REVIEW

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A review on separation and purification techniques for biodiesel production with special emphasis on Jatropha oil as a feedstock

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Abstract

Biodiesel is a promising alternative to conventional fuels. Research on biodiesel has vast experimental findings, but the outcomes are not always unidirectional. The sequence of unit operation for various transesterification processes is studied. The review work emphasizes on the separation and purification of Jatropha-derived biodiesel. The study on the downstream processes of alcohol recovery, glycerol-rich and biodiesel-rich phase separation, and biodiesel purification techniques is the main part of this paper. The biodiesel purification includes wet and dry washing and membrane techniques. The purpose of the review is to find separation techniques that are less energy-intensive and environmentally friendly purification processes for biodiesel production from Jatropha. The strategies to reduce the cost of biodiesel production from Jatropha are discussed. The Jatropha biodiesel possesses huge potential as one of the alternative energy sources for commercial exploitation in India.

KEYWORDS

separation and purification, biodiesel, Jatropha

1 | INTRODUCTION

The continuous increase in global energy requirement demands a need to pursue all economic sources to keep up with this considerable growth. The world fuel oil demand is expected to reach up to 109.4 million barrels per day by 2040 according to the Organization of the Petroleum Exporting Countries). The renewable transition has been a peak of discussion these days with the aim of achieving a 100% renewable energy system globally.[1] The consumption of renewable energy sources is reported to be the fastest growing.[2] The expected increase in renewable energy is 3% by 2030 with 60% of the energy accounted for Asia, South America, the Middle East, and Africa. The import oil demand of Asia Pacific is expected to increase to 80% in 2040, which expecting the net energy requirement from liquid hydrocarbon to be 10–

20%. The power generation capacity of the Asia Pacific Economic Cooperation) countries has increased by 75% from 1990 to 2013.[3]

The primary energy consumption in India has increased from 117 to 715 million tonnes of oil equivalent between 1960 and 2010. According to the International Energy Outlook 2018 projection, the share of global energy demand will increase to 11% in 2040 for India. The import in coal and crude oil in India has increased approximately twice during 2012–2013.[4] The transportation sector with a share of 27% is one of the important contributors emitting greenhouse gases to the atmosphere.[5] The energy requirement in the field of the transportation sector is expected to grow by 2% every year.[6] The automotive industry is growing fast, and the growth rate of the Indian automotive industry is reported to be one of the largest in the world.[7] The increasing

requirement and depleting conventional energy source demands for an improved large-scale low-carbon technology that addresses the issue of a global energy crisis. Worldwide efforts are being made to find an alternative fuel to meet the present and future demands of energy, without causing further global warming effects.

Biodiesel is a promising alternative fuel that is not commercialized to the extent of its potential. It is a mixture of mono-alkyl esters of long-chain fatty acids derived from various feedstocks like edible and non-edible vegetable oil crops, animal fats and waste oil. The production techniques for biodiesel are primarily categorized into four types which are direct use of vegetable oil after pretreatment, micro-emulsions, pyrolysis and transesterification.[8] Transesterification is an attractive and widely accepted method of all.[9] The technical difficulties in refining the transesterification reaction products and the extra cost incurred in the downstream separation and purification hinder the large commercial production of biodiesel. The biodiesel production is estimated to be approximately $11X10^{10}$ litres by 2020.[10] It is reported that the downstream separation and purification accounts for 60–80% of the total processing cost of biodiesel production.[11] It is important that the purity level of biodiesel matches the standards ASTM D6751 and EN 14214.

Biodiesel was expected to replace 41.14% diesel in India by 2012, which could not be the case. Also, the production target of 16.72 million tons with 20% blending of biodiesel with other fuels by 2017 could not be achieved. The Indian government has the vision to cultivate 10 million ha of wasteland with an objective to replace 20% of diesel consumption by 2020.[12] The United States and Brazil are leaders producing 5.5 and 3.8 billion litres of biodiesel, respectively, in 2016.[13] India has not significantly progressed in the biodiesel industry whereas the expected rise in biodiesel production has gone to $39Mm^3$ from $29.7Mm^3$ from 2014 to 2017.[14]

The slow progress of India for biodiesel production is addressed in literature with a majority of them suggesting the unavailability of Jatropha seeds, less oil yield, less utilization of wasteland for cultivation, and higher gestation period of crops with long payback period.[15-17] The feedstock for biodiesel shows a large compositional variation and can be broadly categorized into three types, namely, oil from vegetables, waste frying oils, and animal fats. The selection of feedstock for biodiesel production is country-specific depending on climate and availability. The production of edible oil in India is not sufficient enough to meet the human requirement, and 46% edible oil has to be imported.[18] In such cases of scarcity, the oil from non-edible sources like Jatropha and Karanja holds promising potential for biodiesel production. The advantages of using Jatropha oil for biodiesel production is the biodegradability, lower sulfur content, and no modification of the engine. Jatropha and Karanja are the most promising oil sources for biodiesel production in the context of India according to the biodiesel policy of the Indian government.[19] Other than socioeconomic issues, the technical disadvantages of Jatropha biodiesel include higher free fatty acid (FFA), higher viscosity, and a higher percentage of carbon residue, which results in complex separation and purification steps.

This paper attempts to review the conventional and recent separation and purification techniques emphasizing on an assessment of economically better techniques for biodiesel production from Jatropha. The conventional technologies used for biodiesel separation and purification have proven to be inefficient, time and energy consumptive, and less cost-effective.

The improper separation and purification of biodiesel results in a higher content of impurities affecting engine performance. Though a certain amount of impurities is permissible under finished commercial biodiesel, it should comply with the international standards and specifications. It is reported that the majority of the impurities of biodiesel are the same regardless of the type of feedstock, alcohol, and catalyst, as well as operational conditions applied to the biodiesel process production.[20] The effects of impurities on biodiesel are summarized in Table 1, which demands separation and purification techniques suitable for crude biodiesel complying the standards.

This work is emphasized on the comparative assessment of various production processes with respect to

TABLE 1 Effects of impurities present in finished biodiesel and its drawbacks

Impurities	Drawbacks
Glycerol	Decantation, fuel tank bottom deposits, injector fouling, storage problem, settling problems, and severity of engine durability problems
Water	Reduces the heat of combustion, corrosion of system, failure of fuel pump, formation of ice crystals, bacteriological growth, and pitting in the piston
Methanol	Lower the flash points, lower viscosity, and causes corrosion
Soap/catalyst	Pose corrosion problem, damage injectors, plugging of filters, and weakening of engine
Free fatty acids	Less oxidation stability and corrosion of vital engine components
Glycerides	Turbidity, higher viscosity, and deposition at piston, valves, and nozzles

Note. Adopted from.[21-23]

separation and purification. The study includes the downstream processing of biodiesel production, which includes alcohol recovery, biodiesel–glycerol separation, and purification.

The objective of this review paper is to present the separation and purification methods that have been used to date in biodiesel production via transesterification processes especially for Jatropha as a feedstock. Furthermore, the merits and demerits of conventional (wet and dry) and novel (ion-exchange, extraction, and membrane) purification processes are summarized. Finally, the strategies for reducing the cost of biodiesel production from Jatropha in underdeveloping nations like India are discussed. The reliability of the proposed technique is not under the scope of the present paper. However, the inclusion of such techniques defines the scope of future work.

2 | BIODIESEL VIA TRANSESTERIFICATION

Transesterification is a reaction of triglycerides with or without a catalyst that removes glycerol and replaces short-chain alcohol. The properties like cetane number and heating value are well maintained, whereas viscosity, long carbon chain, and density are reduced during the process of transesterification. A lot of research is being carried in the field of operating parameters for transesterification reaction, which includes the reaction temperature, the type and amount of catalyst, the ratio of alcohol to oil, the mixing intensity, the reaction time, etc. The choice of catalyst in the transesterification reaction influences the complexity of the downstream separation and purification operations resulting in a direct impact on the techno-economic aspect of biodiesel production. It is important to study the recent biodiesel production techniques via transesterification and its influence on downstream unit operations before reviewing the separation and purification of crude biodiesel.

The homogeneous base and acid catalysts are mostly used in the transesterification reaction for worldwide commercial production of biodiesel.[24] A review of reaction conditions and separation and purification steps for biodiesel production using a single-step base-homogeneous catalyst suggests mild reaction condition and complex downstream separation and purification stages.[25-33] One of the prime reasons for the complexity in the separation and purification process is due to the fact that non-edible oil has high FFA, which forms soap, reducing the yield of the main product, biodiesel. The acid homogeneous catalysts are not likely to be influenced by FFA content, but they are rarely used in the single-step process due to the slowness of alcoholysis reaction resulting in a long time to achieve the desired yield. It was reported that the rate of base-catalyzed transesterification is 4,000 times faster than that of the acid-catalyzed one.[34]

Heterogeneous catalysts are an attractive solution for the problems of homogeneous catalysts. They are added in the solid phase as the reaction mixture, which makes the separation of biodiesel easy, and catalyst may also be reused. Compared with classical homogeneous catalysts, heterogeneous solid catalysts have gained more interests among biodiesel producers due to its easier separation and less wastes. Neutralization and washing steps are avoided by the use of a heterogeneous catalyzed process but in turn, there is an addition of catalyst preparation, solid catalyst filtration, catalyst regeneration for reusability considering the activity. The major disadvantage of a heterogeneous catalyst process is the lower yield and longer reaction time due to limiting mass transfer involving oil, alcohol, and solid catalyst.[35-42] Attempts have been made to improve the yield biodiesel from Jatropha oil by using magnesium- and aluminium-based layered double hydroxide catalyst resulting in 75.2%[35] and 91.2%[36] yield with a reaction time of 6 hr in both the cases. The preparation of catalyst and separation, recovery, and regeneration of solid catalyst includes energy intensive unit operations, which make the heterogeneous processes economically challenging in comparison with other methods.

Enzymes (lipases) are the separate class of heterogeneous catalyst type, which has gained a lot of attention recently due to the fact that the process has simple separation and purification steps. Lipases are the enzymes present in microorganisms, plants, and animals. They can be classified depending on the nature of being intracellular or extracellular, which further can be in free or immobilized form. The later form is developed to improve catalyst stability, easy recovery, and reusability.[43] The immobilized lipases, in particular, have found scope in scaling up of continuous biodiesel production. The presence of excess methanol and glycerol after transesterification reaction influences on lipases, making it inactive. The high cost of catalyst production and longer reaction time hinders the biocatalytic transesterification process for being a primary choice for biodiesel industry.[44] The high FFA and water content does not affect the efficiency of biodiesel production in the case of the biocatalyst. There have been attempts to produce biodiesel from Jatropha using biocatalysts at lab scale.[44-46]

Supercritical transesterification deals with severe reaction condition, but the downstream separation and

purification steps are simple, and a large number of pieces of equipment required are less compared with other production techniques. Recently, a supercritical process for biodiesel production using Jatropha is reported to yield 99.5 % biodiesel for oil to methanol molar ratio 1:42 at 35 MPa pressure and 325°C temperature.[47] Attempts have been made to produce biodiesel from Jatropha oil using a supercritical process.[48,49] It is reported that the cosolvents play an active role in increasing the mutual solubility of methanol and oil at low reaction temperatures at supercritical conditions. The supercritical methanol with 0.3 wt. % potassium hydroxide as cosolvent yielded >90% biodiesel from camelina sativa oil at 180°C with a reaction time of 20 min and oil to methanol molar ratio of 30.[50] A similar result of an 85% yield is reported for supercritical biodiesel production process from cameline oil at 295°C, oil to ethanol molar ratio of 1:45, and hexane as cosolvent at the reaction time of 20 min.[51]

The direct use of a homogeneous alkali catalyst for transesterification of high-FFA oils is not recommended, which is usually found high in non-edible oil. It is reported that the two-step transesterification process is best suitable for non-edible oils for the production of biodiesel.[37]

In the two-step process, acid-catalyzed esterification reduces FFA followed by alkali-catalyzed transesterification. It is reported that acid catalyst treatment at 50°C esterifies complete FFAs in some oils.[33] However, the two-step process increases the production cost and causes corrosion problems and consequent poses environmental hazards.[52] The two-step process eliminates the issue of saponification due to high FFAs, but the complexity of downstream separation and purification steps increases as compared with single-step biodiesel production processes. The commercial production of Jatropha biodiesel with the presently available separation and purification techniques is done using a two-step acid-base process. The process almost doubles the number of equipment and consecutively increases the amount of energy. Though the energy requirement is very less in the transesterification reaction for the two-step process is 87808.37 J/mol.[53]

3 | CONVENTIONAL SEPARATION AND PURIFICATION TECHNIQUES

One of the major reasons leading to uneconomic biodiesel production is the cost incurred in downstream separation and purification operations. A review of the separation and purification operation sequence for commercial biodiesel production from simulative studies is presented in Table 2. It is made evident from the study in the previous section and the present section that the separation operation on recovery of unreacted excess alcohol (except biocatalyst process), glycerol-rich phase separation, and removal of impurities and purification of crude biodiesel cannot be circumvented irrespective to the type of process selected for biodiesel production. The crucial parameters have been compared for the five biodiesel production processes in Table 3.

The quantity of alcohol in transesterification is reported to be an important parameter followed by reaction time and concentration of catalyst.[61] Transesterification is a reversible reaction and requires three moles of alcohol to react with one mole of oil theoretically. The problems of reversibility are encountered in stepwise reactions to produce biodiesel, and, to overcome the problem, higher alcohol molar ratios are used which shifts the equilibrium to the product side. The separation is more difficult in the case of ethanol rather than methanol as emulsion formed is very strong.[62] The maximum permissible limit of alcohol in the final product as per standard is 0.2%. The negative effect of excess alcohol presence in biodiesel includes the deterioration of natural rubber seals and gaskets while biodiesel is used in an engine. It would lower down the flashpoints of final produce, increasing the problems in storage, transport, and utilization. It would also lower the viscosity and density values of biodiesel and cause corrosion for aluminium and zinc pieces.[63] It was tested that the flashpoint of biodiesel can reduce from 170°C to less than 40°C with as little as 1% residual methanol left in the biodiesel produced.[64] Alcohol concentration is a very crucial parameter that has a major effect on the reaction yield. It is necessary to recover methanol efficiently as it influences the unit production price of biodiesel.

The common approach for methanol recovery is to separate it from two already-separated layer, namely, biodiesel-rich and glycerol-rich phases. The conventional operation used for the recovery is distillation, which is an energy intensive process, and the use of multiple columns for the same purpose might increase operating as well as capital cost. Methanol recovery prior to separation of glycerol-rich and biodiesel-rich phases have also been reported.[55] The optimum sequencing and designing of the alcohol recovery column might reduce the energy requirement and consequently reduce the production cost.

The transesterification reaction results in two-phase dispersion of the glycerol-rich phase which generally makes up for 10–20% of the total product by volume and continuous biodiesel-rich phase.[65] Abundant glycerol has been produced as a result of an increase in the production of biodiesel every year. The byproduct glycerol

TABLE 2 A review on separation and purification operation sequence for biodiesel production

Type of process and reaction condition	Unit operation sequence					Reference
	Step 1	Step 2	Step 3	Step 4	Step 5	
Two-step process (O:A 1:6*, 1:6, 5% w/w H₂SO₄*, 1% w/w NaOH*, 60°C*, 60°C)	Glycerol washing column* (3 stages): catalyst removal. Water-glycerol-catalyst are further separated*	Distillation column: recovery of excess alcohol (4 stages, 1.5 RR, 94% recovery)	Water washing column: biodiesel-glycerol-rich phase separation	Vacuum distillation column (6 stages and 1.5 RR): crude biodiesel separation from impurities	Unreacted oil and biodiesel can be further separated which is not considered in study	4
Single stage acid catalyzed process (O:A 1:50, 1.3% w/w H₂SO₄, 80°C)	Methanol recovery column (4 stages, 2 RR, 94% recovery)	Neutralization of H₂SO₄ catalyst with CaO	LLE: water washing column	Distillation column: biodiesel purification (6 stage, 1.5 RR)	Glycerol purification column	54
Supercritical process (O:A 1:24, 280°C, A:C 1:0.05)	Flash evaporation (pressure reduced to 506.6 kPa), methanol and propane recycled back	Separation column of crude biodiesel from methanol and glycerol	Flash evaporator to remove excess methanol and propane from biodiesel	By product glycerol is purified using flash evaporator recycling methanol and propane		54
Single step alkali catalyzed process (O:A 1:12, 1% w/w NaOH, 70°C)	Ethanol recovery column (3 stages, RR >2, recovery)	LLE: water washing column with 10 plates	Glycerol separation column, 3 stages and 0.5 RR			55
Two-step process O:A 1:6*,1:6, 1% w/w H₂SO₄*/1% w/w NaOH, 60°C*/60°C	Glycerol washing column*: catalyst removal	Water washing: (25°C and 4.05 bar): biodiesel – glycerol separation	Vacuum distillation column (130°C and 0.2 bar): biodiesel separation	Methanol, glycerol and water effluents can be collected and pumped into trains of distillation column		56
Single-step alkali catalyzed process (O:A 1:6, 1% w/w NaOH, 60°C)	Centrifugation: unreacted oil and biodiesel are separated from glycerol	Mixing and pH adjustment tank: water washing with HCl to neutralize catalyst	Glycerol recovery column: operates above atmospheric pressure	Methanol recovery column: 50kPa	Biodiesel purification column: Flash drum (5 kPa)	57
Homogenous acid catalyzed process (O:A 1:50, 1:1.3 oil: H₂SO₄, 4 hr, 80°C)	Distillation column (5 stages, 2 RR, 94% recovery): alcohol recovery	Neutralization of H₂SO₄ catalyst with CaO	LLE: water washing column	Biodiesel purification column (4 stages, 2 RR)	Glycerol separation column (4 stages, 2 RR)	58
Two steps pretreated alkali-catalyzed (O:A 1:6*/1:6, 70*/60°C, catalyst: H₂SO₄*/ NaOH, 1*/4 hr)	Pretreatment: glycerol washing column.	Methanol recovery column (5 stages, 2 RR)	LLE: water washing column	Catalyst neutralization: H₃PO₄	Biodiesel purification column (5 stages, 2 RR)	59

(Continues)

TABLE 2 (Continued)

Type of process and reaction condition	Unit operation sequence					Reference
	Step 1	Step 2	Step 3	Step 4	Step 5	
Homogenous acid catalyzed process (O:A 1:50, 80°C, catalyst: H_2SO_4, 4 hr)	Methanol recovery column (6 stages, 2 RR)	Neutralization of H_2SO_4 catalyst with CaO	LLE: water washing column	Biodiesel purification column (10 stages, 2 RR)	Glycerol purification column	59
Heterogeneous acid-catalyzed (O:A 1:4.5, 60°C, catalyst: SnO)	Solid catalyst separation using hydrocyclone	Alcohol recovery column (14 stages, 3.99 RR)	Glycerol-rich phase separation: gravity settling (1 hr residence time with vessel size aspect ratio 2)	Biodiesel purification column (8 stages, 2 RR)		59
Supercritical process (O:A 1:42, 350°C, 20x10³kPa)	Alcohol recovery column (12 stages, 3.42 RR, 94% recovery)	Glycerol-rich phase separation: Gravity settling (1hr residence time with vessel size aspect ratio 2)	Biodiesel purification column (8 stages, 2 RR)			59
Biocatalyst process (O:A 1:3, immobilized lipase 4 wt%, 25°C, 16 hr)	Counter currant water washing to separate biodiesel-rich and glycerol-rich phases	Biodiesel purification distillation column to separate methanol and unreacted oil	Glycerol purification distillation column to separate glycerol from wastewater			60

Note. O:A is the molar ratio of oil to alcohol.

TABLE 3 Comparison between various biodiesel productions processes[25-53]

Parameter↓/type of process→	Homogenous base catalyst	Heterogeneous chemical catalyst	Biocatalyst	Supercritical	Two-step acid-base process
Time of reaction	1–3 hr	6–8 hr	48–60 hr	1.5–5 hr	1–3[*]/1–3 hr
Biodiesel purification	Difficult	Moderate	None	Easy	Difficult
Reaction temperature (°C)	60–70	180–220	25–40	239–385	
O:A molar ratio	1:6 to 1:12	1:11 to 1:50	1:3 to 1:6	1:24 to 1:45	1:6to1:12[*]/1:6to1:9
Alcohol recovery	Moderate	High	Not needed	High	Moderate
Number of equipments	Moderate	Moderate	Less	Less	High
Influence of FFA	Sensitive	Not sensitive	No influence	No influence	Sensitive
Soap formation	Yes	Yes[*]	No	No	Yes
Catalyst cost	Low	Moderate	High	N/A	Moderate
Catalyst reuse	No	Yes	Yes	N/A	No
Influence of catalyst	Yes	No	No	No	Yes
Influence of water content	High	Low	Moderate	Low	High

Note. O:A is the molar ration of oil to alcohol.

cannot be used directly as an ingredient or processing aid in healthcare products, fuel additives, lubricants, personal care products, cosmetics, and food as it is not pure enough.[66] Amongst the downstream processes for biodiesel production, separation of free glycerol from crude biodiesel is one of the most important as it is related to the effectiveness of the purification procedure, and its maximum limit is 0.02% mass in finished product.[67] The density difference of both the phase is greater enough to undergo gravity settling. The glycerol-rich phase being denser than biodiesel sediments out of the biodiesel-rich phase under gravity once the mixing is stopped.[65] The gravity settling process for the separation of non-polar biodiesel and polar glycerol is a slow process. It takes longer operating times and bigger equipment and consequently utilizes a larger amount of steel, and then the washing step consumes a large amount of water. The acceleration of glycerol/biodiesel decantation could play an important role in the overall biodiesel refinery process.[68] The conventional operation for separation of biodiesel-rich and glycerol-rich phase includes gravity settling and centrifugation. Many commercial biodiesel productions employ centrifugation for speedy separation of biodiesel-rich and glycerol-rich phases.[62,69]

The conventional separation techniques have proven to be inefficient, and it demands the further purification of the final product to match the standards. Biodiesel purification is an important step for satisfying the standard specifications, which make biodiesel eligible to be used as a fuel. The conventional purification step of crude biodiesel is mainly divided into two categories, that is, wet washing and dry washing.

Biodiesel water washing is a simple technique in which an optimized amount of water-based on crude biodiesel is added and agitated gently to avoid emulsion formation. The washing is repeated until complete impurities are removed, and it is indicated once colourless wash water is observed. Water washing is a conventional liquid–liquid extraction operation that uses water as a solvent. Water shows good solubility with residual glycerol and methanol, and, hence, such impurities can be well wet washed and eliminated from crude biodiesel. Biodiesel-glycerol separation is usually a gravity-settling process, and the settling duration is 18–24 hr. It is reported that better results of water washing are obtained after a prolonged settling duration of 36–48 hr.[19] Many studies have revealed better results while using acidified water for wet washing.[65,70] The application of distilled water at an elevated temperature coupled with gentle water washing eliminates precipitation of saturated biodiesel and prevents the formation of emulsions. Water washing processes are not recommended for purification of crude biodiesel from calcium-based heterogeneous processes as it might form very stable calcium soaps dissolved into crude biodiesel. But residual methanol and a trace amount of free glycerol, which is highly soluble in water, can be eliminated from crude biodiesel by water washing.[71] Wet washing conventionally is being done using hot distilled water and various solvents, and acidified water through water washing is a most widely used purification technique. Dry washing overcomes the disadvantage of wet washing using a large amount of water. A method of dry washing is developed that purifies crude biodiesel using silicates, ion exchange resins,

activated clay, activated carbon, activated fibre, etc. as adsorbents. The dry washing process requires a mixing unit and the spent adsorbent, which must be generally discarded if not regenerated.

4 | RECENT SEPARATION AND PURIFICATION TECHNIQUES

The production of biodiesel from Jatropha as feedstock demands for pretreatment which increases the number of equipment, amount of energy and consequently the production cost. The next section pertains to the discussion over the recent attempts made to improve the separation and purification processes.

4.1 | Alcohol recovery

High recovery of alcohol requires higher energy input for distillation. A focus on alcohol recovery section is often missed as it gets recovered easily due to the high boiling point difference between oily reactants and alcohol. It is recommended to find a promising alternative to methanol, which is a fossil-derived alcohol. In case of a high amount of excess alcohol, the operation to recover it immediately next to the transesterification reaction is recommended in order to reduce the load in the downstream units.[65] Distillation column and flash evaporation are the most frequently used unit operation to remove excess alcohol.[72] In many cases, multistage distillation is used to recover the excess methanol.[60]

The majority of the biodiesel production process has adopted distillation as a separation unit for excess methanol and almost above 90% of alcohol recovery is achieved[61-67] due to the fact that boiling point gap of alcohol and biodiesel-glycerol is large. One of the simulative studies has reported that simple flash units cannot achieve the desired recovery of methanol even though the boiling point of methanol is much smaller than the biodiesel and glycerol.[73]

Biodiesel and glycerol can thermally decompose above 250 and 150°C, respectively. It is reported in the case of homogeneous alkali-catalyzed transesterification that the recovery of methanol uses distillation column operating under vacuum preventing degradation of biodiesel and glycerol.[74] It was studied that reducing methanol recovery to 50% in an alkali-catalyzed biodiesel production increased all recorded toxicity levels by at least 20%. The molar ratio of alcohol to oil should not be higher than 1:1 to avoid denaturing of lipase-catalyst due to alcohol toxicity. The alcohol recovery is an important step as excess alcohol immobilizes the lipase-based catalyst. Alcohol recovery directly affects the economic

viability of different biodiesel production technologies.[75] Few researchers have studied the energy-saving potential using an integration approach over the alcohol recovery column.

4.1.1 | Biodiesel-glycerol separation

The choice of technology for the separation of biodiesel and glycerol is crucial. The extent of separation depends on several techno-economic factors. These factors include the quality of biodiesel, flow rate, solid contamination, and the cost incurred for the initial capital, operating, waste disposal, and maintenance of technology. The liquid–liquid separation of biodiesel and glycerol depends on the interfacial tension, viscosity, density, and temperature. Low interfacial tension, high viscosities, the low difference in densities, and high temperatures can negatively affect the ease of biodiesel–glycerol separation. An electrostatic coalescence application is reported for the separation of biodiesel–glycerol. The applied electric field polarizes an individual drop and each drop acts as a dipole with induced positive and negative charges at two polar ends. Liquid–liquid coalescencer is used for many applications. They are used to accelerate the merging of many droplets to form a lesser number of droplets with a greater diameter. An electrostatic coalescencer for promoting glycerin coalescence in a biodiesel stream was designed and patented for a heterogeneous catalyzed transesterification process. As the biodiesel–glycerol mixture enters the electric field established by the electrode surfaces, glycerol droplets coalesce. Once the droplets reach a size that overcomes gravity, the droplets fall to a glycerol phase located at a lower portion of the vessel. Though, the economic analysis of such coalescencer needs to be studied due to the consumption of voltage (2 kV/inch to 8 kV/inch) for the separation process.[76]

The effect of salt added for the enhanced settling of the glycerol phase in the continuous biodiesel phase is reported.[77] The quick separation is due to the fact that NaCl addition to the mixture increased the bulk density of crude glycerol phase and increased surface charge of glycerol droplets. The acceleration rate was reported to increase 100% by the addition of 1 gm NaCl per 100 ml of biodiesel with an 89.02% yield. It was later extended to study the effect of excess alcohol and temperature along with NaCl addition. The optimum condition was reported to 40°C temperature, 1 gm NaCl per 100 ml of biodiesel, and 20% excess alcohol yielding 90% biodiesel with 200% acceleration in decantation rate.[78] Though these conditions favour fast decantation, the purification steps are not eliminated.

4.2 | Biodiesel purification

4.2.1 | Wet washing

The wet washing with acids such as phosphoric acid, sulphuric acid and hydrochloric acid are reported to provide better separation. The washed biodiesel has to be dried using vacuum flash evaporator, hot air bubbling, anhydrous salts, or other water absorbents. It was reported that acidified water with 3% H_3PO_4 at 60°C temperature with water to biodiesel ratio 1:1.5 resulted in better catalyst and soap reduction than normal conventional washing.[77] Similarly; washing with 2% H_3PO_4 at 55°C temperature removed excess alcohol and free glycerol efficiently, but the insoluble soap formed by the ions of the catalyst was not eliminated to match the biodiesel standards nor did the value of acid number.[72]

Water washing of crude biodiesel is reported to be an essential step in order to remove 90% residual catalyst used in biodiesel production using ultrasonic assisted process.[73] Wet washing leads to the problems such as emulsions from high soap levels of high-FFA feeds and poor separation and long separation time with loss of yield. And the additional disadvantage is the cost incurred due to effluent treatment of water.[79] Organic solvent like petroleum ethers are used to purify crude biodiesel. The use of petroleum ether is reported to extract residual alcohol and tetrahydrofuran, which is used as cosolvent, and the residual catalyst then after was removed by the filtration process in heterogeneous $AlCl_3$ catalyzed transesterification process.[74] Attempts have been made to purify Jatropha biodiesel using repeated water washing for homogeneous catalyzed process[80] and precipitation using various reagents for heterogeneous catalyzed process.[81] The precipitating agents like oxalic acid and citric acid were tested for decalcification of solid CaO catalyst purifying Jatropha biodiesel resulting 92.2% and 96.2% efficiency, respectively, for the same reagent to catalyst molar ratio 1:1.[81] Whereas, water washing in the same study with water to biodiesel mass ratio 1:10 resulted in low yield of 69.5%. An attempt is made to treat and reutilize biodiesel waste water,[82] but the lowered yield cannot be compensated.

The wet water washing purification leads to large losses due to formation of emulsion. Deep eutectic solvents (DES) have shown potential for purifying crude-biodiesel eliminating the conventional method of water washing. The majority of the work pertaining to the application of DES for extraction in focused on palm-based biodiesel.[83-86] The DES application over Jatropha biodiesel is yet not examined. The fatty acid profile of palm and Jatropha oil derived biodiesel are compared to understand if DES-employed purification technique can be employed over Jatropha biodiesel. The saturate fatty acid content of Jatropha biodiesel is almost half that of palm oil-derived biodiesel, which make palm biodiesel more non-polar. Other properties are almost similar implying the scope of DES application over Jatropha biodiesel as shown in **Table** 4.

An attempt has been made to see if a DES is formed spontaneously by adding salt to the in situ glycerol resulting in extraction. But the salts all remained in a solid phase and did not dissolve in the liquid phase. It probably happened due to the enthalpy of formation of the eutectic mixtures. The process for recovery of salt is not optimized. Moreover, only 25% of the solvent was recovered by using 1-Butanol as cosolvent.[86] The application of DES may be justified for the separation of biodiesel glycerol if the solvent is recovered efficiently.

4.2.2 | Dry washing

Dry-washing is an upcoming method in the field of biodiesel purification as special adsorbents for the dedicated purpose of washing are being searched. Four different adsorbents were tested for two-step biodiesel production process from Jatropha using a homogeneous catalyst. The natural adsorbents like 3% banana peel powder and 3% mushroom powder at 65°C temperature and 25 min showed comparative results to organic adsorbents.[88] In

TABLE 4 Fatty acid profile and properties of palm and Jatropha oil derived biodiesel[87]

Sr. no.	Common name	Structure	Formula	PBD	JBD
1	Lauric	12:0	$C_{12}H_{24}O_2$	-	0.1 (Wt.%)
2	Myristic	14:0	$C_{14}H_{28}O_2$	-	0.1 (Wt.%)
3	Palmitic	16:0	$C_{16}H_{32}O_2$	40.1 (Wt.%)	14.1 (Wt.%)
4	Palmitoleic	16:1	$C_{16}H_{30}O_2$	-	0.6 (Wt.%)
5	Stearic	18:0	$C_{18}H_{36}O_2$	4.3 (Wt.%)	7.6 (Wt.%)
6	Oleic	18:1	$C_{18}H_{34}O_2$	43.1 (Wt.%)	45.1 (Wt.%)
7	Linoleic	18:2	$C_{18}H_{32}O_2$	12.5 (Wt.%)	31.9 (Wt.%)
8	Linolenic	18:3	$C_{18}H_{30}O_2$	-	0.3 (Wt.%)
9	Arachidic	20:0	$C_{20}H_{40}O_2$	-	-
10	Eicosenoic	20:1	$C_{20}H_{38}O_2$	-	0.3 (Wt.%)
Saturated				43.5 (Wt.%)	24.4 (Wt.%)
Unsaturated				56.5 (Wt.%)	75.6 (Wt.%)
Total				100 (Wt.%)	100 (Wt.%)
Density (kg/m^3)				851.2	862.2
Kinematic viscosity at 40°C (mm^2/s)				4.62	4.73

Abbreviations: JBD: Jatropha Biodiesel; PBD: Palm Biodiesel.

another comparative study, silica gel as an adsorbent performed better than rice hull in the purification of biodiesel by reducing FFA.[89] A similar adsorbent in three different forms was employed for biodiesel purification, but the results in case of Jatropha biodiesel were poor compared with biodiesel produced from other feedstocks.[90] A comparative study on different adsorbents suggested that inorganic adsorbents resulted better for purification of crude biodiesel produced using alkaline transesterification for soybean oil. The results for 1% (w/w) magnesol and 2% (w/w) silica at 65°C purify crude biodiesel, which matches the standard specified limits.[73] Magnisol and silica are the commercial adsorbents used for purification of crude biodiesel. Though, their application on Jatropha biodiesel is not reported yet. Silica as an adsorbent is reported to remove impurities from crude biodiesel with a single washing stage with an optimum operating condition as follows: 0.2 bar vacuum pressure, 90°C temperature, contact times longer than 45 min, and 1.1% (w/w) SiO_2 adsorbent dosage.[91] Magnisol as an adsorbent is reported to better purification results with a dosage of 1.5–3% (w/w) of crude biodiesel followed by microfiltration. The application of acid clay treated with sulphuric is reported to be useful for de-alkaline, deodorant, and decolouring effects.[63] Methods of purifying crude biodiesel with an adsorbent clay with at least 60% wt. SiO_2 content and <15% wt. Al_2O_3 have shown good results for a reduction in contaminants.[90]

Cation-exchanged resins are reported to perform better than magnesol for purification of biodiesel produced from homogeneous alkali catalyzed transesterification.[92] In general, the ion exchange purification techniques use vertical column forming a bed of ion exchange resins like amberlite, activated carbon, and other commercial resins, which removes several types of impurities such as fatty acid, inorganic salt, and free ion impurities efficiently. An attempt has been made to develop simultaneous biodiesel production and purification using three ion-exchange beds. The cation-exchange resin column is used as a reactor for the esterification reaction of high-FFA Jatropha oil, and the other two anion-exchange resin column acts as transesterification reactor and adsorbent column purifying biodiesel. The produced biodiesel meets the standard specifications EN14214 and ASTMD6751 except for alcohol content, which is evaporated using distillation.[93] Another application of cation-resin was reported to purify crude biodiesel produced from heterogeneous CaO catalyst where protonated resins consisting of polymer matrix resulted in the high removal efficiency solving the issue of calcium leaching which is the general issue with CaO based heterogeneous catalyst. The calcium removal by cation-exchange resin was significantly promoted by adding methanol 20% (v/v) to the crude biodiesel. However, the free glycerol content was not reduced in the presence of methanol.[94]

The dry and wet purification processes for Jatropha biodiesel is reviewed in Table 5. The major disadvantages of ion-exchange technique in the purification of crude biodiesel is the high cost of resins, which are yet not specifically developed for application, high molar ratio of oil

TABLE 5 Survey on Jatropha-biodiesel purification. Comparison of various purification techniques for biodiesel

Technique (reagent)	Procedure	Remarks	References
Wet washing (Na/Si_2)	Washing: 3% (w/w) of Na/SiO_2, drying over Na_2SO_4	Product meets the standard specifications	[80]
Wet washing (citric acid)	Washing and stirring at 45°C, 20 min, reagent to catalyst ratio 1:1	Efficient than water washing. Product meets the standard specifications	[81]
Dry washing (organic[a]/natural[b] adsorbents)	3% (w/w) adsorbent, stirring for 25 min, 25°C	All adsorbents meet EN 14214 defined standards. Process condition for natural adsorbents in not optimized	[89]
Dry washing (RHA-GB)	Single stage adsorption: 4% (w/w) of RHA-GB, stirring for 5 min, 20°C followed by filtration	Loss of final product, Jatropha biodiesel performed poor, % yield 84. Does not meet EN-14214 standards	[90]
Dry washing (sugarcane bagasse)	Single stage adsorption: 3% (w/w), stirring for 120 min at 120 rpm, 30°C followed by filtration	Glycerol was removed efficiently but water content didn't match the standards	[95]
Dry washing (anion resin PA3065)	Two packed column: 50°C, 0.233 L/h, followed by methanol recovery	Product meets the standard specifications	[94]

*Carbonated rice husk ashes-gray black at 500°C for 8 hr.

[a]Natural adsorbents: banana and mushroom powder.

[b]Organic adsorbent: PurolitePD 206.

to alcohol, and additional water or water-free washing steps are required. Also, a part of biodiesel remains in a column after purification reducing biodiesel yield. The general schematic diagram of the wet and dry purification processes is shown in Figure 1. The recent techniques used for separation and purification of biodiesel include membrane process and extraction using ionic liquid or deep eutectic solvents.

4.2.3 | Membrane separation technique

Membrane technology is used in the field of biodiesel, either by using a membrane reactor or using it for separation and purification of biodiesel. The membrane applications for separation and purification for Jatropha-based biodiesel is scare. The performance of various micro- and ultrafiltration membranes resulting better separation of biodiesel-glycerol is reviewed for the key parameters like transmembrane pressure, membrane pore size, and temperature for biodiesel produced from various feedstocks other than Jatropha in Table 6.
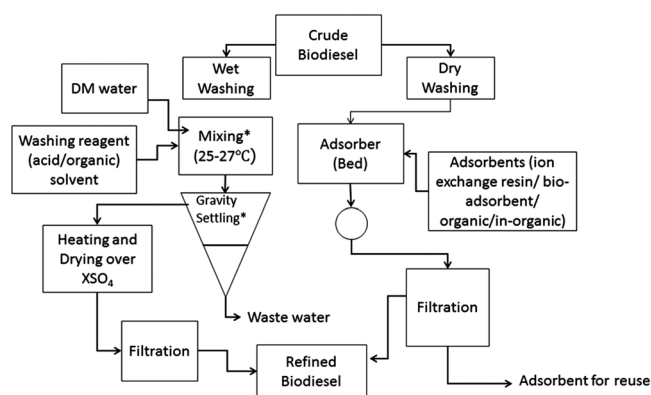
The pore size diameter of a membrane has a wide range with transmembrane pressure ranging from 1 to 3 bar.[96-98] The nanofiltration pore size results in the better purity of product, but the permeate flux has to be compromised. The operating temperature commonly ranges from 25 to 40°C with elevated temperature providing better results. The presence of alcohol had a negative influence as it solubilizes both the phases making separation operation difficult. The acidified water shows positive influence as it agglomerates with dispersing glycerol phase increasing drop size and increasing the glycerol-rich phase rejection. The membrane technology is an attractive and environmentally friendly alternative to conventional biodiesel–glycerol separating techniques. The produced biodiesel from membrane separation process matches the international standard and specification. The general schematic diagram of the membrane separation process in general is shown in Figure 2.

The membrane application for biodiesel purification had showed the ability to remove free glycerol particles from biodiesel without using a water washing step. It is
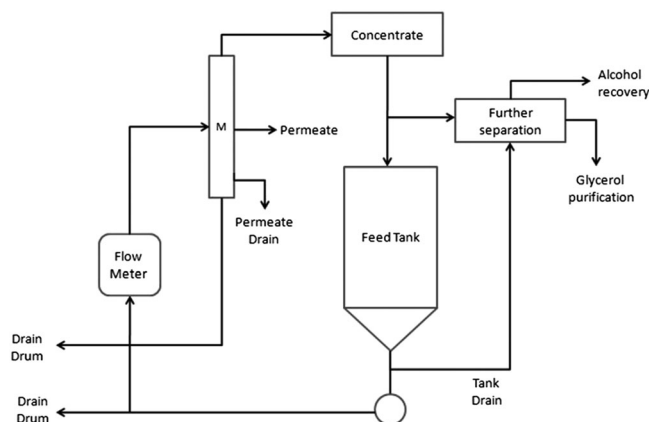

FIGURE 1 Schematic flow process for a wet and dry biodiesel purification process X can be Na or Mg

FIGURE 2 Schematic diagram of membrane separation process for biodiesel purification. M: Membrane module

TABLE 6 Summary of membrane technologies for biodiesel purification

Feedstock	Membrane type	Pore size	Operating condition	Glycerol in permeate (mass %)	Reference
Canola oil	polyacrylonitrile	100 kD	25°C and 552 kPa	0.018 (86% retention)	[57]
Soybean[a]	α-Al$_2$O$_3$/TiO$_2$ ceramic	0.05 μm, 20 kDa	2 bar, 50°C	0.017 mass %	[64]
Soybean	α-Al$_2$O$_3$/TiO$_2$ ceramic	0.2 μm	2 bar, 50°C	0.006 (96.6% glycerol retention)	[97]
Palm	α-Al$_2$O$_3$/TiO$_2$ ceramic	0.5 μm	2 bar, 40°C	0.0108 (98.08% retention)	[98]
Soybean BD (85%), Glycerol 10 % and ethanol 5%	α-Al$_2$O$_3$/TiO$_2$ ceramic	0.2 μm	2.0 bar, 60°C	0.04 (99.6% retention)	[99]

[a]10% acidified water was added before feeding mixture for membrane separation.

reported that the extent of glycerol separation depends on the concentration of water, methanol, and soap in the FAME phase. It has been reported that the small quantity of 2-g water is utilized to treat 1 L of biodiesel, whereas 10 L is utilized conventionally for a litre of biodiesel.[64] The small quantity of water content forms large particles within the dispersed glycerol aiding better separation process. The standard ASTM D6751 values were achieved getting the highest rejection of 99.6% glycerol content in retentate.[98] Though membrane separation technology has several advantages like lower water consumption and production of high-grade biodiesel, its application still lacks large scale application due to extreme separation condition and limited choice of the membrane, none particularly dedicated to the application of biodiesel separation and purification. The feasibility of membrane technology for the large-scale application also depends on the accountability of water used for cleaning and restoring membrane module.

5 | STRATEGIES FOR REDUCING THE COST OF BIODIESEL PRODUCTION FROM JATROPHA

The high cost of Jatropha oil as a feedstock with lower oil yield hinders the development of biodiesel production. The factors like production scale and efficient separation–purification affect the economic viability of biodiesel from Jatropha. The strategies to reduce the production cost and bring the process of jatropha for biodiesel production into reality includes (a) Jatropha cultivation in rural area in waste/degraded land; (b) simultaneous Jatropha oil production with other valuable utilization of cake and fruit as a feed to cattle or biogas plant; (c) technology alternatives for economic efficiency; and (e) integrative approaches reducing capital and operating cost. The separation and purification process for Jatropha is proposed based in Figure 3 for reducing the cost of biodiesel production. A simulative study on integrated reactive absorption showed a significant reduction in energy for biodiesel production with high FFA.[99] It is reported that an application of self-heat recuperation technology for methanol recovery for production of Jatropha biodiesel reduced 71% total energy requirement.[100] The glycerol–biodiesel separation can be achieved by extraction using ionic liquid-based deep eutectic solvents and adsorption using effective commercial adsorbent or membrane separation technology. Separations and purification steps account for the large part of the total costs. A combination of proposed techniques is yet not tested for its reliability. Adopting an improved recent separation and purification techniques complement the production processes of biodiesel ensuring technical as well as economic viability.

5.1 | Jatropha cultivation in rural area in waste/degraded land

The Jatropha cultivation till 2008 was about 900,000 ha globally with Asia leading the cultivation of about 85% followed by Africa and Latin America.[101] The shortage of Jatropha seeds and less efficient oil yield has been one of the reasons for the slow progress in the nation's biodiesel development programme. The reasons addressed in research work are the lack of infrastructure, poor economic conditions of the Jatropha farmers, and other communication facilities. It is reported that labour cost plays an important role in accounting for 64% of the total biodiesel production cost.[102] The international experience with Jatropha cultivation revealed that the failure of the project was due to lack of information, and the farmers were disappointed due to high-labour
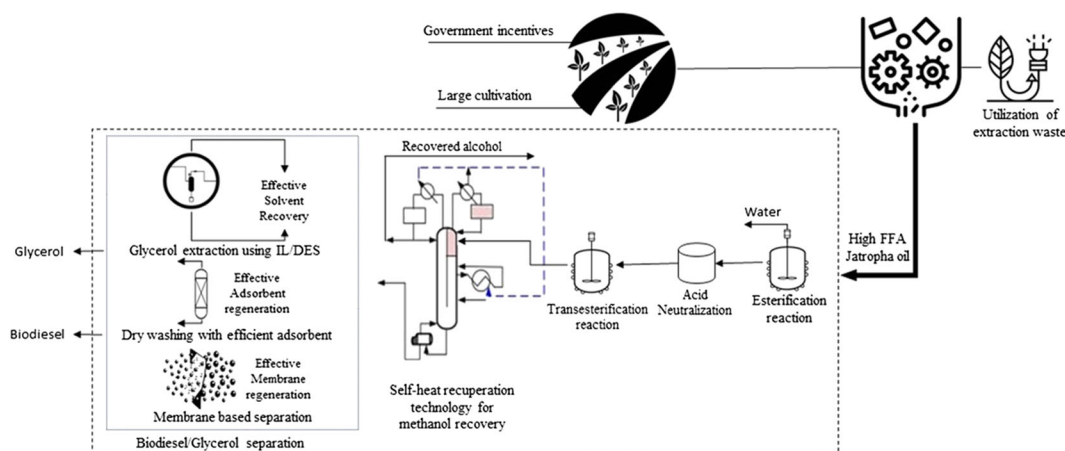

FIGURE 3 Proposed separation and purification process for reducing the biodiesel production cost

cost. The review paper summarized that the Jatropha plant has a large potential as an energy source. The plant can easily adapt to adverse climatic conditions, and it can grow on unfertile land.[103] In India, the underutilized wasteland covering degraded forests and scrubs is up to 32 million ha.[104] The concern for farmers is the substantial amount of capital, and the gestation lag for Jatropha plantation is 3–4 years.[105] The promotion and incentives to a farmer for the cultivation of Jatropha cultivation from the planning commission, Government of India, can benefit the sustainable biodiesel production. The Jatropha cultivation in rural areas of India would reduce poverty and improve access to modern energy services. In India, majority of the farmers are cultivating Jatropha in a land less than 1 ha. The poor economic conditions of the Jatropha farmers usually restrict them to bear the high labour, pesticide, and fertilizer costs. Moreover, Jatropha seed is normally harvested twice in a year, which demands the need for storage.[103] The cultivation 3,250 kg ha^{-1} year^{-1} of Jatropha seeds is necessary to reduce the cost of biodiesel making it economically viable.[103] The unit cost of biodiesel reduces by 18.5% when the production capacity increases from 500 tons to 1,000 tons.[104] The strategy of Jatropha cultivation for a reduction in biodiesel cost necessitates large cultivation, which demands good management practices for land and government policy to promote biodiesel production from Jatropha.

5.2 | Jatropha oil production with utilization of extraction waste

Generally, after extracting Jatropha oil from seeds, the residual biomass was considered to be dumped as a waste though there are options for using the extraction waste as combustion, fermentation, utilization as animal feed, or fertilizer. It has been reported that the Jatropha cake after oil extraction is treated and used as a catalyst during the transesterification process yielding 94% biodiesel.[106] The Jatropha seed cake can be introduced to domestic boilers for direct combustion. The cake can also be used as feed for gasifiers to produce biogas.[107] The pyrolysis of Jatropha extraction waste was studied with pellets made with Jatropha Shell and seed cake biochar showing good combustion characteristics with a heating value of 22.14 MJ/kg.[108] The glycerol is considered to be the only byproduct taken into account during economic analysis. The other byproducts, which include Jatropha shall, husk, pruning waste, and cake, are usually brought back to the field as a soil amendment or treated as a feed for cattle or biogas plant. As per life cycle assessment, the biomass generated per hectare from Jatropha-based agriculture is 5,000 tons, whereas soybean is 1.8 tons.[109] The utilization of Jatropha extraction waste might not influence the cost of biodiesel production to a greater extent. Though, the economic analysis considering complete utilization of Jatropha extraction needs to be studied. The utilization of extraction waste is a promising way to bring down the production cost of biodiesel produced from Jatropha.

5.3 | Technology alternatives for economic efficiency

The economics of biodiesel from Jatropha can be seen for various production routes. The single-step homogenous alkali and acid production route has economic advantages over two-step production route in terms of less unit operation, which in turn reduce the number of equipment. In other cases, the supercritical production route has an economical advantage due to minimum number of unit operations with high operation costs. The single homogeneous alkali process for biodiesel production from Jatropha is been widely accepted economically at a large industrial scale.[110,111] Commercial production from Jatropha demands pretreatment increasing the number of equipment and complex separation and purification steps. Water washing techniques are conventionally used for crude biodiesel purification as it meets the international standards and specifications. The amount of wastewater generated due to repeated washing and the reduction in biodiesel yield are the major issues with the conventional technique. The centrifugation and filtration cost (6.08 US $/L) were reported to have a very slight impact on the production cost.[112] The acid-catalyzed technology can tolerate high-FFA content of Jatropha. In alkali catalyzed technology, the FFA would be converted into soap consuming more catalyst demanding for extra separation and purification cost.[113,114] Supercritical and enzymatic technology would tolerate higher Jatropha FFA, but both the technology cannot compete with the acid-catalyzed process in economic terms.[115]

The separation of biodiesel and glycerol is a crucial step as it dictates the necessary purification requirement. The conventional gravity-settling takes a prolonged time with inefficient separation. Membrane separation techniques have shown results at the laboratory scale. The cost of the membrane, fouling issue, and uncertain purification has stopped large scale applications. The cleaning requires various reagents and deionizer water at elevated temperature to ensure removal of clogged impurities and membrane performance. The energy and water requirement for cleaning should be accounted for comparing purification techniques. The conventional separation

TABLE 7 Comparison of various purification techniques for biodiesel

Type of process	Advantages	Disadvantages
Wet washing	• Simple and effective • Possible use of aqueous solution of acids • Combination with an organic solvent can remove hydrophobic compound • Purifies biodiesel to match specified international standards	• Increases production time due to multiple washing • Large amount of waste effluent generation • Reduction in biodiesel yield • Requires the use of deionized water • Heating and drying might to remove water
Dry washing	• No risk of water in fuel • Decrease time of production as compared with wet washing • Requires less space than wet washing • Allows continuous operation • Low cost natural adsorbents can be used	• Cost of commercial adsorbents are too high • Requires separate mixing and filtration unit • Impurities like glycerides and FFA are sometimes difficult for some adsorbents to adsorb • Regeneration and disposing deactivated synthetic adsorbents is an issue • Excess alcohol is required
Membrane technology	• Increased yield • Purified biodiesel meets the standards (separates soap and alcohol efficiently) • The emulsion issue of Jatropha biodiesel is avoided • Simple operation and easy quality control • Water usage is reduced compared with wet washing	• Fouling issue • Cleaning of membrane requires ionized water • Membranes are relatively costlier • Contamination in crude biodiesel decreases throughput • No commercial applications developed yet
DES extraction	• Efficient in purifying biodiesel • Eliminates waste water generation • Simpler operation and high potential in separating biodiesel-glycerol, water and unreacted glycerides • Environmentally friendly and no reactivity with waste. Might work well with two step Jatropha biodiesel	• Raw material for solvents is relatively costlier • Solvents have to be synthesized • Solvent recovery and regeneration might be energy intensive and separate unit operations are needed• Jatropha biodiesel might not produce results as good as palm biodiesel

and purification techniques have to change in view of the large-scale biodiesel production. Various biodiesel purification techniques already into practices are compared with their advantages and disadvantages in Table 7.

5.4 | Integrative approaches

The approach of strategically converting whole fruit into energy and the extracted oil into biodiesel lowers down the production cost.[116] In general, the transesterification reaction is followed by a complex separation train in almost all the Jatropha-based biodiesel production processes. Several simulative studies have proposed an appealing configuration claiming a reduced energy and/ or equipment cost for biodiesel production.[61,117-124] It is reported that an application of self-heat recuperation technology over Jatropha biodiesel reduced 71% total energy requirement.[100] The reactive separation operation where simultaneous reaction and separation is allowed in a single unit has shown improved engineering attributes. Such operations include reactive distillation,[125,126] reactive absorption,[127-129] reactive extraction,[130-134] and reactive membrane.[135-137] The novel integrative approaches

overcome the equilibrium limitation and reduce the production cost with an additional energy-saving potential of 45 to 85%.[138] The economic assessment of biodiesel plant design with an integrated approach revealed an 18% decrease in an overall cost.[139] There is a great scope of equipment and energy integration for biodiesel production making the process economically attractive and practically feasible.

6 | CONCLUSIONS

The increasing demand with depleting conventional petroleum fuel in India points out an urgent necessity of a determined policy and strategic planning at regional and national levels. A source of biodiesel raw material dictates the route of production. Jatropha is a significant feedstock for biodiesel production in India. The problem with this low-cost non-edible feedstock is their higher amount of impurities demanding the use of additional pretreatment and product separation and purification. Improved novel separation and purification technologies with an integrative approach can lower the overall biodiesel production cost. Biodiesel is an attractive alternative

fuel, but, to meet the demand–supply chain in a developing nation, the biodiesel production processes need to move from a small-scale laboratory setups to commercial reality with an improved separation and purification steps.

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