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RESEARCH ARTICLE

Biodiesel blends: a comprehensive systematic review on various constraints

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Abstract
Biodiesel is a renewable, clean-burning diesel replacement that can be used in existing diesel engines without modification. Biodiesel is among the nation's first domestically developed and economically usable advanced biofuels. Throughout the field of biodiesel including FAME/FAGE diesel variants, the concentrations of close to around 20% conform to every requirement out from the existing fuel content guidelines. Larger blending ratios are essential for hydrotreated vegetable oil blends to lubricity enhancers. Of organic biobutanol blends, the suggested blending ratio is restricted to 10% or less to prevent high water content and low cetane content. Here, the presented survey intends to make a review of 65 papers that concerns with biodiesel blends. Accordingly, systematic analyses of the adopted techniques are carried out and presented briefly. In addition, the performances and related maximum achievements of each contribution are also portrayed in this survey. Moreover, the chronological assessment and various blends of biodiesel in the considered papers are reviewed in this work. Finally, the survey portrays numerous research problems and weaknesses that may be helpful for researchers to introduce prospective studies on biodiesel blends.

Keywords Biodiesel blends · Glycerol · Blending ratio · Lubricity enhancers · Cetane content

Introduction

Biodiesel is defined as the mixture of mono-alkyl esters of animal fats or vegetable oils (Maawa et al. 2020). Both oils and fats were added chemically to the biodiesel with a biodiesel catalyst, a glycerin co-product, and a short chain of alcohol (such as methanol) (Veinblat et al. 2018). Biodiesel would therefore be technically mixed through petroleum diesel at some cost. Biodiesel could be used on its very own as B100 or mixed for petroleum diesel in certain ratios (Devarajan et al. 2020). According to potential depletion and growing price of oil along with environmental issues generated using fossil fuel consumption, desire based on renewable fuels has drawn a great deal of interest (Bencheikh et al. 2019; Oliveira and Caires 2019). Moreover, the waste cooking oils and non-edible oils were used within appealing as starting materials in biodiesel in an easy manner (Beatrice et al. 2014;Jamrozik 2017). One of the important advantages in fuel is that its performance and properties were identical to traditional diesel fuels (Das et al. 2018).

Generally, diesel fuel will be really significant based on the wealthy financial system in countries because it has a broad variety of applications like mobile drives, power generators, as well as in mechanical engines (Najafi 2018). The usage of animal fats or vegetable oils as fuel will produce several issues in the engine, such as inadequate combustion, engine fouling, low fuel atomization, and oil toxicity based on increased viscosity (Shen et al. 2018; Jagtap et al. 2020). However, the

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vegetable oil's viscosity would be decreased using a variety of processes, including cracking/pyrolysis, microemulsification, transesterification, and oil blending (Ng and Yung 2019). Among these, transesterification is commonly used in the processing of industrial biodiesel. In addition, the blending biodiesel combines traditional petroleum diesel through biodiesel used for creating a biodiesel mix that would be connected to some amount of petro-diesel (Anis and Budiandono 2019; Bora and Saha 2016a, 2016b). Biodiesel could still be used in the pure form B100 which will involve some alteration of the engine to prevent maintenance and performance issues (Gnanamoorthi and Devaradjane 2014).

Nowadays, large energy consumption countries set strong semi-permanent goals for biodiesel development and carbon emission reduction (Rakopoulos 2013). The main features of biodiesel fuels include lower carbon emissions and renewable nature that were generated internally in most countries (Prabu et al. 2017; Natarajan et al. 2017a). Biodiesel consumption may increase the number of concerns, such as efforts to increase agricultural land and its effect on natural ecosystems, increasing food prices and its effect on the poor, improve the use of agrichemicals, etc. (Natarajan et al. 2017b; Ong et al. 2017;Mostafa and El-Gendy 2017). Moreover, the environmental and economic effects of biodiesel have been shown to be heterogeneous (Garcia-Perez et al. 2010; Wu et al. 2017). Even though a variety of developments, namely sustainable energy such as wind and solar photovoltaic and carbon-free technology such as nuclear, are ready to threaten coal and natural gas in the power market, it still appears that no alternative could balance with oil in terms of cost and comfort for transport (El-Araby et al. 2017; Nabi et al. 2017).

The main contribution of this paper can be given as follows.

1. This paper presents an extended review based on biodiesel blends and the varied techniques adopted in each paper are portrayed.
2. Consequently, the performance measures and their corresponding maximum achievements are also analyzed in this review work.
3. Furthermore, various blended materials used in each work are examined and a chronological review is also carried out.
4. Finally, the research problems that exist in classifying the biodiesel blend were described and the future directions were given in this work area.

This paper deals with the following sections: Section 2 describes the related works. The wide-ranging review using adopted techniques, performances, and the maximum attainments is described in Section 3 and the evaluation on biodiesel blends and chronological review in each work is represented in Section 4. Furthermore, Section 5 organized the research gaps and challenges, and Section 6 indicates the conclusion.

Literature review

Related works

Maawa et al. (2020) have proposed emulsified diesel-biodiesel blends in CI engines with various water contents for determining the emission, combustion, and performance characteristics. However, the present output indicated a 28% improvement in engine torque and hence was found to be more effective in the emulsification of biodiesel-diesel with water. Veinblat et al. (2018) have suggested a comparative analysis of linseed oil-derived biodiesel on the compression and performance of ignition engine combustion. Biodiesel blends were comparable to diesel fuels in all modes of operation at the low-load condition that reduced the accumulation of particulate matter when it was fed with diesel fuel mixtures. Finally, the blended oil has shown a reduction in emission than diesel with high loads in the engine.

Devarajan et al. (2020) have developed the performance aspects that limited emissions from papaya seed biodiesel operation. Moreover, the impacts of decanol and DTBP on biodiesel/diesel blends were invested in research engines. At last, this work demonstrated an enhanced better performance and low fuel consumption than other fuels. Bencheikh et al. (2019) have demonstrated the emission performance and fuel properties of an engine were analyzed based on ternary waste cooking oil with proposal mixtures. In addition, an improvement in the properties of cold flow has reduced the density of proposal blended biodiesel. In the end, the emission and engine performance were raised and NO_X, EGT, smoke, and CO were decreased.

Oliveira and Caires (2019) have proposed molecular dynamic simulations for identifying the picture of interactions. Consequently, the accumulation of diesel molecules was computed quantitatively for methyl esters using the distribution functions. Finally, the simulation outcome indicated reduced mobility, fewer diffusion coefficients, and increased molar mass when compared to the biodiesel molecules. Das et al. (2018) have identified the spray characteristics based on non-vaporizing transient of gasoline and biodiesel mixture with 3 different ratios in various conditions of injection pressure and low load at constant volume chamber. In addition, the z-type shadowgraph used optical method and image processing algorithm as modified for determining the spray characteristics. At last, the outputs have shown increased blending fraction of biodiesel and weak air-fuel mixing ability than gasoline.

Najafi (2018) have investigated CNT and Ag nanoparticles based on biodiesel-diesel mixtures for determining the diesel engine characteristics of combustion. Using TEM and XRD analysis, nanoparticles were characterized and blended with biodiesel-diesel blends using an ultrasonicator. Finally, the simulation outputs have shown less ignition delay and increased cylinder pressure. Shen et al. (2018) have proposed

PEMS for calculating exhaust emissions and the fuel consumption of diesel vehicle fuels in waste cooking oil biodiesel blends. From the outcomes, the biodiesel blend offered minimal NO_X, CO, HC emissions, and PM2.5 were compared with diesel for deceleration and acceleration modes.

Jagtap et al. (2020) have suggested the emission and combustion analysis that increased the usage of blending biodiesel with diesel engine as slow heat rejection. Moreover, the optimum EJO blends based on CE as well as LHRE were computed for attaining the characteristics of every biodiesel blends based on normal diesel during CE operation. Moreover, the usability of biodiesel and BTE were increased and hence NO_X was decreased. Ng and Yung (2019) have developed NMR spectroscopic characteristics based on palm biodiesel with its blends. Usually, for determining its palm biodiesel–petroleum diesel blending ratio, the presence of vegetable oil components in the samples cannot be identified by the FT-IR method. However, this work presented NMR spectroscopy with accurate and quick characteristics of blend level in palm oil-based biodiesel.

Anis and Budiandono (2019) have implemented preheating temperature based on the biodiesel/diesel fuel blends based on the injection pump performance and fuel spray characteristics. Fuel injection system equipment was used as a fuel and then given to the injector using a single-plunger-based fuel injection pump. At last, the proposed work indicated increased preheating temperature that prevailed over the transport complexity of high viscosity fuels. Bora and Saha (2016a, 2016b) have proposed optimization of injection timing and CR using raw biogas powered with the dual-fuel diesel engine. Moreover, the engine output power was normalized under DFM and the biogas runs dual fuel diesel engines in an attractive substitute for traditional diesel. At last, better efficiency was obtained in the proposed work.

Gnanamoorthi and Devaradjane (2014) have identified the effect in CR depending on the emission, combustion, and performance of DI diesel engine fuels with single cylinder on ethanol diesel blend. On observing the outcomes, the brake thermal efficiency was increased at complete load with a better percentage of ethanol at greatest CR. Rakopoulos (2013) has investigated the emissions and combustion in cottonseed oil within its biodiesel blends using diethyl ether or *n*-butanol in HSDI diesel engine. Finally, the proposed method provided better performance in biodiesel blends than other existing methods.

Prabu et al. (2017) have proposed the diesel blends/waste cooking oil biodiesel with additives for identifying the combustion, performance, and emission characteristics of diesel engine fuels. Transesterification processes were converted vegetable oil to biodiesel by breaking oil molecules into methyl or ethyl esters with the presence of glycerol as a catalyst and a by-product. Natarajan et al. (2017a) have suggested the direct-injected HCCI engine for computational analysis by deploying diesel blends and bioethanol as fuels. In addition, the HCCI engine emitted a UBHC and thus the HC emission caused incomplete combustion in the engines. However, the temperature and pressure profiles played a major role during various operating conditions and thus the emission was reduced than other works.

Natarajan et al. (2017b) have developed a PCCI engine and its fuels were based on diesel and bioethanol blends. Here, the emission characteristics, combustion, and pressure were identified using the 0.6 equivalence ratio. In addition, the timing of fuel injection was controlled by crank angle timing in the ECU unit. The partial homogeneous charge and the vaporized fuel were fed in the engine by a suction stroke in the pre-chamber. Finally, the outputs were compared with other fuel diesel operations and hence there were fewer oxides of nitrogen at lower levels. Ong et al. (2017) have implemented a “Calophyllum inophyllum biofuel blend in a diesel engine” via vibration analysis technique. Here, the biofuel blend B20 with the smallest amount of shaking in general RMS acceleration at complete speed was compared with other biofuel blends.

Mostafa and El-Gendy (2017) have proposed “microalgae spirulinaplatensis bio-diesel” and its blends for evaluation of fuel properties with petro-diesel. Here, the mixtures of petro-diesel and microalgae biodiesel were organized based on a volume basis and the characteristics of physico-chemical can be obtained. Finally, the characteristics of the blend indicated a better engine performance. Garcia-Perez et al. (2010) have identified the fuel properties and production of biodiesel blends/fast pyrolysis oil. Extracting bio-oil compounds with biodiesel utilized the phenolic fraction as fuel additives from bio-oils. However, the oxidation stability of biodiesel improved when compared to various fuel properties.

El-Araby et al. (2017) have investigated alternative fuels using palm oil methyl esters/palm oil blends for diesel engines. Finally, the simulation result indicated better outcomes compared to the correlation prediction. Wu et al. 2017 have proposed hydrogenated biomass-pyrolysis-oil with diesel in diesel engines were experienced by surrogate-ethylene glycol. Here, the engine performance with ethylene glycols was compared with ethyl acetate and ethanol. At last, the proposed work performed better possibility and hence proved that ethylene glycol was a good additive in diesel.

Beatrice et al. (2014) have suggested an injection parameter optimization by DoE with a light-duty diesel engine fed in the RME/diesel/bioethanol blend. In the end, the outcome of this proposed method indicated less heat content and more ignition delay time. Nabi et al. (2017) have developed the “13-Mode European Stationary Cycle” based on emissions and engine performance with diesel-butanol and diesel blends. The parameters used in combustion like in-cylinder peak pressure, rate of maximum pressure rise, start of injection timing, and boost pressure. Here, the simulation output has shown better engine performance with fewer emissions.

Jamrozik (2017) has implemented the alcohol content in fuel blends based on the emissions and performance characteristics of direct injection diesel engine fuels using diesel-ethanol and diesel methanol blends. However, the disturbances in the combustion process occurred due to arise in volume percent of methanol in unsteady engine work and in-cylinder pressure. Finally, the alcohol content had a limit in the steady works of the combustion engine. Majhi et al. (2012) have proposed Hempel distilled bio-oil for blending optimization with diesel. From the analysis, the proposed characteristics of diesel and four blends were compared with the other diesel blends.

Bora and Saha (2016a, 2016b) have identified the characteristics of CR on performance, combustion, and emission characteristics of rice bran biodiesel-biogas run dual fuel in the diesel engine. On analyzing various outcomes, the CR values were the same and hence the output was obtained with higher nitrogen oxides and CO_2 emissions correspondingly. Nagaraja et al. (2015) have suggested an effect of CR over the emission and performance characteristics based on diesel-preheated palm oil blends of variable CR engine fuel. In addition, the output efficiency has shown better performance such as emission characteristics, brake power, and effective pressure.

Senthil et al. (2015) have proposed the effects of engine design parameters such as fuel IT and CR combined with SFC, BTHE, and emissions of HC, CO, NOx, and smoke with annona methyl ester as fuel. A20 had the performance and emission comparison of various values of CR with injection timing for identifying the best possible mixture in an operating engine. Kumar et al. (2015) have suggested esterified punnai oil based on the emission and performance characteristics tested in VCR engine. Finally, the properties of biodiesel were compared with diesel provided better results for the proposed work.

Selvabala et al. (2011) have introduced a two-step process used for producing biodiesel from *Calophyllum inophyllum* oil. Moreover, RSM and CCD were used for determining the higher operating condition in the pre-treatment step. In addition, the processes of biodiesel produced were tested based on the properties of the fuel. Fattah et al. (2014) have implemented a diesel engine with CIBD blends accompanied by oxidation inhibitors for determining the performance and regulated emissions. Finally, the performance results generated lower mean BP and higher mean BSFC compared to diesel.

Bapu et al. (2015) have identified the characteristics of combustion chamber geometry based on DI diesel engine fuelled by *Calophyllum inophyllum* methyl ester. Here, the emissions were decreased, and the combustion characteristics were getting better by enhancing the fuel-air mixture preparation.

Muthukumaran et al. (2015) have identified fly ash catalyst for diesel engine application for the synthesis of cracked *Calophyllum inophyllum* oil. However, the fuel development process was carried out with a fixed bed catalytic converter to test the properties of a fly ash catalyst. Fly ash characterization learned using SEM and EDS distinguished the surface and internal properties of fly ash particles pre and post cracking. At last, the emission of NOX was reduced when compared with B25 with diesel. Tinprabath et al. (2016) have investigated the effect of cold temperatures on the process of fuel injection of biodiesel mixtures. Moreover, the higher proportion of biodiesel in the mix, the discharge ratios lowered the stream, the penetration improved and the stream angle decreased dramatically in cold environments. In addition, in this proposed study, the correlation coefficients determined the discharge coefficient as well as the spray angle during cold conditions.

Hossain and Davies (2010) have proposed a technical review on both non-edible and edible plant oils of CI engines and comparisons with standard diesel fuel. Moreover, greenhouse gas emission and life-cycle energy analyses have the benefits of natural plant oils from fossil fuel and biodiesel. Simultaneously, the outputs have shown that the life-cycle energy-to-input ratio of raw plant oil was 6 times greater than those of fossil diesel. Hossain and Bayindir (2010) have suggested the cottonseed oil methyl ester in a diesel engine used for analyzing the emission characteristics and performance. Finally, experimental outcomes indicated less CSOME in the blends as diesel fuel in engines.

Çelikten et al. (2010) have developed soybean oil and rapeseed methyl esters during various pressures for the comparison of performance and emissions in diesel fuel. Rapeseed oil methyl ester and soybean oil methyl ester were developed from both the engine performance and emission perspective of the four-cylinder diesel engine. Moreover, both injection pressures include a lower amount of CO and smoke than fossil fuel and even reduced NOx emissions. Kratzeisen and Müller (2010) have implemented phosphorus production of coconut oil dependent on the efficiency of vegetable oil pressure stoves. The overall toxicity of debris, Conradson carbon traces, iodine content, and acid value were measured using fuel mixtures. Eventually, the test findings revealed higher concentrations of the phosphorous material in the vaporizer.

Rehman et al. (2011) have proposed esterified jatropha oil diesel blended with an alternative fuel for the gas turbine. At last, the experimental results obtained during the simulation procedure have shown the better performance of diesel fuel in normal conditions, and better outcomes were attained by the proposed work. Chen and Chen 2011 have modeled rapeseed-based biodiesel of energy costs that were exploited. This process of biodiesel production included four main stages such as "wastewater treatment, transesterification, agricultural crop production, and transportation." Finally, the overall energy costs of rapeseed-based biodiesel were estimated.

Nita et al. (2011) have investigated the physico-chemical properties in pseudo-binary mixtures with biodiesel for correlations and measurements. Biodiesel þ benzene mixtures and pseudo-binary biodiesel þ diesel fuel were prepared based on their densities, viscosities, and refractive indices of mixtures in preparation of biodiesel blends. At last, the study provided really high consistency using Kay's mixing law or empiric equations derived from the regression analysis. Mallikappa et al. (2012) have proposed the double-cylinder CI engine powered by cardanol biofuel blends for both the assessment of performance and pollution characteristics. Biofuels produced through non-edible oils are regarded as a sustainable alternative to fossil diesel. In this situation, the thermal performance of the brakes was improved with higher brake strength and pollution rates of up to 20% mixtures.

Leoneti et al. (2012) have suggested biodiesel production with glycerol as a by-product in Brazil. For identifying these viable alternatives, by-product production of co-gasification, chemical products, animal feed, production of hydrogen, development of fuel cells, co-digestion, ethanol or methanol production, fuel additives, and waste treatment were used for biodiesel productions. Finally, the promising possibilities provided the better performance of unrefined glycerol in the biofuel market than other methods. Shukla et al. (2011) have developed an optimization process for the cost-effective operation of refueling station systems including alternative energy automobiles. Refueling stations at sites have greatly increased the number of vehicles operated under expenditure constraints. Finally, the use of transport simulation offered a clearer approach to the dynamic large-scale issue of a real-life transport network.

Sayin and Gumus (2011) have implemented performance and pollution of a DI diesel engine fuelled by biodiesel-blended diesel fuel including CR effect and injection parameters. Effects on CR and injecting parameters and emissions of the DI diesel engine were obtained through the utilization of biodiesel blended-diesel fuel. Finally, BSFC, BTE, and BSEC were improved with an increase in CR when compared over the original and decreased CRs. Aydin and Ilkılıç (2010) have proposed the influence of ethanol blending into biodiesel on engine performance and exhaust pollution in CI engines. Ethanol has been used as an ingredient to work in unaltered diesel engines using industrial diesel fuel, 20 percent biodiesel, and 80 percent jet fuel named B20 in a single cylinder. Finally, the experimental results indicated the improved performances of the CI engine.

Atadashi et al. (2011) have presented refining technology based on the purification in crude biodiesel. The most recent biodiesel membrane refining technologies through membrane purification have shown promised biodiesel production and quality with low water use and wastewater discharge. Sherbiny et al. (2010) have investigated microwave technology for the processing of biodiesel. Radiofrequency microwave energy provided a quick, simple route to this useful biofuel with both the advantages of growing the response time to boost the separation cycle. Nonetheless, this new technique needs to be more explored for future scale-up of industrial applications.

Qiu et al. (2011) have proposed mixed soybean oil and rapeseed oil for biodiesel production. The biodiesel blend prepared by the process of transesterification using mixed oil with NaOH was used as a catalyst. The biodiesel structures were characterized by FT-IR spectroscopy and sulfur content of biodiesel can be specified by "Inductively Coupled Plasma emission spectrometer." In the end, the proposed works have offered satisfying outputs. Atapour and Kariminia (2011) have suggested biodiesel production based on classification and transesterification of Iran's bitter almond oil. The BAO obtained from resources as its physical and chemical properties of the contribution of unsaturated fatty acids as strong has been verified by the study of the fatty acid content listed.

Demirbas (2011) has developed a solution to pollution problems using fixation of carbon dioxide by microalgae and biodiesel from oilgae. Microalgae appeared as renewable biodiesel were used as transport fuels in meeting the global demand and biodiesel production. At last, the microalgae biofixation of CO2 operated large-scale systems and hence the CO2 outputs were converted into biofuels in the power plant. Sharon et al. (2012) have implemented the test on DI diesel engine fuelled in methyl esters for palm oil. Here, the palm oil was converted into methyl esters during the transesterification process and the produced biodiesel was mixed with gasoline in various volume amounts measured in a DI diesel engine by changing loads at constant rpm. However, the experimental analysis indicated better performances in terms of performance, emission, and combustion profile. Bezergianni et al. (2011) have proposed a linear programming method trying to maximize the blending level of biodiesel depending on the actual product requirements. Here, the formula used to estimate the properties of diesel–biodiesel mixtures with various mixing ratios and the ultimate mixing ratio with biodiesel was established, taking into account standard fossil diesel forms and four biodiesel forms. By the end of the day, the theoretical model was applied to utilize MATLAB and the subsequent biodiesel optimization was analyzed.

Fahmi and Cremaschi (2012) have developed a model using ANN that surrogates the models for synthesizing of the biodiesel production plant. However, the superstructure optimization model has reduced the computational cost for solving the disjunctive programming, and the surrogate models utilizing ANNs were developed. Singh et al. (2010) have investigated the characterization, engine efficiency, and emission characteristics including preparation of coconut oil-based hybrid fuels. In comparison, CCO extracted through copra using the conventional approach and VCO extracted from both the direct microexpulsion process were used during the proposed research. Simultaneously, the simulation outcomes indicated better efficiency of hybrid fuels compared to diesel.

Fang et al. (2013) have proposed four heavy-duty diesel engine cylinders are used to monitor the influence of ethanol during most of the combustion cycle and the release of premixed LTC. The medium degree of EGR and the extended ignition delay were accomplished by the premixed LTC. Finally, smoke emissions were reduced in high loads when compared to diesel fuels. Balat and Balat (2010) have suggested biodiesel processing. However, the four techniques such as transesterification, dilution, microemulsification, and pyrolysis have solved the problems that occurred during high fuel viscosity. The presented model has offered higher combustion duration, reduced particulate emissions, and less ignition delay.

Mejía et al. (2013) have developed blends that use diesel and palm-castor biodiesel depending on their cloud level, viscosity as well as the flash stage. However, palm oil is often used as a biomass raw material to produce a large concentration of saturated fatty acids. Ultimately, the suggested calculation of viscosity and cloud level for liquid mixtures demonstrated fewer differences than other approaches. Yang et al. (2013) have implemented dominant weathering processes of incrementing biodiesel and its mixing in atmospheric conditions. An increase in mass and chemical content is focused on tests obtained from soya bean and canola oil, petrol, and coal. Moreover, the individual FAME compounds and the total biodiesel concentration provided limited evaporation of the biodiesels with better stability. In addition, the proposed biodiesel blends provided better performance and more boiling point than other traditional diesel.

Jose et al. (2011) have proposed the multi-variant method for optimizing requirements for the production of biodiesel utilizing rubber seed oil. The DOE approach has been used to improve process parameters by acid-related, two-stage esterification, and alkaline-related catalytic converters. Finally, the fuel properties were tested and compared with the alternate fuel over the existing engine.

Lin and Huang (2012) have presented a cost-benefit calculation of the usage of biodiesel as an alternate fuel for fishing vessels in Taiwan. In the global environment, air pollution was a significant source for fishing boats as pollutant emissions and examined the biodiesel that replaced fishing-boat fuel to reduce pollutant emissions. At last, the proposed biodiesel provided a larger reduction in emissions, the highest cost-benefit ratio, and lower fuel cost than other fuels. Kiss and Ignat (2012) have investigated enhanced recovery of methanol and isolation of glycerol in the manufacture of biodiesel utilizing DWC. The effective intensification process using DWC isolated all high-purity materials in one unit of equipment. Also, the proposed DWC have shown better outcomes with lower investment costs and less energy.

Zhang et al. (2012) have proposed the dynamic and kinematic viscosities of biodiesel-diesel blends utilizing mid-to near-infrared spectroscopy. Here, a PLSR modelling method employed using the calibration models based on information depending on biodiesel including three commercial petrol oils. Finally, the proposed findings showed that both MIR and NIR had correctly estimated the viscosity of biodiesel–diesel blends. Park et al. (2012) have suggested the effect of biodiesel in bioethanol blended diesel on both the efficiency of the engine as well as the pollution characteristics of the compression ignition system. The fuel properties for diesel-bioethanol blends were calculated and the engine experiments were performed using only a single-cylinder diesel engine. Finally, the simulation outcomes have shown higher biodiesel blended ratio and less fuel density with reduced EI-NO_x emission.

Wide-ranging review on adopted techniques, performances, and the maximum attainments

Review on adopted techniques

The review of different methods adopted in each work is discussed in this section and is shown in a diagrammatic representation by Fig. 1. From the review, it was observed that least-squares methods were adopted in Veinblat et al. (2018) and El-Araby et al. (2017), and TG and DSC analysis in Bencheikh et al. (2019) and Mostafa and El-Gendy (2017). Fuel injection systems were adopted in Anis and Budiandono (2019), Gnanamoorthi and Devaradjane (2014), Natarajan et al. (2017a), and Natarajan et al. (2017b). In addition, perturbation techniques were adopted in Bora and Saha (2016a, 2016b) and the transesterification method was deployed in Prabu et al. (2017), Nagaraja et al. (2015), Senthil et al. (2015), Kumar et al. (2015), Bapu et al. (2015), Muthukumaran et al. (2015), Rehman et al. (2011), Chen and Chen (2011), Sherbiny et al. (2010), Atapour and Kariminia (2011), Demirbas (2011), Sharon et al. (2012), Balat and Balat (2010), and Mejía et al. (2013). In addition, the DOE method was exploited in Beatrice et al. (2014) and Jose et al. (2011) and ASTM/IP test method was employed in Majhi et al. (2012) and Nita et al. (2011) respectively. Moreover, other biodiesels blending algorithms such as direct data acquisition system were adopted in Maawa et al. (2020), splash blending method was deployed in Devarajan et al. (2020), molecular dynamics simulation analysis was exploited in Oliveira and Caires (2019), optical and automatic threshold determination method was employed in Das et al. (2018), and CVD method and root sum square method was adopted in Najafi (2018) correspondingly. In addition, the PEMS method was deployed in Shen et al. (2018), the standard titrimetric method was employed in Jagtap et al. (2020), the NMR spectroscopy method was exploited in Ng and Yung (2019), simple time marching technique was adopted in Rakopoulos (2013), and advanced vibration analysis technique was deployed in Ong et al. (2017) respectively. However, the analytical fitting methods were adopted in Garcia-Perez et al. (2010), Gaussian package was deployed in Wu et al. (2017), ESC protocol was exploited in Nabi et al. (2017), NDIR methods were employed in Jamrozik (2017), and RSM process was adopted in Selvabala et al. (2011). Similarly, the linear approximation method was adopted in Fattah et al. (2014), Bernoulli's principle was deployed in Tinprabath et al. (2016), emulsification method was employed in Hossain and Davies (2010), non-destructive infrared techniques were exploited in Hossain and Bayindir (2010), polymerization was adopted in Çelikten et al. (2010), Conradson carbon residue measurement was employed in Kratzeisen and Müller (2010), and single-stage fractional distillation method was deployed in Mallikappa et al. (2012). At last, the impregnation method, agent-based modelling methods, combined container method, exhaust gas analyzer, adapted supercritical methanol method, ICP technique, linear programming method, ANN method, direct microexpelling methods, opacimeter analyzer, dominant weathering process, cost-benefit method, DWC system, PLSR modelling method, and shoot analyzer were adopted in Leoneti et al. (2012), Shukla et al. (2011), Sayin and Gumus (2011), Aydin and Ilkılıç (2010), Atadashi et al. (2011), Qiu et al. (2011), Bezergianni et al. (2011), Fahmi and Cremaschi (2012), Singh et al. (2010), Fang et al. (2013), Yang et al. (2013), Lin and Huang (2012), Kiss and Ignat (2012), Zhang et al. (2012), and Park et al. (2012) respectively.

Analysis of biodiesel blends and engine characteristics

The performance measures that are taken from various contributions regarding biodiesel blend are described in Table 1. From Table 1, it is observed that 8 papers have utilized ethanol blend and diesel/biodiesel, respectively, which have contributed about 12.31% of the reviewed works in each oil, and the palm oil was used in 6 papers that had contributed about 9.23%. Moreover, Tamanu oil has been adopted in 5 papers, which have contributed about 7.69%. Also, waste cooking oil and rapeseed and soya bean oil have been contributed about 6.15% (4 papers), and 7.69% (5 papers). Likewise, punnai oil, rapeseed oil, cardanol oil, crude oil, bitter almond oil, microalgae, rubber seed oil, algae oil, lubricating oil, linseed oil, papaya seed oil, pine and oil mallee, sugarcane trash pyrolysis oil, and rice ban oil, respectively, have been contributed about 1.54% (2 papers) in each oil. Furthermore, vegetable oil, jatropha oil, plant oil blend, cottonseed oil, esterified jatropha, crude oils, and annona squamosa oil were adopted in 3 papers, which contributed about 3.08% in each oil. The single-cylinder characteristics of diesel engines have been adopted in 16 papers, contributing to 24.61%. Likewise, four cylinder characteristics of diesel engine have been adopted in 5 papers, which have been contributed about 7.69%. Similarly, 6-cylinder was assumed in 1 paper, which contributed about 1.54%.

Analysis of maximum performance

The maximum performance attained by each of the reviewed papers based on biodiesel blend systems is represented in Table 2. From the review, speed adopted in Aydin and Ilkılıç (2010) has attained a better value of 7500 rpm, and power adopted in Nabi et al. (2017) has attained a higher value of 162 kW. In addition, the compression ratio attained a higher value of 21:1 and it has been adopted by Wu et al. (2017) and density has attained a higher value of 914 kg/m^3, which was adopted by Çelikten et al. (2010) respectively. Similarly, pressure, temperature, efficiency, and performance have attained better values of 300 bar, 800 °C, 85%, and 98% and it has been adopted by Çelikten et al. (2010); Leoneti et al. (2012); Fahmi and Cremaschi (2012) and Sherbiny et al. (2010). , correspondingly. The measures such as molar ratio, torque, and NOx emission have attained higher values of 7.5:1, 820 Nm, and 358.36 tons and they have been adopted in Sherbiny et al. (2010); Nabi et al. (2017) and Lin and Huang (2012) respectively. Also, energy cost, PM emission, and CO emission were exploited in Chen and Chen (2011); Lin and Huang (2012), and Lin and Huang (2012), and they have acquired higher values of 9272.7 MJ, 43.03 tons, and 83.10 tons correspondingly. In addition, viscosity and BSFC have attained higher values of 4.6 mm^2/s and 4.90% and they have been measured in El-Araby et al. (2017) and Fattah et al. (2014) respectively. Also distance, frame rate, heat release rate, ignition delay, displacement, torque error, specific gravity, calorific value, correlation value, accuracy, CH emission, SO emission, mixing ratio, multiplying factor, separating factor, maximum output, bore, stroke, volume, weight, *F*-value, *p*-value, and prediction error have attained higher values 2.2 A°, 40,000 frames, 28%, 8.98%, 4.75 L, 0.5, 0.8681, 17.05 MJ/kg, 0.975, 0.012%, 1.35, 474.44 tons, 6.51%, 7.189, 90%, 3.8 hp, 70 mm, 55 mm, 40%, 95%, 12.12, 0.0001, and 0.45% correspondingly and they were attained by Oliveira and Caires (2019); Das et al. (2018); Najafi (2018); Najafi (2018); Shen et al. (2018); Ong et al. (2017); Mostafa and El-Gendy (2017); Majhi et al. (2012); Selvabala et al. (2011); Nita et al. (2011); Demirbas (2011); Lin and Huang (2012); Bezergianni et al. (2011); Fahmi and Cremaschi (2012); Fahmi and Cremaschi (2012); Singh et al. (2010); Singh et al. (2010); Singh et al. (2010); Mejía et al. (2013) and Zhang et al. (2012) respectively.

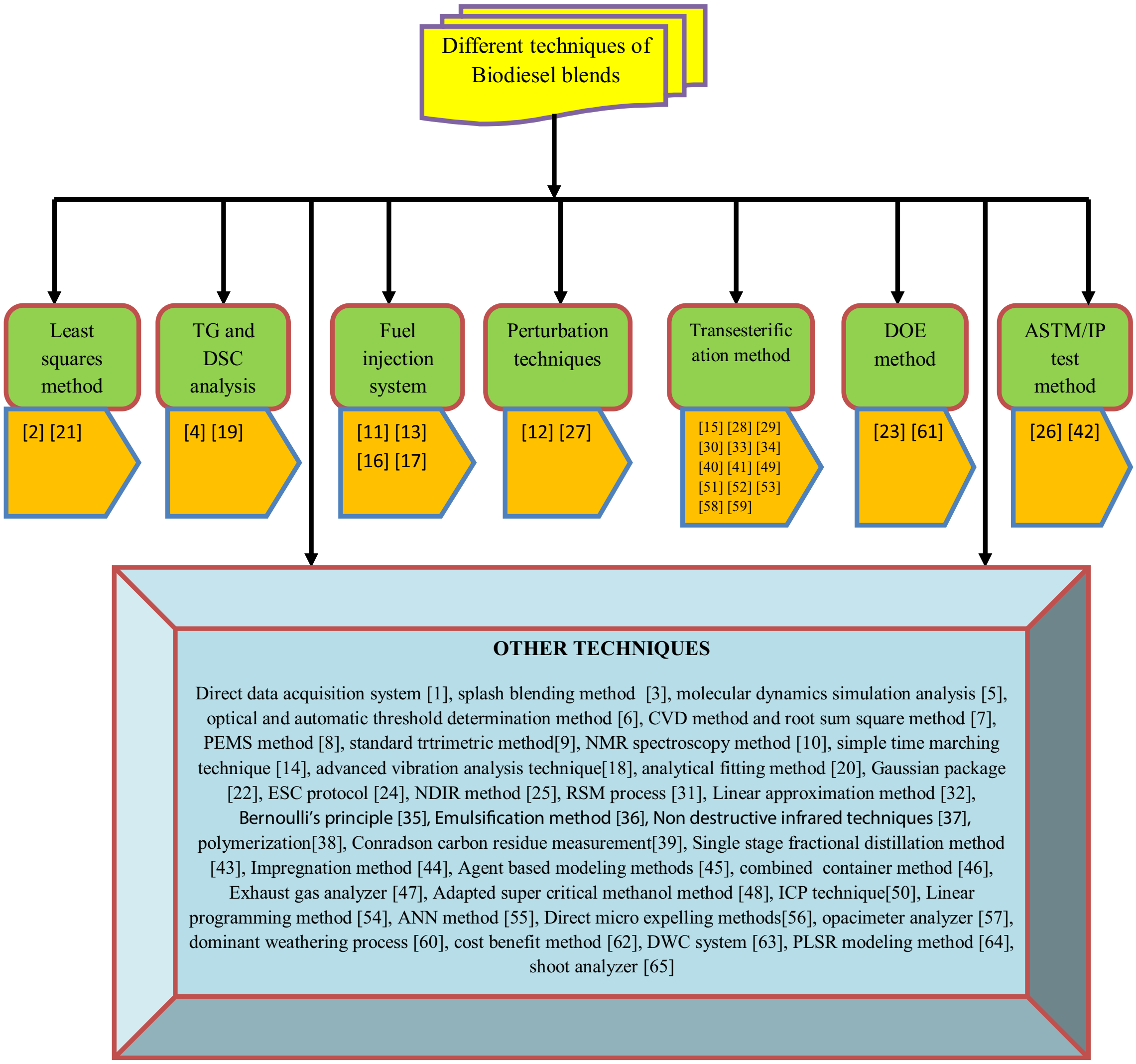

Fig. 1 Pictorial representation of biodiesel blending techniques

Evaluation of biodiesel blends and chronological review

Review on biodiesel blends

The reviewed works are processed using various biodiesel blends. The pictorial representation of the different biodiesel blends in the reviewed works is given in Fig. 2. Accordingly, the biodiesel blends mixed with ethanol were used in Bora and Saha (2016a, 2016b); Gnanamoorthi and Devaradjane (2014); Natarajan et al. (2017a); Natarajan et al. (2017b); Beatrice et al. (2014); Jamrozik (2017); Aydin and Ilkılıç (2010); Fang et al. (2013) and Park et al. (2012) respectively. In which the main aim of Bora and Saha (2016a, 2016b) was to eradicate the negative impact of the dual fuel combustion on the environment and engine using the pilot CR and fuel IT of a biogas run dual fuel diesel engine. Moreover, Gnanamoorthi and Devaradjane (2014) contributed on finding the optimum replacement and maximum possible of diesel fuel by ethanol. In Natarajan et al. (2017a) and Natarajan et al. (2017b), the emission, as well as combustion and characteristics of the diesel and bioethanol, were compared and studied. Beatrice et al. (2014) have analyzed numerous papers on the co-combustion of blends of diesel with methanol and ethanol. In addition, Jamrozik (2017) exploited a solution to the real use of the bio-EtOH blend in diesel engine. Aydin and Ilkılıç (2010) proposed influence of ethanol blending into biodiesel on engine performance and exhaust pollution in CI engines. Fang et al. (2013) have focused on improving the fuel characteristics of biodiesel utilizing a fuel extender to use pure biodiesel in diesel engines. Furthermore, Park et al. (2012) have studied the impact of biodiesel fuel on the exhaust emissions and engine performance characteristics.

The biodiesel blends with palm oil were adopted in Maawa et al. (2020); Ng and Yung (2019); El-Araby et al. (2017); Nagaraja et al. (2015); Demirbas (2011) and Mejía et al. (2013). Maawa et al. (2020) have examined the exhaust emissions, combustion characteristics, and effect of water

Table 1 Review on various biodiesel blend, cylinder, and engine characteristic schemes

Review categories		Citation
Biodiesel blend	Ethanol blend	Bora and Saha (2016a, 2016b); Gnanamoorthi and Devaradjane (2014); Natarajan et al. (2017a); Natarajan et al. (2017b); Beatrice et al. (2014); Jamrozik (2017); Aydin and Ilkılıç (2010); Fang et al. (2013); and Park et al. (2012)
	Palm oil	Maawa et al. (2020); Ng and Yung (2019); El-Araby et al. (2017); Nagaraja et al. (2015); Demirbas (2011); and Mejía et al. (2013)
	Diesel/biodiesel	Oliveira and Caires (2019); Najafi (2018); Anis and Budiandono (2019); Tinprabath et al. (2016); Sayin and Gumus (2011); Sharon et al. (2012); and Zhang et al. (2012)
	Tamanu oil	Ong et al. (2017); Selvabala et al. (2011); Fattah et al. (2014); Bapu et al. (2015); and Muthukumaran et al. (2015)
	Waste cooking oil	Lin and Huang (2012); Shen et al. (2018); Prabu et al. (2017); Bencheikh et al. (2019)
	Vegetable oil	Balat and Balat (2010); Singh et al. (2010)
	Algae oil	Mostafa and El-Gendy (2017)
	Rapeseed and soya bean oil	Çelikten et al. (2010); Chen and Chen (2011); Qiu et al. (2011); Yang et al. (2013); and Leoneti et al. (2012)
	Jatropha oil	Sherbiny et al. (2010); Majhi et al. (2012)
	Plant oil blend	Hossain and Davies (2010); Kratzeisen and Müller (2010)
	Cottonseed oil	Rakopoulos (2013); Hossain and Bayindir (2010)
	Esterified jatropha	Jagtap et al. (2020); Rehman et al. (2011)
	Crude oils	Das et al. (2018); Shukla et al. (2011)
	Lubricating oil	Nabi et al. (2017)
	Linseed oil	Veinblat et al. (2018)
	Papaya seed oil	Devarajan et al. (2020)
	Pine and oil mallee	Garcia-Perez et al. (2010)
	Sugarcane trash pyrolysis oil	Wu et al. (2017)
	Rice ban oil	Bora and Saha (2016a, 2016b)
	Annona squamosa oil	Senthil et al. (2015)
	Punnai oil	Kumar et al. (2015)
	Rapeseed oil	Nita et al. (2011)
	Cardanol oil	Mallikappa et al. (2012)
	Crude oil	Atadashi et al. (2011)
	Bitter almond oil	Atapour and Kariminia (2011)
	Microalgae	Demirbas (2011)
	Rubber seed oil	Jose et al. (2011)
	Cardanol oil	Mallikappa et al. (2012)
	Crude oil	Atadashi et al. (2011)
	Coconut oil	Fahmi and Cremaschi (2012)
Cylinder characteristics	Single cylinder	Natarajan et al. (2017b); Jamrozik (2017); Aydin and Ilkılıç (2010); Park et al. (2012); Nagaraja et al. (2015); Sharon et al. (2012); Ong et al. (2017); Selvabala et al. (2011); Prabu et al. (2017); Bencheikh et al. (2019); Rakopoulos (2013); Jagtap et al. (2020); Devarajan et al. (2020); Bora and Saha (2016a, 2016b); Wu et al. (2017); Mallikappa et al. (2012)
	Four cylinder	Fattah et al. (2014); Beatrice et al. (2014); Fang et al. (2013); Maawa et al. (2020); Çelikten et al. (2010)
	6-cylinder	Nabi et al. (2017)
Engine characteristics	Water cooled, direct injection diesel engine	Gnanamoorthi and Devaradjane (2014)
	Air cooled, naturally aspired direct	Aydin and Ilkılıç (2010)

Table 1 (continued)

Review categories		Citation
	Natural aspirated direct injection diesel engine	Prabu et al. (2017)
	Direct injection, diesel engine	Jagtap et al. (2020); Maawa et al. (2020)
	Direct injection compression ignition	Hossain and Bayindir (2010); Mallikappa et al. (2012)
	4-cycle, direct injected, water-cooled Changchai R170 diesel engine	Wu et al. (2017)
	Water cooled, and naturally aspirated, indirect injection diesel engine	Fattah et al. (2014)
	CI engine	Najafi (2018); Anis and Budiandono (2019); Hossain and Davies (2010); Atadashi et al. (2011)
	Homogeneous charge compression ignition (HCCI) engine	Natarajan et al. (2017a)
	Variable compression ratio engine	Kumar et al. (2015)
	Compression ignition engine	Senthil et al. (2015)
	Internal combustion engine	Shukla et al. (2011)
	662cc CI engine	Natarajan et al. (2017b)
	VCR engine	Bapu et al. (2015)
	DI, NA, watercooled,3.5 kw VCR diesel engine	Bora and Saha (2016a, 2016b)
	In-line LD (light-duty) Injection diesel engine	Beatrice et al. (2014)
	Turbocharged and heavy-duty diesel engine	Fang et al. (2013)
	Aspirated, DI diesel engine	Nagaraja et al. (2015)
	Water cooled diesel engine	Rakopoulos (2013)
	Diesel engines	Mostafa and El-Gendy (2017)
	Turbocharged common rail diesel engine	Nabi et al. (2017)
	Internal combustion engine	Jose et al. (2011)
	n/a	Atapour and Kariminia (2011); Demirbas (2011); Garcia-Perez et al. (2010); Veinblat et al. (2018); Rehman et al. (2011); Das et al. (2018); Kratzeisen and Müller (2010); Sherbiny et al. (2010); Majhi et al. (2012); Leoneti et al. (2012); Chen and Chen (2011); Qiu et al. (2011); Yang et al. (2013); Lin and Huang (2012); Shen et al. (2018); Tinprabath et al. (2016); Zhang et al. (2012); Oliveira and Caires (2019); Ng and Yung (2019); El-Araby et al. (2017); Demirbas (2011); Mejía et al. (2013); Nita et al. (2011)

n/a, not available

emulsification on engine performance. Ng and Yung (2019) have illustrated the use of NMR spectroscopy in categorizing biodiesel derived from palm oil and its blends by using NMR spectroscopy. In addition, El-Araby et al. (2017) have developed mixing rules to compute the necessary assets of biodiesel, palm oil, and its blends with diesel fuel as the function of diesel content on the basis of investigational values of blended fuel assets. Also Nagaraja et al. (2015) have illustrated the effect of the compression ratio of preheated palm oil–diesel blended fuels on the emission performance and the emission characteristic of fuel. Besides, Demirbas (2011) has explored the utilization of algae for solving the global warming problem in a short period. Further, Mejía et al. (2013) have investigated the properties of binary mixtures POB-COB.

In addition, the diesel-biodiesel blending mixture was used in Oliveira and Caires (2019); Najafi (2018); Anis and Budiandono (2019); Tinprabath et al. (2016); Sayin and Gumus (2011); Sharon et al. (2012) and Zhang et al. (2012). Oliveira and Caires (2019) have examined the diesel-biodiesel interactions at the molecular level by utilizing MD simulations. Najafi (2018) have investigated the effect of Ag and CNTs nanoadditives in diesel blends and biodiesel in a diesel engine. Anis and Budiandono (2019) have contributed a novel insight about the injector condition and injection pump in delivering high viscosity fuel as the effect of preheating temperatures. Tinprabath et al. (2016) have studied the injection flow characteristics in cold conditions and at room temperature. Sayin and Gumus (2011) have illustrated the effects of IP, IT, CR as well as biodiesel-blended diesel fuel on the exhaust emissions and engine performance of the same DI diesel engine.

The mixture of biodiesel blending mixture with *Calophyllum inophyllum* was exploited in Ong et al. (2017); Selvabala et al.

Table 2 Maximum performance attained by the reviewed works

Review categories		Citation
Exhaust emission	NOx emission is 358.36 tons	Lin and Huang (2012)
	PM emission is 43.03 tons	Lin and Huang (2012)
	CO emission is 83.10 tons	Lin and Huang (2012)
	CH emission is 1.35	Demirbas (2011)
	SO emission is 474.44 tons	Lin and Huang (2012)
Engine performances	Stroke is 55 mm	Singh et al. (2010)
	Speed is 7500 rpm	Aydin and Ilkılıç (2010)
	Power is 162 kW	Nabi et al. (2017)
	Compression ratio is 21:1	Wu et al. (2017)
	Efficiency is 85%	Fahmi and Cremaschi (2012)
	Torque is 820 Nm	Nabi et al. (2017)
	Torque error is 0.5	Ong et al. (2017)
	Displacement is 4.75 L	Shen et al. (2018)
	Bore is 70 mm	Singh et al. (2010)
	Volume is 40%	Mejía et al. (2013)
	Weight is 95%	Jose et al. (2011)
	Accuracy is 0.012%	Nita et al. (2011)
	F-value is 12.12	Jose et al. (2011)
	p-value is 0.0001	Jose et al. (2011)
	Prediction error is 0.45%	Zhang et al. (2012)
	Viscosity is 4.6 mm^2/s	El-Araby et al. (2017)
Combustion parameters	Pressure is 300 bar	Çelikten et al. (2010)
	Density is 914 kg/m^3	Çelikten et al. (2010)
	Temperature is 800 °C	Leoneti et al. (2012)
	Molar ratio is 7.5:1	Sherbiny et al. (2010)
	Heat release rate is 28%	Najafi (2018)
	Ignition delay 8.98%	Najafi (2018)
	Mixing ratio is 6.51%	Bezergianni et al. (2011)
	Temperature is 800 °C	Leoneti et al. (2012)
	Molar ratio is 7.5:1	Sherbiny et al. (2010)
	Density is 914 kg/m^3	Çelikten et al. (2010)
	Temperature is 800 °C	Leoneti et al. (2012)
	Molar ratio is 7.5:1	Sherbiny et al. (2010)

(2011); Fattah et al. (2014) and Bapu et al. (2015). Ong et al. (2017) have investigated the feasibility of biodiesel production from microalgae Spirulinaplatensis. Selvabala et al. (2011) have focused on minimizing the computational cost of resolving the resulting disjunctive programming. Fattah et al. (2014) have demonstrated the use of TBHQ, BHT, BHA, as well as stabilized CIBD blends of emission and engine performance characteristics of an indirect injection diesel engine. Bapu et al. (2015) have focused on attaining better combustion with a modified piston bowl design by utilizing 20% of biodiesel.

The biodiesel blends such as rapeseed and soya bean oil were deployed in Çelikten et al. (2010); Chen and Chen (2011); Qiu et al. (2011) and Yang et al. (2013) respectively. Çelikten et al. (2010) investigated the emission variation and performance of the alternative fuels. Chen and Chen (2011) have estimated the energy cost of rapeseed on the basis of biodiesel in China and accounted life span of biodiesel production. Qiu et al. (2011) have investigated the influence of the ratio, catalyst concentration, co-solvent, temperature and methanol/oil on biodiesel yield from the mixed vegetable oils. Yang et al. (2013) have examined the effects of storage and aging circumstances on diverse types of biodiesel and biodiesel/diesel blends under ambient temperature and open-air conditions.

From the review, it is observed that the biodiesel blends with glycerol were used in Leoneti et al. (2012); Sherbiny et al. (2010); Kiss and Ignat (2012), and Leoneti et al. (2012) have presented alternatives at present considered for the utilization of raw glycerol as the result of biodiesel production, with the

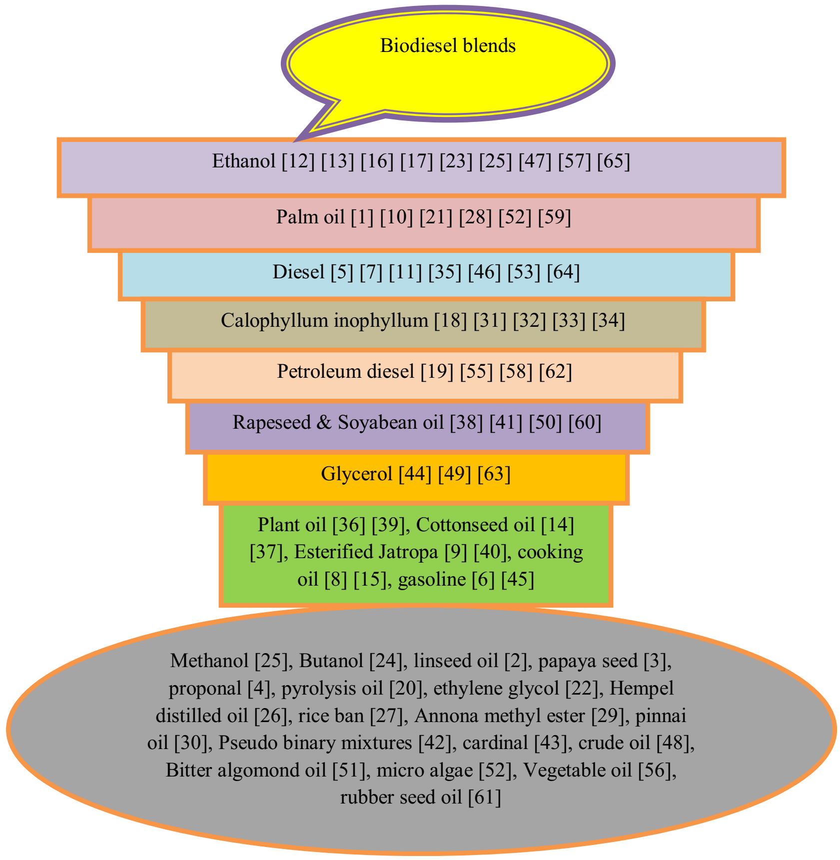

Fig. 2 Pictorial representation on adopted biodiesel blends in reviewed works

intension to contribute the reasonable consolidation of the biofuel market. Sherbiny et al. (2010) have demonstrated the radio frequency microwave energy application provides an easy, fast route to the biofuel with the benefit of improving the reaction rate as well as the separation process. Kiss and Ignat (2012) have presented a well-organized process intensification approach for separation of ternary, such as the utilization of a DWC which can able to divide all products at better purity, in single unit of equipment.

Plant oil blend was exploited in Hossain and Davies (2010) and Kratzeisen and Müller (2010), cottonseed oil in Rakopoulos (2013); Hossain and Bayindir (2010); esterified jatropha in Jagtap et al. (2020) and Rehman et al. (2011); cooking oil in Shen et al. (2018) and Prabu et al. (2017); and gasoline in Das et al. (2018) and Shukla et al. (2011) correspondingly. Hossain and Davies (2010) have assessed the aggregated environmental inference of plant oils as fuels in CI engines. Kratzeisen and Müller (2010) have investigated the predominance of phosphorus lipids of plant oil on formation of deposits and the performance of the plant oil pressure stove. Rakopoulos (2013) has compared and evaluated the exhaust emissions as well as combustion characteristics of its methyl ester biodiesel in blends and cottonseed oil.

The biodiesel blending mixture with methanol was deployed in Jamrozik (2017), butanol in Nabi et al. (2017), linseed oil in Veinblat et al. (2018), papaya seed in Devarajan et al. (2020), proposal in Bencheikh et al. (2019), pyrolysis oil in Garcia-Perez et al. (2010), ethylene glycol in Wu et al. (2017), hempel distilled oil in Majhi et al. (2012), rice ban in Bora and Saha (2016a, 2016b), annona methyl ester in Senthil et al. (2015), punnai oil in Kumar et al. (2015), pseudo-binary mixtures in Nita et al. (2011), cardinal in Mallikappa et al. (2012), crude oil in Atadashi et al. (2011), bitter almond oil in Atapour and Kariminia (2011), microalgae in Demirbas (2011), vegetable oil in Singh et al. (2010) and rubber seed oil in Jose et al. (2011) respectively. Jamrozik (2017) has analyzed several papers of the co-combustion of blends of diesel by ethanol as well as methanol. Nabi et al. (2017) examined the access of *n*-butanol addition to diesel fuel of exhaust emissions as well as engine performance in a 13-Mode European Stationary Cycle. Veinblat et al. (2018) have reported the effects of biodiesel pretended from linseed oil on ICE performance with an intention on particle emissions are compared and discussed to the soybean oil-derived biodiesel fuels and commercial diesel.

Chronological review

The survey analyzed from various papers was developed in different years. Fig. 3 indicates the number of contributions for corresponding years in bar chart format. Initially, 46.15% of papers are reviewed from the years 2010 to 2012. Similarly, 18.46% of the total reviewed papers were taken during 2013 to

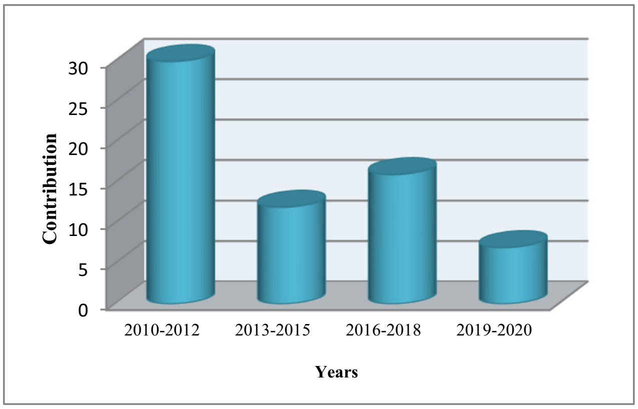

Fig. 3 Bar chart representing chronological review

the 2015 year. Furthermore, 24.61% of contributions on biodiesel blends are reviewed from the year 2016 to 2018. The number of papers reviewed based on the biodiesel blends in the years 2019–2020 is 10.76% of the whole contribution. The contribution of biodiesel blends from 2010 to 2020 is illustrated in Table 3. From the table, we can observe that palm oil and diesel/biodiesel blends focused more in recent years from 2019 to 2020, which is 3.077%, but the esterified jatropha and papaya seed oil contributed only about 1.538% in 2019–2020. Moreover, on observing the table, it can be noticed that in the entire years lab from 2010 to 2020, palm oil has been utilized, while ethanol, diesel/biodiesel, and Tamanu oil are utilized in 3-year slab. Similarly, the waste cooking oil, cottonseed oil, rapeseed and soya bean oil, and crude oil have been used in two slabs and all other blends were used in one slab. When considering the year from 2019 to 2020, palm oil and esterified jatropha are cheap and papaya seed oil is costly. The Algae oil produces less NOx emission (Demirbas 2011), while comparing with the other oils, and the Aydin and Ilkılıç (2010) achieves the high performance in speed of about 7500 rpm.

Research gaps and challenges

Biodiesel is a form of diesel fuel produced from oils like soybean, recycled cooking oils, or animal fats. These fats

Table 3 Contribution of biodiesel blends from 2010 to 2020

Biodiesel blends	2010–2012	2013–2015	2016–2018	2019–2020
Ethanol	3.077	4.615	6.15	-
Palm oil	1.538	3.077	1.538	3.077
Diesel/biodiesel	4.61	-	3.077	3.077
Tamanu oil	1.538	4.615	1.538	-
Waste cooking oil	1.538	-	3.077	-
Vegetable oil	3.077	-	-	-
Algae oil	-	-	1.538	-
Rapeseed and soya bean oil	4.615	3.077	-	-
Jatropha oil	3.077	-	-	-
Plant oil blend	3.077	-	-	-
Cottonseed oil	1.538	1.538	-	-
Esterified jatropha	-	-	-	1.538
Crude oils	1.538	-	1.538	-
Lubricating oil	-	-	1.538	-
Linseed oil	-	-	1.538	-
Papaya seed oil	-	-	-	1.538
Pine and oil mallee	1.538	-	-	-
Sugarcane trash pyrolysis oil	-	-	1.538	-
Rice ban oil	-	-	1.538	-
Annona squamosa oil	-	3.077	-	-
Punnai oil	-	1.538	-	-
Rapeseed oil	1.538	-	-	-
Cardanol oil	1.538	-	-	-
Crude oil	1.538	-	-	-
Bitter almond oil	1.538	-	-	-
Microalgae	1.538	-	-	-
Rubber seed	1.538	-	-	-
Coconut oil	1.538	-	-	-

and oils chemically react to the processing of biodiesel by the source of both a short chain of alcohol (such as methanol) and biodiesel catalyst and a co-product of glycerine (Sezer 2011). Biodiesel could be used on its own (B100) or in any proportion paired with petroleum fuel. However, ultra-low sulfur diesel fuels can have weak lubrication properties. Low rates of biodiesel used as a lubricant additive will help to enhance fuel efficiency and to decrease CO2 emissions from commercial vehicles and cars by diminishing friction (Leung et al. 2010). Advancements in many bio-based or renewable energy developments have broadened the reach of what is considered as a feasible response to global energy problems (Kim and Choi 2010). Biobutanol has often been shown to be more harmful to humans and animals in the short term when compared to ethanol or diesel. Moreover, it is not known if butanol could kill the components currently used in vehicles that come into contact with motor fuels.

Biodiesel often contains a greater level of cetane than other fossil fuels. Cetane tests the ability of diesel to auto-ignite in the vehicle and is equivalent to that of gasoline. Higher cetane energy sources have shorter ignition delays than lower cetane fuels. Nevertheless, fuels with such cetane numbers less than the minimum requirements of the engine may cause rough engine operation and can be more difficult to start, particularly in cold weather or at high altitudes (Lin et al. 2011). Low cetane fuels can raise engine deposits resulting in increased exhaust emissions, increased engine wear, and more smoke. Inadequate fuel tank cleaning with fuel mixing, biodiesel blends B20 were used in any diesel engine using those with sophisticated fuel injection systems, without compromising efficiency or durability. However, user feedback has shown that maintenance specifications for diesel engines running on or below B20 biodiesel blends are the same as those operating on normal diesel engines (Jegannathan and Nielsen 2013). Considering these drawbacks on biodiesel blends, further research is required for deploying it in broader areas in an effective way.

Conclusion

This paper has offered a complete review of biodiesel blends. Here, various methodologies adopted in the reviewed works were analyzed and described. Furthermore, this survey analyzes the performance measures associated with the reviewed biodiesel blends. Finally, this paper described about the reviews in 65 papers and declared the significant analysis of various algorithms. The analysis has reviewed the performance measures and the corresponding maximum achievements were contributed by different biodiesel blending techniques. Further, the various blended materials exploited in each reviewed works were also examined and specified diagrammatically. Moreover, the chronological reviews were also done for the analyzed 65 works. Finally, this paper presented a variety of research problems that may be helpful for researchers to carry out further work on the biodiesel blending schemes.

Nomenclature Ag, Silver; ANN, Artificial neural network; ASTM, American Society for Testing and Materials; BAO, Bitter almond oil; BP, Brake power; BSEC, Brake-specific fuel consumption; BSFC, Brake-specific energy consumption; BTHE, Brake thermal efficiency; CCD, Central composite design; CCO, Crude coconut oil; CE, Conventional engine; CI, Compression ignition; CIBD, *Calophyllum inophyllum biodiesel*; CNT, Carbon nanotubes; CO, Carbon monoxide; CR, Compression ratio; CSOME, Cottonseed oil methyl ester; DCCI, Homogeneous charge compression ignition; DEE, Diethyl ether; DFM, Dual fuel mode; DI, Direct injections; DOE, Design of experiments; DSC, Differential scanning calorimetry; DTBP, Di-tetra-butyl-peroxide; DWC, Dividing-wall column; ECU, Engine control unit; EDS, Energy-dispersive spectroscopy; EGR, Exhaust gas recirculation; EGT, Exhaust gas temperature; EJO, Esterified jatropha biodiesel; FAME, Fatty acid methyl esters; FT-IR, Fourier transform infrared; HC, Hydrocarbon; HCC, Hemispherical combustion chamber; HSDI, High-speed direct injection; HCCI, Homogeneous charge compression ignition; ICP, Inductively coupled plasma; IP, Injection pressure; IT, Injection timing; KOH, Potassium hydroxide; LHRE, Low heat rejection engine; LTC, Low temperature combustion; MHCC, Modified hemispherical combustion chamber; MIR, Mid-infrared spectroscopy; NA, Natural aspirated; NaOH, Sodium hydroxide; NIR, Near-infrared spectroscopy; NMR, Nuclear magnetic resonance; NOx, Nitrogen oxides; PCCI, Premixed charge combustion ignition; PEMS, Portable emission measurement system; PLSR, Partial least square regression; PM, Particulate matter; PN, Particle number; PSD, Particle size distribution; RME, Rapeseed methyl ester; RMS, Root mean square; RSM, Response surface methodology; SEM, Scanning electron microscopy; SFC, Specific fuel consumption; TEM, Transmission electron microscopy; TG, Thermogravimetric; UBHC, Unburned hydrocarbons; VCO, Virgin coconut oil; VCR, Variable compression ratio; XRD, X-ray diffraction

Availability of data and materials Not applicable.

Author contribution Rajkumar Kamaraj conceived the presented idea and designed the analysis. Also, he carried out the experiment and wrote the manuscript with support from Yarra Pragada and Bala Krishna. All authors discussed the results and contributed to the final manuscript. All authors read and approved the final manuscript.

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Availability of data and materials Not applicable.

Declarations

Ethical approval This paper does not contain any studies with human participants or animals performed by any of the authors.

Consent to participate Not applicable.

Consent for publication Not applicable.

Conflict of interest The authors declare that they have no conflict of interest.

References

Anis S, Budiandono GN (2019) Investigation of the effects of preheating temperature of biodiesel-diesel fuel blends on spray characteristics and injection pump performances. Renew Energy 140:274–280

Atadashi IM, Aroua MK, Aziz ARA, Sulaiman NMN (2011) Refining technologies for the purification of crude biodiesel. Appl Energy 88:4239–4251

Atapour M, Kariminia H-R (2011) Characterization and transesterification of Iranian bitter almond oil for biodiesel production. Appl Energy 88:2377–2381

Aydin H, Ilkılıç C (2010) Effect of ethanol blending with biodiesel on engine performance and exhaust emissions in a CI engine. Appl Therm Eng 30:1199–1204

Balat M, Balat H (2010) Progress in biodiesel processing. Appl Energy 87:1815–1835

Bapu BRR, Saravanakumar L, Prasad BD (2015) Effects of combustion chamber geometry on combustion characteristics of a DI diesel engine fueled with calophyllum inophyllum methyl ester. J Energy Inst

Beatrice C, Napolitano P, Guido C (2014) Injection parameter optimization by DoE of a light-duty diesel engine fed by bio-ethanol/RME/diesel blend. Appl Energy 113:373–384

Bencheikh K, Atabani AE, Shobana S, Mohammed MN, Bokhari A (2019) Fuels properties, characterizations and engine and emission performance analyses of ternary waste cooking oil biodiesel–diesel–propanol blends. Sustain Energy Technol Assess 35:321–334

Bezergianni S, Kalogeras K, Pilavachi PA (2011) On maximizing biodiesel mixing ratio based on final product specifications. Comput Chem Eng 35:936–942

Bora BJ, Saha UK (2016a) Optimisation of injection timing and compression ratio of a raw biogas powered dual fuel diesel engine. Appl Therm Eng 92:111–121

Bora BJ, Saha UK (2016b) Experimental evaluation of a rice bran biodiesel–biogas run dual fuel diesel engine at varying compression ratios. Renew Energy 87(1):782–790

Çelikten I, Koca A, Arslan MA (2010) Comparison of performance and emissions of diesel fuel, rapeseed and soybean oil methyl esters injected at different pressures. Renew Energy 35:814–820

Chen H, Chen GQ (2011) Energy cost of rapeseed-based biodiesel as alternative energy in China. Renew Energy 36:1374–1378

Das SK, Kim K, Lim O (2018) Experimental study on non-vaporizing spray characteristics of biodiesel-blended gasoline fuel in a constant volume chamber. Fuel Process Technol 178:322–335

Demirbas A (2011) Biodiesel from oilgae, biofixation of carbon dioxide by microalgae: a solution to pollution problems. Appl Energy 88:3541–3547

Devarajan Y, Beemkumar N, Ganesan S, Arunkumar T (2020) An experimental study on the influence of an oxygenated additive in diesel engine fuelled with neat papaya seed biodiesel/diesel blends. Fuel 268:117254

El-Araby R, Amin A, Morsi AKE, El-Ibiari NN, El-Diwani GI (2017) Study on the characteristics of palm oil–biodiesel–diesel fuel blend. Egypt J Pet

Fahmi I, Cremaschi S (2012) Process synthesis of biodiesel production plant using artificial neural networks as the surrogate models. Comput Chem Eng 46:105–123

Fang Q, Fang J, Zhuang J, Huang Z (2013) Effects of ethanol–diesel–biodiesel blends on combustion and emissions in premixed low temperature combustion. Appl Therm Eng 54(230):541–548

Fattah IMR, Masjuki HH, Kalam MA, Wakil MA, Ashraful AM, Shahir SA (2014) Experimental investigation of performance and regulated emissions of a diesel engine with Calophyllum inophyllum biodiesel blends accompanied by oxidation inhibitors. Energy Conserv Manag 83:232–240

Garcia-Perez M, Shen J, Wang XS, Li C-Z (2010) Production and fuel properties of fast pyrolysis oil/bio-diesel blends. Fuel Process Technol 91(3):296–305

Gnanamoorthi V, Devaradjane G (2014) Effect of compression ratio on the performance, combustion and emission of DI diesel engine fueled with ethanol–diesel blend. J Energy Inst 1–8

Hossain AK, Bayindir H (2010) Performance and emission analysis of cottonseed oil methyl ester in a diesel engine. Renew Energy 35:588–592

Hossain AK, Davies PA (2010) Plant oils as fuels for compression ignition engines: a technical review and life-cycle analysis. Renew Energy 35:1–13

Jagtap SP, Pawar AN, Lahane S (2020) Improving the usability of biodiesel blend in low heat rejection diesel engine through combustion, performance and emission analysis. Renew Energy 155:628–644

Jamrozik A (2017) The effect of the alcohol content in the fuel mixture on the performance and emissions of a direct injection diesel engine fueled with diesel-methanol and diesel-ethanol blends. Energy Convers Manag 148:461–476

Jegannathan KR, Nielsen PH (2013) Environmental assessment of enzyme use in industrial production a literature review. J Clean Prod 42:228–240

Jose DFM, Raj RE, Prasad BD, Kennedy ZR, Ibrahim AM (2011) A multi-variant approach to optimize process parameters for biodiesel extraction from rubber seed oil. Appl Energy 88:2056–2063

Kim H, Choi B (2010) The effect of biodiesel and bioethanol blended diesel fuel on nanoparticles and exhaust emissions from CRDI diesel engine. Renew Energy 35:157–163

Kiss AA, Ignat RM (2012) Enhanced methanol recovery and glycerol separation in biodiesel production–DWC makes it happen. Appl Energy 99:146–153

Kratzeisen M, Müller J (2010) Influence of phosphorus content of coconut oil on deposit and performance of plant oil pressure stoves. Renew Energy 35:2585–2589

Kumar TA, Chandramouli R, Mohanraj T (2015) A study on the performance and emission characteristics of esterified punnai oil tested in VCR engine. Ecotoxicol Environ Saf 121:51–56

Leoneti AB, Aragão-Leoneti V, Oliveira SVWB (2012) Glycerol as a by-product of biodiesel production in Brazil: alternatives for the use of unrefined glycerol. Renew Energy 45:138–145

Leung DYC, Wu X, Leung MKH (2010) A review on biodiesel production using catalyzed transesterification. Appl Energy 87:1083–1095

Lin C-Y, Huang T-H (2012) Cost–benefit evaluation of using biodiesel as an alternative fuel for fishing boats in Taiwan. Mar Policy 36:103–107

Lin L, Cunshan Z, Vittayapadung S, Xiangqian S, Mingdong D (2011) Opportunities and challenges for biodiesel fuel. Appl Energy 88:1020–1031

Maawa WN, Mamat R, Najafi G, Goey LPHD (2020) Performance, combustion, and emission characteristics of a CI engine fueled with emulsified diesel-biodiesel blends at different water contents. Fuel 267:117265

Majhi A, Sharma YK, Naik DV (2012) Blending optimization of Hempel distilled bio-oil with commercial diesel. Fuel 96:264–269

Mallikappa DN, Reddy RP, Murthy CSN (2012) Performance and emission characteristics of double cylinder CI engine operated with cardanol bio fuel blends. Renew Energy 38:150–154

Mejía JD, Salgado N, Orrego CE (2013) Effect of blends of diesel and palm-castor biodiesels on viscosity, cloud point and flash point. Ind Crop Prod 43:791–797

Mostafa SSM, El-Gendy NS (2017) Evaluation of fuel properties for microalgae Spirulina platensis bio-diesel and its blends with Egyptian petro-diesel. Arab J Chem 10:s2040–s2050

Muthukumaran N, Saravanan CG, Yadav SPR, Vallinayagam R, Vedharaj S, Roberts WL (2015) Synthesis of cracked

Calophyllum inophyllum oil using fly ash catalyst for diesel engine application. Fuel 155:68–76

Nabi MN, Zare A, Hossain FM, Bodisco TA, Brown RJ (2017) A parametric study on engine performance and emissions with neat diesel and diesel-butanol blends in the 13-Mode European Stationary Cycle. Energy Convers Manag 148:251–259

Nagaraja S, Sooryaprakash K, Sudhakaran R (2015) Investigate the effect of compression ratio over the performance and emission characteristics of variablecompression ratio engine fueled with preheated palm oil-diesel blends. Procedia Earth Planet Sci 11:393–401

Najafi G (2018) Diesel engine combustion characteristics using nanoparticles in biodiesel-diesel blends. Fuel 212:668–678

Natarajan S, Kumar MA, Sundareswaran AUM (2017a) Computational analysis of an early direct injected HCCI engine using bio ethanol and diesel blends as fuel. Energy Procedia 105:350–357

Natarajan S, Shankar SA, Sundareswaran AUM (2017b) Early injected PCCI engine fuelled with bio ethanol and diesel blends—an experimental investigation. Energy Procedia 105:358–366

Ng MH, Yung CL (2019) Nuclear magnetic resonance spectroscopic characterisation of palm biodiesel and its blends. Fuel 257:116008

Nita I, Geacai S, Iulian O (2011) Measurements and correlations of physico-chemical properties to composition of pseudo-binary mixtures with biodiesel. Renew Energy 36:3417–3423

Oliveira IP, Caires ARL (2019) Molecular arrangement in diesel/biodiesel blends: a molecular dynamics simulation analysis. Renew Energy 140:203–211

Ong ZC, Mishani MBM, Chong WT, Soon RS, Ismail Z (2017) Identification of optimum Calophyllum inophyllum bio-fuel blend in diesel engine using advanced vibration analysis technique. Renew Energy 109:295–304

Park SH, Cha J, Lee CS (2012) Impact of biodiesel in bioethanol blended diesel on the engine performance and emissions characteristics in compression ignition engine. Appl Energy 99:334–343

Prabu SS, Asokan MA, Roy R, Francis S, Sreelekh MK (2017) Performance, combustion and emission characteristics of diesel engine fuelled with waste cooking oil bio-diesel/diesel blends with additives. Energy 122:638–648

Qiu F, Li Y, Yang D, Li X, Sun P (2011) Biodiesel production from mixed soybean oil and rapeseed oil. Appl Energy 88:2050–2055

Rakopoulos DC (2013) Combustion and emissions of cottonseed oil and its bio-diesel in blends with either n-butanol or diethyl ether in HSDI diesel engine. Fuel 105:603–613

Rehman A, Phalke DR, Pandey R (2011) Alternative fuel for gas turbine: esterified jatropha oilediesel blend. Renew Energy 36:2635–2640

Sayin C, Gumus M (2011) Impact of compression ratio and injection parameters on the performance and emissions of a DI diesel engine fueled with biodiesel-blended diesel fuel. Appl Therm Eng 31: 3182–3188

Selvabala VS, Selvaraj DK, Kalimuthu J, Periyaraman PM, Subramanian S (2011) Two-step biodiesel production from Calophyllum inophyllum oil: optimization of modified β-zeolite catalyzed pretreatment. Bioresour Technol 102(2):1066–1072

Senthil R, Silambarasan R, Ravichandiran N (2015) Influence of injection timing and compression ratio on performance, emission and combustion characteristics of annona methyl ester operated diesel engine. Alexandria Eng J 54(3):295–302

Sezer I (2011) Thermodynamic, performance and emission investigation of a diesel engine running on dimethyl ether and diethyl ether. Int J Therm Sci 50:1594–1603

Sharon H, Karuppasamy K, Kumar DRS, Sundaresan A (2012) A test on DI diesel engine fueled with methyl esters of used palm oil. Renew Energy 47:160–166

Shen X, Shi J, Cao X, Zhang X, Yao Z (2018) Real-world exhaust emissions and fuel consumption for diesel vehicles fueled by waste cooking oil biodiesel blends. Atmos Environ 191:249–257

Sherbiny SAE, Refaat AA, El Sheltawy ST (2010) Production of biodiesel using the microwave technique. J Adv Res 1:309–314

Shukla A, Pekny J, Venkatasubramanian V (2011) An optimization framework for cost effective design of refueling station infrastructure for alternative fuel vehicles. Comput Chem Eng 35:1431–1438

Singh PJ, Khurma J, Singh A (2010) Preparation, characterisation, engine performance and emission characteristics of coconut oil based hybrid fuels. Renew Energy 35:2065–2070

Tinprabath P, Hespel C, Chanchaona S, Foucher F (2016) Impact of cold conditions on diesel injection processes of biodiesel blends. Renew Energy 96(Part A):270–280

Veinblat M, Baibikov V, Katoshevski D, Wiesman Z, Tartakovsky L (2018) Impact of various blends of linseed oil-derived biodiesel on combustion and particle emissions of a compression ignition engine—a comparison with diesel and soybean fuels. Energy Convers Manag 178:178–189

Wu S, Yang H, Hu J, Shen D, Xiao R (2017) The miscibility of hydrogenated bio-oil with diesel and its applicability test in diesel engine: a surrogate (ethylene glycol) study. Fuel Process Technol 161:162–168

Yang Z, Hollebone BP, Wang Z, Yang C, Landriault M (2013) Effect of storage period on the dominant weathering processes of biodiesel and its blends with diesel in ambient conditions. Fuel 104:342–350

Zhang W, Yuan W, Zhang X, Coronado M (2012) Predicting the dynamic and kinematic viscosities of biodiesel–diesel blends using mid- and near-infrared spectroscopy. Appl Energy 98: 122–127