of wastelands for feedstock generation, local communities from Gram Panchayats/ talukas will be encouraged for plantations non-edible oil seeds bearing trees/ crops such as Pongamia pinnata (Karanja), Melia azadirachta (Neem), castor, Jatropa Carcus, Callophylum Innophylum (polanga), Simarouba glauca (laxmitaru), mahua etc.

2.0 Current Scenario of Bio-fuel In India:

India"s biofuel production accounts for only 1% of the global production. This includes 380 million litres of fuel ethanol and 45 million litres of biodiesel [2]. India is not self-sufficient in edible oil production and depends upon large quantities of import of palm oil and other vegetable oils to meet the domestic demand. So India does not use vegetable oils derived from rapeseed, mustard or palm oil for production of biodiesel.

Biodiesel in India is mostly produced from oils extracted from non-edible seeds of shrubs like jatropha and ongamia[2,3]. Over the last decade, Government has undertaken multiple interventions to promote biofuels in the Country through structured programmes like Ethanol Blended Petrol Programme, National Biodiesel Mission, Biodiesel Blending .Programme. Learning from the past experiences and demand supply status, Government has revamped these programmes by taking steps on pricing, incentives, opening alternate route for ethanol production, sale of biodiesel to bulk and retail customers, focus on R&D etc. These steps have impacted the biofuels programme in the Country positively.

3.0 Indian Bio-fuel Policy 2018:

The Government of India approved the "National Policy of Biofuels" on June 2018. The policy and the developments following it have strengthened India"s energy security by encouraging the use of renewable energy resources to supplement transport fuels. India's energy security will remain vulnerable until alternative fuels to substitute/supplement petro-based fuels are developed based on indigenously produced renewable feedstock. To address these concerns, Government has set a target to reduce the import dependency by 10 per cent by 2022. Government has prepared a road map to reduce the import dependency in Oil & Gas sector by adopting a five pronged strategy which includes, Increasing Domestic Production, Adopting biofuels & Renewables, Energy Efficiency Norms, Improvement in Refinery Processes and Demand Substitution. This envisages a strategic role for biofuels in the Indian Energy basket.

4.0 Non-Edible Vegetable Oil for Biodiesel Production:

Non-edible oils are not feet for human consumption due to presence of some toxic chemical compounds in the oils. Production of biodiesel from various non-edible feed stocks overcome the problems of food verses fuel, environmental and economic issues related to edible oils. These plants can be planted at low fertile and unutilised land a Biofuel production using edible oils as a feedstock has certain limitations with respect to their cost and source from which they are derived. So, for this issue to be addressed, there is a need of less expensive feedstocks. Non-edible oils have a great capability to be used as feedstocks for biofuel production particularly biodiesel. Non-edible oils as feedstocks for biodiesel production can help in reducing the cost of biodiesel production. The production of biodiesel from different non-edible oil seeds crops has been extensively investigated over the last few years. Jatropha, Pongamia, Palm, Mahua, etc. are the various sources that are present in nature in excess amounts and can serve as a great feedstock. A serious, which increases the biodiesel production cost. The type and fatty acid contents quantification of non-edible oils depend on the plant species and on the growth condition of the plants. drawback of non-edible is their high free fatty acid (FFA) content When compared to edible oils, these plants are very economical and are readily available in Indian coastal states. Using vegetable oils directly as fuels can become harmful for the engine with respect to fuel atomization, incomplete combustion, engine fouling, etc. In order to decrease the viscosity of vegetable oils and to make them use as fuels, there are several methods available that can carry out this processnamely: micro-emulsification, pyrolysis, transesterification, etc. For the commercial production of biodiesel, the most commonly used method employed is transesterification because within a shorter reaction time and the use of low temperature and high pressure it gives a high yield (Shikha and Rita, 2012; Liaquat et al., 2012).

Major tree born oil seeds available in India:

4.1 Laxmitaru (Simarouba Glauca):

Simarouba belongs to the family Simaroubaceae Quasia. It had also been known as paradise tree, Laxmi taru, Acetuno, a multipurpose tree that can grow well under a wide range of hostile ecological condition. Its origin is native to North America, now found in different regions of India and Odisha. It was a medium sized tree and suited for temperature range 10 – 40 0C, rainfall distribution (around 400 mm), pH of the soil should be 5.5 – 8. It produces bright green leaves 20-50cm length, yellow flowers and oval elongated purple colored fleshy fruits. Its seeds contain about 40 % kernel and kernels content 55 -65% oil. The amount of oil would be 1000 – 2000 kg/ha/year for a plant spacing of 5m x5m. It was used for industrial purposes in the manufacture of Soaps, Detergents and Lubricants etc. The oil and its derivatives are useful for making pharmaceuticals, surfactants, detergents, soaps, shampoos, cosmetics, plasticizers, stabilizers, lubricants, grease, emulsifiers, paints, varnishes, candles etc.[7]

4.2 Jatropha (*Jatropha curcas* L.).

Jatropha , commonly known as Ratanjot is a fast growing multi-purpose deciduous large shrub capable to grow and establish in tropical and subtropical region of the country and even on wasteland. It has the capacity to rehabilitate degraded or dry lands by improving water retention capacity. It has various advantageous characteristic features *viz.*, not browsed by cattle, best hedge plant, less gestation period (two years), capable to grow and establish in various biotic and abiotic stress conditions, high oil content (30-42% in seed), which has multiple uses as biodiesel, direct fuel, lubricant, medicine, besides other industrial uses. The by-product of biodiesel are also quite useful for industrial application such as glycerine and biofertilizers. The residue is a good substrate for biogas production.

4.3* Karanja (*Pongamia pinnata

Karanj (*Pongammia pinnata*), a leguminous tree has many traditional uses and is one of the important species in this category. This tree is known by many names *viz.*,Indian Beech, Pongam, Honge, Ponge and Karanj, *etc.* and mostly used for landscaping purposes as a wind break or for shade due to the large canopy and showy fragrant flowers. The seed oil is an important component of this tree being used as lamp oil, in soap making, and as a lubricant for thousands of years. This oil is rapidly gaining popularity as an important source of biofuel. This tree is largely planted in different parts of the country such as Odisha, U.P, Bihar, Haryana, Rajastan etc. The oil content is about 35-50% as reported by various researchers.

4.4 Neem (*Melia azadirachta* L.).

Neem belongs to Meliaceae Family. It grows in tropical and semi tropical regions and is native to India and Burma. This tree can attain a height of around 15-40 m and it grows fast. The fruits of this plant are ovoid in shape and they possess kernels (one kernel for each seed). The seed kernels of neem tree have a good content of fat (ranges from 33%-45%). Neem oil can be used for other purposes such as soaps, medicines and insecticides. This oil has been used for manufacturing of soap, cosmetics and pharmaceutical products.

4.5 Mahua (*Madhuca indica*).

It is known by the common name as 'Indian butter tree', mahua is found abundantly in tribal areas of India. Seeds of this plant have about 30%-40% of oil content known as mahua oil . In India it is found mostly in the states of Orissa, Chhattisgarh, Jharkhand, Bihar, Madhya Pradesh, and Tamilnadu. The maadhuca indica oil contains high level of free fatty acid (FFA) i.e upto 20%.

4.6 Calophyllum inophyllum (Polanga)

Calophyllum inophyllum, commonly known as polanga or honne, is a large evergreen,belongs to the Clusiaceae family, widespread in East Africa, India, South East Asia, and Australia (Silitonga et al., 2013). Calophyllum inophyllum is a medium and large-sized evergreen sub-maritime tree that averages 8–20m in height with a broad spreading crown of irregular branches. Each tree yields about 20–100 kg of whole fruits per year (Venkanna and Reddy, 2009). Trees begin to bear significantly after 4–5 years. The nut kernel contains 50%–70% oil and the mature tree may produce 1–10 kg of oil per year depending upon the productivity of the tree and the efficiency of extraction process. Traditionally, Calophyllum inophyllum oil has been used as a medicine, soap, lamp oil, hair grease, and cosmetic in different parts of the world

4.7 Schleichera oleosa (Kusum)

Schleichera oleosa, also called as kusum, is medium-sized (up to 40m in height) deciduous or nearly evergreen tree belonging to the Sapindaceae family that is native to South and South East Asia. The fruits, seeds, and young leaves of this plant are edible and used for medicinal and dye purposes (Kant et al., 2011). The oil content of kusum seeds is 51%–62% but the yields are 25%–27% in village ghanis (oil mills) and about 36% oil in expellers (Acharya et al., 2011). Iodine value of the oil is 215–220 and its total fatty acid content is 91.6%

5.0 Literature Search on Biodiesels from Plant Oils:

Over the last few years, there has been increasing amounts of research and interest in the different edible feedstocks that can be used to make biodiesel and the effects of the different feedstocks on the quality of the biodiesel. Currently, biodiesel is produced from different crops such as, Jojoba oil, palm oil, soybean oil, canola, rice bran, sunflower, coconut, rapeseed, soybean and sunflower oil [5]. The major difference between various edible oils is the type of fatty acids attached in the triglyceride molecule. Fatty acid composition effects the yield percentage, reaction temperature, FFA content and molar ratio of the plant oils.

Meeta Sharma et.al [6] prepared the biodiesel from Argemone Mexican oil by transesterification reaction with $CaO\text{-}Ca_{12}Al_{14}O_{33}$ heterogeneous catalyst at the doses of 5% of oil in 1:6molar ratio of oil to methanol at 60 C for 3.5 hrs reaction period. And compared with conventional alkali transesterification reaction. The yield of fatty acid methyl ester from these two processes are 97.8% and 98.7 % in 90 minutes and 210 minutes respectively.

Mishra SR et.al [7] produced biodiesel from simarouba glauca oil by transesterification reaction with KOH as catalyst with 1:6 molar ratio of oil to methanol at 65C temperature witnthe yield of 92%. In this paper, they have tested the methyl ester of simarouba oil as per standard specification. Nabnit and et.al [8] extracted the oils from various non-edible trees such as mahua, neem, polanga, simarouba and characterized their fuel properties. Fatty acid methyl esters prepared from these oils by esterification and transesterification reaction process at 60C reaction temperature, 1% alkali catalyst, 1:6 molar ration of oil/methanol. The biodiesel prepared from these oil evaluated for various properties such as density, viscosity, flash point, calorific value etc.

S K Karmee et.al [10] prepared the Biodiesel from the non-edible oil of Pongamia pinnata by transesterificationof the crude oil with methanol in the presence of KOH as catalyst. A maximum conversion of 92%(oil to ester) was achieved using a 1: 10 molar ratio of oil to methanol at 60° C. Tetrahydrofuran (THF), when used as a co-solvent increased the conversion to 95%. Solid acid catalysts viz. Hβ-Zeolite, Montmorillonite K-10 and ZnO were also used for this transesterification.

De BK et.al [11] studied the scope of two minor vegetable oils, ie karanja (Pongamia glabra) oil and nahor (Mesua ferrea L., Guttiferae) oil, as raw material for biodiesel fuel. The distilled fatty acid methyl esters obtained from karanja oil and nahor oil have the following characteristics: cetane indices 56.2, 54.6; heat of combustion (kcal/mol) 8.26, 8.39; flash points (° C) 134, 142; cloud points (° C) 8.3, 6.1, respectively. All these properties of the distilled methyl esters reveal that karanja oil and nahor oil can be suitably used as cheaper fuel for diesel engines.

MM Azam et.al [12] examined the Fatty acid profiles of seed oils of 75 plant species having 30% or more fixed oil in their seed/kernel were examined. Saponification number (SN), iodine value (IV) and cetane number (CN) of fatty acid methyl esters of oils were empirically determined and they varied from

169.2 to 312.5, 4.8 to 212 and 20.56 to 67.47, respectively. Fatty acid compositions, IV and CN were used to predict the quality of fatty acid methyl esters of oil for use as biodiesel. Fatty acid methyl ester of oils of 26 species including Azadirachta indica, Calophyllum iinophylum.

Gaurav Dwivedi et.al [13] studied the Biodiesel yield of 99% from Pongamia oil by transesterification under the molar ratio of 6:1 of alcohol to oil with Sodium hydroxide as a catalyst of 0.5 vol% and operating temperature of 60 °C with time for production process being 1 h. The study shows that brake specific fuel consumption and brake thermal efficiency of B_{20}biodiesel from Pongamia is quite comparable to diesel.

A.E Atabani et.al [14] investigates the potential of Calophyllum inophyllum as a promising feedstock for biodiesel production. In this paper, several aspects such as physical and chemical properties of crude Calophyllum inophyllum oil and methyl ester, fatty acid composition, blending and engine performance and emissions of Calophyllum inophyllum methyl ester were studied. Overall.

B K Venkana et.al. [15] examines the production of a biodiesel from a non-edible oil namely honne oil (*Calophyllum inophyllum* linn). A three stage process viz., pre-treatment, alkali catalyzed transesterification and post treatment adopted for the production is discussed. The reaction parameters such as methanol to oil molar ratio, catalyst concentration, temperature and time have been optimized for the production of biodiesel. The yield of biodiesel from the honne oil under the optimized conditions is found to be 89%.

Alok kumar et.al [16] studied Response surface methodology (RSM) based on central composite rotatable design (CCRD) to optimize the three important reaction variables—methanol quantity (M), acid concentration (C) and reaction time (T) for reduction of free fatty acid (FFA) content of the oil to around 1% as compared to methanol quantity (M') and reaction time (T') and for carrying out transesterification of the pretreated oil. Using RSM, quadratic polynomial equations were obtained for predicting acid value and transesterification. Verification experiments confirmed the validity of both the predicted models. The optimum combination for reducing the FFA of *Jatropha curcas* oil from 14% to less than 1% was found to be 1.43% v/v H_2SO_4 acid catalyst, 0.28 v/v methanol-to-oil ratio and 88-min reaction time at a reaction temperature of 60 °C as compared to 0.16 v/v methanol-to-pretreated oil ratio and 24 min of reaction time at a reaction temperature of 60 °C for producing biodiesel. This process gave an average yield of biodiesel more than 99%.

Rakesh Sarin et.al [17] examined the possibilities in using mixture of palm oil and jatropha oil based biodiesel. Soybean and Rapeseed are common feedstocks for Biodiesel productarin ion in USA and Europe, respectively. However, Asian countries are not self sufficient in edible oil and exploring non-edible seed oils, like Jatropha and Pongamia as biodiesel raw materials. However there is a gestation period of few years before these crops start yielding seeds and oil. On the other hand, South Eastern countries like Malaysia and Thailand have surplus Palm crops. But due to substantial amount of saturated fats in Palm, the Palm biodiesel has poor low temperature properties. In order to exploit the proximity of South Asian and South-East Asian countries, blends of Jatropha and Palm biodiesel have been examined to study their physico-chemical properties and to get an optimum mix of them to achieve better low temperature properties, with improved oxidation stability.

Sahoo PK et.al [19] worked on the preparation of biodiesel from non-edible oils of Karanja, Jatropha and polanga oils and optized the reaction parameters for highest yield.

6.0 Production Technologies:

Biodiesel is produced from any vegetable oil or fat through a chemical process called transesterification reaction. Triglycerdides present in the oil transesterified preferably with methanol in presence of catalysts such as acid, base or bio-catalyst / enzymes to produce fatty acid methyl ester called biodiesel and glycerol as by product. The transesterification reaction can be carried out using both homogeneous (acid or base) and heterogeneous (acid, base or enzyme) catalyst. Other than transesterification reaction, there are other technologies such as microemulsion, pyrolysis etc for biodiesel production are less preferable on transesterification due to more enzyme cost and more reaction time. Among these various conversion technologies, the base catalyzed transesterification reaction has become commercial success due to high yield in fast reaction. In this process, the large and branched triglyceride molecules of the vegetable oils converts into smaller, straight chain molecules, almost similar in size to the molecules of the species present in the diesel fuel.[5-18]

7.0 Effects of Different Parameters on Transesterifictaion Reaction:

The yield of biodiesel in the process of transesterification is affected by several process parameters such as molar ratio of alchohol to oil, reaction temperature, catalyst doses, reaction time, mixing rate (rpm) and presence of free fatty acid content [4-6]].

7.1 Effect of methanol/ oil molar ratio:

Methanol/ oil molar ratio is an important variable affecting the yield of ester. The stoichiometry of the transesterification reaction requires 3mol of alcohol per mole of triglyceride to yield 3mol of fatty esters and 1 mol of glycerol. To shift the transesterification reaction to the right, it is necessary to use either a large excess of alcohol or to remove one of the products from the reaction mixture. When 100% excess alcohol is used, the reaction rate is at its highest. Higher molar ratio of alcohol to oil interferes in the separation of glycerol. It was observed that lower molar ratios required more reaction time. With higher molar ratios, conversion increased but recovery decreased due to poor separation of glycerol. It was found that optimum molar ratios depend upon type & quality of oil [21].

7.2 Effect of reaction temperature:

The rate of reaction is strongly influenced by the reaction temperature. However, given enough time, the reaction will proceed to near completion even at room temperature. Generally, the reaction is conducted close to the boiling point of alcohol at atmospheric pressure. These mild reaction conditions require the removal of free fatty acids from the oil by refining or pre-esterification. Further increase in temperature is reported to have a negative effect on the conversion. The rate of reaction is strongly influenced by the reaction temperature. Further increase in temperature is reported to have a negative effect on the conversion. Literature Studies have indicated that given enough time, transesterification can proceed satisfactorily at ambient temperatures in the case of the alkaline catalyst. It was observed that bio-diesel recovery was affected at very low temperatures but conversion was almost unaffected.

7.3 Effect of reaction time:

The conversion of oil to biodiesel approaches to equilibrium conversions with increased reaction times. The maximum ester conversion is obtained at 2 hour reaction time. Similar reaction time has been reported in Madhuca Indica and Karanja oil have reported that the reaction is very slow during the first minute due to mixing and dispersion of methanol into catalyst. From 1 to 5 min, the reaction proceeded very fast. The production of beef tallow methyl esters reached the maximum value at about 15 min[24]

7.4 Effect of catalyst type and Concentration:

Alkali metal alkoxides are the most effective transesterification catalyst compared to the acidic catalyst. Sodium alkoxides are among the most efficient catalysts used for this purpose. Transmethylations occurs approximately 4000 times faster in the presence of an alkaline catalyst than those catalyzed by the same amount of acidic catalyst. Partly for this reason and partly because alkaline catalysts are less corrosive to industrial equipment than acidic catalysts, most commercial transesterification are conducted with alkaline catalysts. Further, increase in catalyst concentration does not increase the conversion and it adds to extra costs because it is necessary to remove it from the reaction medium at the end. Further, increase in catalyst concentration does not increase the conversion and it adds to extra costs because it is necessary to remove it from the reaction medium at the end. It was observed in literature studies higher amounts of NaOH catalyst were required for higher FFA oil [22].

7.5 Effect of mixing Intensity:

The mixing is most significant during the slow rate region of the transesterification reaction. As the single phase is established, mixing becomes insignificant. The understanding of the mixing effects on the kinetics of the transesterification process is a valuable tool in the process scale-up and design. It was observed in literature studies that after adding alcohol & catalyst to the oil, 5-10 minutes stirring helps in higher rate of conversion and recovery [12].

Stirring can play an important role in the yield of biodiesel production. Transesterification reaction was carried out with 180, 360 and 600 revolutions per minute (rpm) and reported incomplete reaction with 180 rpm. The yield of methyl ester was same with 360 and 600 rpm. Mode of stirring too plays a vital role in the transesterification reaction. The yield of biodiesel increased from 85% to 89.5% when magnetic stirrer (1000 rpm) was replaced with mechanical stirrer (1100 rpm). A plausible explanation may be a thorough mixing of the reactants by mechanical stirrer [26].

7.6 Effect of free fatty acids:

Free fatty acids (FFAs) content after acid esterification should be minimal or otherwise less than 2% FFAs. These FFAs react with the alkaline catalyst to produce soaps instead of esters. There is a significant drop in the ester conversion when the free fatty acids are beyond 2% [25].

8.0 Conclusions:

Biofuels are important renewable and alternate source of petroleum fossil fuels. India has a rich potential, with more than 100 diverse tree species producing seed oil suitable for biodiesel. These oil tree species can be grown on non-agricultural lands and hence does not compete for food and fodder. With both National Biofuel policy (2009) and National Agroforestry Policy (2014) being launched in the country, the first policy targets the replacement of fossil fuels by biofuel to the extent of 5% by 2012, 10% by 2017 and above 10% beyond 2017 and the second policy aims at integrated land use option for livelihood, environment and energy security. Some of the important TBOs like Jatropha, Karanj, Mahua, Simarouba etc., are efficiently included in the agroforestry systems and resulted in beneficial results, thus providing a large source of non-edible tree borne oilseeds.

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