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Review Paper

A Review of Jatropha and Pongamia FAME

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Abstract

The need of energy in transport sector is increasing tremendously. That's why; economy in this sector is always fluctuating with high cost. The research on alternative fuel which should be economically feasible, easily processed and should be easy to use. Biodiesel is such a fuel that is gaining attraction due to its low cost synthesis from waste oils and its suitability in current diesel engines with no modification. Along with that it has several reasons to accept as a substitute to commercial diesel fuel due to its ecofriendly nature and is supportive to agricultural economy and is nontoxic. The cost of feedstock is the major factor which is responsible for viability of biodiesel. India has huge potential containing more than 100 various species producing seed oil which is suitable for production of biodiesel. Transesterification reaction is the most favourable way to convert oil into its ester form. The present article reviews the synthesis, optimization and characterization of biodiesel that especially synthesised from Jatropha curcus linn and Pongamia pinnata feedstock oils.

Keywords: Biodiesel, Transesterification, Methanol, Jatropha Curcas, fossil fuel.

Introduction

The need of energy in transport sector is increasing tremendously. That's why; economy in this sector is always fluctuating with high cost. The research on alternative fuel which should be economically feasible easily processed and should be easy to use[1]. Biodiesel/ Fatty acid methyl ester (FAME) is such a fuel which fulfils these conditions, it is synthesized from in edible plant oils or from waste oils (low cost) by a simple chemical process called as alcoholysis or transesterification reaction (easy to process, most accepted method) and can be used directly or in mixture form with diesel fuel in diesel engine (easy to use). Transesterification or alcoholysis is the displacement of alcohol from an ester by another in a process similar to hydrolysis, except an alcohol is used instead of water. This process has been widely used to reduce the high viscosity of triglycerides. Transesterification is a chemical reaction between triglyceride and alcohol in the presence of catalyst. It consists of a sequence of three consecutive reversible reactions where triglycerides are converted to diglycerides and then diglycerides are converted to mono-glycerides followed by the conversion of monoglycerides to glycerol. In each step an ester is produced and thus three ester molecules are produced from one molecule of triglycerides[2]. The transesterification reaction requires a catalyst such as sodium hydroxide to split the oil molecules and an alcohol (methanol or ethanol) to combine with the separated esters. It is carried out by using homogeneous as well as heterogeneous catalysts. As homogenous catalysts are easily get dissolved in solvent and fasters the rate of reaction but they cannot be recovered and reused. Rather heterogeneous catalysts are more preferable, as they easily get dissolved in solvent, separated easily after reaction completion. And the most important is that these catalysts are easily recovered back and reused by purifications so that most of purification steps get reduced with heterogeneous catalysts. The transesterification is the most viable process adopted known so far for the lowering of viscosity. It also gives glycerol as a by-product which has a commercial value. Among all these alternatives, transesterification seems to be the best choice as the physical characteristics of FAME are very close to those of diesel fuel and the process is relatively simple. In the esterification of an acid, an alcohol acts as a nucleophilic reagent; in the hydrolysis of an ester, an alcohol is displaced by a nucleophilic reagent. This alcoholysis (cleavage by an alcohol) of an ester is called transesterification[3]. Along with that it has several reasons to accept as a substitute to commercial diesel fuel due to its ecofriendly nature and is supportive to agricultural economy and is nontoxic[4,5]. The cost of feedstock is the major factor which is responsible for viability of FAME. As feedstocks takes about 80 % of total cost of biodiesel production[6]. In our country identification of new feedstock (which should be non-edible in nature) is a challenging work for researchers and scientists, as we have major area of emphasis. Indian Government supported non-edible feedstocks for the development of renewable energy sector since 2005[7]. However with availability of limited land for plantation rather identification of forest based plants having oil contents in its seed is challenging work for researchers. India has huge potential containing more than 100 various species producing seed oil which is suitable for production of biodiesel. These seed oil trees can be grown on waste land or poor lands or on non agricultural lands and so it does not compete with feed and fodder too. Some of tree born oil (TBO) seeds like Jatropha[8,9], Karanja[8,10], undi[8,11], mahua[8,12], thumba[8,13], neem[8], kokum[8], jojoba[8] were identified and have studied its suitability for biodiesel production. These plants are available in Indian forests and non forests area but are scattered and are not collected every year due to lack of awareness regarding its quality[14]. Considering availability and suitability Jatropha and Pongamia seed oil, they are selected for further study. This article reviewed the available literature on production of jatropha and pongamia oil biodiesel and its utilization in diesel engine without modification.

Jatropha Curcus Linn

Jatropha curcus is usually called as ratanjot that belongs to Euphorbiaceae. It is a non-edible shrub plant that grows in irrigated or non-irrigated soils. It is draught resistant plant that grows/ yield up to 40 years after plantation with minimum inputs of water and fertilizers. The plant yield 2-6 kg of fruits after 2-3 of plantation. A fruit contains 2- 3 seed that having approximately 25-30 % of oil which is golden yellow in color. The content of oil was determined by gas chromatography mass spectrometer (GC-MS) that was resulted the presence of higher amount oleic acid (37.27 %) in the oil. The linolenic acid (35.00 %), plamitic acid (14.240 %), stearic acids (6.585 %) were found next to oleic acid. That is jatropha oil contains combination of saturated and unsaturated fatty acids compounds. The FFA of oil was 17.88 mg KOH/gm which is above the limit. So that the oil is need to process by acid esterification reaction[2,8].

Pongamia Pinnata Linn

Pongamia pinnata is usually called as karanja that belongs to Leguminceae family. It is too a non-edible plant that grows in irrigated or non-irrigated soils. It is draught resistant plant that grows/ yield up to 90 years after plantation with minimum inputs of water and fertilizers. The plant yield 900-9000 kg/hectare after 4-5 years of plantation. A fruit contains one or two seed that having approximately 30 – 32 % of oil which is slightly brownish yellow in color. The GC-MS was resulted the presence of higher amount of oleic acid (49.47 %) in the oil. The linolenic acid (17.75 %), plamitic acid (12.37 %), stearic acids (5.90 %) were found next to oleic acid. Like jatropha oil, pongamia oil too contains combination of saturated and unsaturated fatty acids compounds. The FFA of oil was 27.87 mg KOH/gm which is above the limit. So that it is too need to process by acid esterification reaction to lower FFA up to limit[15-17] and along with the utility of this feedstock oil, we have successfully completed use of pongamia leaves for growth of larva, Morus alba (L)[18].

Esterification and Transesterification Reactions

Both the oils contains higher FFA. A two stage process was used for conversion. The first stage (acid catalysed) of the process is to reduce the FFA content of feedstock oil by esterification with methanol (99% pure) and acid catalyst sulphuric acid (98% pure) in one hour time at 60 ± 65 ^{o}C in a closed reactor vessel. The 0.5 wt % of sulphuric acid and 8:1 molar ratio of alcohol were found sufficient to lower FFA for both the selected feedstocks oil. Methyl alcohol is added in excess amount to speed up the reaction. This reaction was processed with stirring at 650 rpm. The major obstacle to acid catalysed esterification for FFA is the water formation. Water can prevent the conversion reaction of FFA to esters from going to completion19. After dewatering the esterified oil was fed to the transesterification process[19]. The esterified oils that having lower FFA contents are now ready for transesterification reaction. In this reaction, solid catalysts like homogeneous or heterogeneous were used. Transesterification of Pongamia oil was carried out by using ZnO, Hβ- Zeolite and Montmorillonite K-10 as catalyst (11.5wt. % of oil) to yield biodiesel at 120 ^{o}C with 1:10 molar ratio of oil to methanol. They required longer reaction time (24 h) and the conversion was 83 % for ZnO, while Hβ- Zeolite and montmorillonite K-10 catalyzed transesterification gave low conversion of 59 and 47 % respectively[20]. Lu et al. had resulted 97 % of conversion and 98 % of yield of jatropha FAME using 6:1 moral ratio (alcohol to oil), 1.3 wt % of KOH, at 64 ^{0}C, in 20 min with agitation of 1500 rpm[21]. However Karmee et al has been resulted 92 % yield of pongamia oil ester with 10 :1 molar ratio (methanol to oil), 1 wt % KOH at 105 ^{0}C, in 1.5 hrs of time[22]. Chavan et al. has used 0.5 % of KOH, as a solid homogeneous catalyst along with 6:1 methyl alcohol, as a solvent that yielded 90% of jatropha FAME in 60 min. Further she has been studied ecofriendly calcined egg shell catalyst as a heterogeneous catalyst in transesterification of Jatropha oil. The catalyst was prepared by calcination of waste egg shells at 900 ^{o}c for 2 hrs which then characterised by Differential thermal analysis (DTA), X-ray diffractometer (XRD), Scanning electron microscopy (SEM) and Fourier transform infrared (FTIR) spectroscopic methods. The 8:1 molar ratio (methanol to oil) was found sufficient to convert triglycerides of jatropha oil to its ester while 2.0 wt % calcined CaO catalyst was required for optimum yield. This quantity of catalyst is almost double than the chemical catalysts like KOH or NaOH. The next important factor is reaction time. 2.5 hrs was found sufficient to give 90 % of yield at 600 – 650 rpm agitation[23]. Further the equivalent reaction parameters were studied by Madhu et al. using Pongamia oil as feedstock oil and ecofriendly calcined crab shell as a heterogeneous catalyst. He found that 2.5 wt % of CaO, 8;1 molar ratio, 120 min reaction time, 65^{o}C reaction temperature, at 700 rpm agitation intensity that given 94 % of yield of pongamia FAME[24].

Table-1
Properties of biodiesel synthesized from Jatropha and pongamia FAME in comparison with diesel fuel

Property	ASTM 6751 limits	Diesel Fuel (DF)	JME[23]	PME[24]
Acid Value in mg KOH/gm	≥0.5	-	0.5	0.32
Density at 15^{0}C in gm/cc	0.86 – 0.90	0.830	0.872	0.881
Kinematic viscosity at 40^{0}C in Cst	1.9 – 6.0	2.7	4.9	4.02
Moisture in %	≥0.05	Nill	0.02	0.005
Flash Point in ^{0}C	130 (min)	67	167	184
Fire Point in ^{0}C	-	74	176	-
Cloud Point in ^{0}C	To report	-6	4	-
Pour Point in ^{0}C	To report	-9	-1	-2
Calorific Value MJ/ Kg		42.5	37.5	36.61

The synthesized FAME were characterized according to ASTM D6751 specifications and compared with current diesel fuel (Table-1). It was observed that after transesterification reaction, most of the thermal parameters drastically get reduced. The acid value was reduced from 17.88 to 0.5 mg KOH/gm for jatropha oil and it was of reduced from 27.87 to 0.32 mg KOH/gm with pongamia oil. Like that kinematic viscosity was reduced up to 4.9 and 4.02 mm^2/s. The flash and fire points were get reduced up to 167, 184 ^{o}c and 176, 189 ^{o}c. The higher flash and fire points of both the FAME indicates its safety in transports and in storage. The cloud point of jatropha oil was report as 4 ^{0}C that indicates methyl stearate in the jatropha biodiesel. The cloud point of biodiesel were much better and were too in limits that were, -1 and -2 ^{0}C. The liberated heat is measure of calorific value of fuel that were found as 37.5 and 36.61 MJ/Kg which is about 80% to running diesel fuel. Considering the above mentioned thermal parameters of synthesized biodiesels, except flash point and fire point, it was noted that both the FAME's satisfied limits those have been mentioned by ASTM standards.

Performance of Jatropha and Pongamia FAME in diesel engine

Kumar et al. has been studied jatropha biodiesel blends in single cylinder engine at 17.5:1 CR. The experiments resulted that, among all blends brake thermal efficiency (BTE) and mechanical efficiency (ME) of blends B40% observed highest by 9.8 % at 75 % load than DF but the reverse results were found in brake specific fuel consumption (BSFC), as all blends, B10%, B20%, B30% and B40% consumed more fuel than DF at equivalent loads. The exhaust temperatures and nitrous oxides emissions of all blends were observed to be highest and CO emissions were decreased up to 25 % than that of DF[25.] Pramanik et al.[26] studied the performance of jatropha oil in single cylinder diesel engine. The blend JB30% showed viscosity closer to diesel fuel. He observed that the temperatures of exhaust gas were diminished due to reduction in viscosity of oil. As nitrogen gas is temperature dependent. The reduction in exhaust gas temperature reduced NOx of JB20 % blend and it displayed nearby results as that of diesel fuel. Finally he concluded that 50% of JME can be used in with diesel engine without major modification. Chauhan et al.[27] reported performance and emissions study of jatropha oil in IC engine. For experimentation, he used neat jatropha oil and compared its performance and emissions to running diesel fuel. He observed that among all the emissions, jatropha oil emits lower NOx gas throughout all trials while other emissions like CO, CO_2 and HC were found lowest for diesel fuel.

Agarwal and Agarwal et al.[28] studied physico chemical characteristics of jatropha oil biodiesel and its blends (with diesel fuel) in various proportions. He observed that viscosity of JB30 % blend found closer to diesel fuel. The equivalent findings were reported by Pramanik[25]. They found that the higher exhaust gas temperatures when jatropha oil blends and diesel fuel were run in engine while emissions like CO, HC and CO2 were found increased with increase in concentration of jatropha oil in diesel fuel. Finally they concluded that emissions and performance characteristics were found near to running diesel fuel with lower concentrations of jatropha oil. Mandepe et al.[29] used common rail diesel engine to study the performance and emission characteristics of Jatropha methyl ester. He observed that the emissions HC and NOx were closer to running diesel fuel but emissions of CO tend to escalate. Along with that PM emissions were found less than that of DF. Jindal et al.[30] used Jatropha biodiesel to study effect of CR and injection pressure on performance and emission properties diesel engine. He noticed that increase in CR, injection pressure was increased which simultaneously supported to improve performance while the exhaust temperature and HC emissions get increased with increase in CR ratio. The other emissions like smoke and CO were get reduced with increase in CR ratio. Along with that NOx emissions did not showed any adverse effect at high injection pressure. He finally concluded that Jatropha biodiesel can be used at higher CR ratio as well as at higher injection pressure. Chavan et al.[23] studied impact of jatropha biodiesel blends like JB10 %, JB20 %, JB30 % and JB100 % on single cylinder VCR engine. The emission parameters like CO, HC and NOx were studied with various CR ratios and found that JB30 % blend gave emission declines in CO up to 43% while in HC and NO_X it gives reduction up to 50 % and 20 % respectively. Gopal et al. had synthesized FAME that produced from pongamia oil by transesterification reaction which further blended with DF as, PME20, PME40, PME 60, PME 80 and PME100. A diesel engine having four strokes, 87.5 bore diameter and water cooled body was used to characterize these blended fuels. He reported that the BSFC of all blended fuels was found 11.1 to 53 % more than that of DF at various loads. The specific energy consumption (SFC) was found to decrease with loads. Almost all the blends were resulted equivalent SFC with DF. The BTE was lowered by 15.5 %, as it is inversely proportional to BSFC. The unbrunt hydrocarbon (UHC) and CO emissions were lowered by 45 % and 19 % but the NOx emissions were found increases up to 26 % at all loads[31].

Lingfa and Das[32] had studied KB2, KB5, KB10 blends of karanja methyl ester blends on engine set up. The resulted BTE of all blended fuels has given very comparable results with DF and it get increased with loads for all blends. BSFC get reduced with loads as well as with increase in concentration of biodiesel. The performance of all karanja blends were observed very comparable to DF. The performance of biodiesel were affected by thermal parameters like calorific value, density, flash point and air fuel ratio. Comparatively lower calorific value, higher density and flash point and presence of more oxygen atom in biodiesel that helps in complete combustion of fuel. The CO and HC emissions were get lowered up to 26 % but NOx emissions were observed higher than that of DF which is due to higher cetane number of biodiesel that shortens ignition delay period. The extra oxygen atom resulted to raise combustion temperatures which simultaneously increases CO_2 and NOx gases Performance, emissions, and heat losses of palm and jatropha biodiesel blends in a diesel engine[33]. Baste et al.[34] and Gujar et al.[35] reported that the performance of engine get improved with high compression ratios and injection timings at higher blends of pongamia biodiesel. Further they concluded that biodiesel can be safely blended with diesel fuel up to 20 % that allows to run on current diesel engines with no modification in it. The applications of biodiesel (and its respective blends) synthesized from non edible numerous oils diminishes exhaust gas emissions as compared with DF. This statement was supported by other researchers[25-44].

Economics of FAME

India imports more than 40% of its edible oil requirement and hence non-edible oils are used for the development of biodiesel. India is a agrarian nation and has rich plant biodiversity which can support the development of biodiesel. India also has a vast geographical area with agricultural lands as well as wastelands on which oil bearing plants can be planted. Common non-edible oil bearing plants and trees include neem, karanja, mahua, jatropha, etc. The oil yields from these species at present are insufficient to meet the demand for raw material on large scale production of biodiesel. Hence, there has been government initiatives and interest from few private firms to enhance the production and distribution facilities of biodiesel throughout the country. The Petroleum Ministry has set a target for biodiesel to meet 20% of India’s diesel demand.

Government’s initiative has resulted in large scale plantation of J. curcas in the state Andhra Pradesh. Oil and Natural Gas Corporation (ONGC) has planned to build an export oriented refinery at Kakinada in Andhra Pradesh which will have a annual production capacity of 5.5–7.5 million tonnes[42].Various factors contributing to the cost of biodiesel include raw material, other reactants, nature of purification, its storage, etc. However, the major factor which contributes the cost of biodiesel production is the feedstock, which is about 80 % of the total operating cost[43]. The profits from glycerol and capital cost for operation was not included[44]. In a study of review on biodiesel production cost found the feedstock to contribute a substantial portion in production cost[45]. A process model was prepared by the authors to estimate biodiesel production costs. Taking all the factors into account viz. raw material (vegetable oil, methanol, and catalysts), utilities (electricity, etc.), labour, supplies, general works and depreciation, the cost of biodiesel was estimated to be US $0.561. The cost of biodiesel after blending with petrodiesel will reduce as the cost of biodiesel becomes less significant in blended form. At present, biodiesel can be blended with 80% petrodiesel (B20) without any engine modification[25-44].

Conclusion

Currently edible oils are used as a source for synthesis of biodiesel by developed nations such as USA and European nations but developing nations are not self-sufficient in the production of edible oils and hence have emphasized in the application of a number of non-edible oils. In a country like India, is rich in plant biodiversity, there are many plant species whose seeds remain unutilized and underutilized have been tried for biodiesel production. These species have shown promises and fulfils various biodiesel standards. However, there still is paucity in terms of all the standards which should be fulfilled for the large commercial applications and its acceptance from public and governing bodies. However, the presently focused on non-edible oil seeds, Jatropha curcus and Pongamia pinnata. The important reason is its availability in many parts of our country, hardy nature, susceptibility of plant with minimum inputs, higher amount of oil content in seeds etc. The review clears that performance parameters like BTE, BP, BSFC and ME etc of both the fuels are in comparable with DF. As biodiesel contains more oxygen than DF but has higher density, flash point and lower calorific values that slightly lowers these parameters for pure biodiesel. But blended biodiesel covers these impacts. The emission parameters like HC and CO gases reduced from 20-26 %, CO_2 gases increased in some extents, NOx emissions were increased up to 12 %. Except NOx emissions, other gases such as CO, HC, CO_2 were observed lowered that that of DF. At present, biodiesel can be blended with 80% petro diesel (B20) without any engine modification.

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