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A REVIEW OF THE EFFECTS OF BIODIESEL AND ETHANOL ON PERFORMANCE AND EMISSION CHARACTERISTICS OF DIESEL ENGINES

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Abstract
The engine emissions caused by burning fossil fuels are one of the concerns across the world. Recently, biodiesel and ethanol are well recognized as appropriate alternative fuels for diesel engines. In many countries, bioethanol and biodiesel have attracted great attention as alternative fuels in application and research because of their renewability and environmentally friendly properties and reduction of fossil resources. Here the benefits and limitations of biofuels as alternative fuels in diesel engines were reviewed. The effects of various mixtures of diesel fuel and biofuels like biodiesel-diesel, ethanol-diesel, and biodiesel-ethanol-diesel blends on diesel engines were discussed. Blending biodiesel and ethanol in diesel fuel and using it as the blended fuel in the diesel engine has a considerable potential to reduce exhaust emissions and subsequently environmental pollution. However, an extra ratio of ethanol and/or biodiesel in the blended fuel can cause some drawbacks in the diesel engine, which turns out the necessity of optimization to introduce the optimally blended fuels in terms of all aspects of operational and environmental issues. Wherefore, simultaneously optimization of the operational factors and the exhaust emissions of the diesel engine fuel by the blended fuels consisting of biofuels and other additives was recommended in future studies.

Keywords: Performance; Emission; Biodiesel; Ethanol; Optimization.

1. INTRODUCTION

The use of fossil fuels by millions of vehicles across the world causes to emit exhaust gases including CO2, CO, NOX, SOX, and PM. These gases cause to amplify environmental pollution and global warming. The emitted greenhouse gases by fossil fuels are among the main contributors causing severely changing climate, while drought is considered as a serious disaster for all organisms as the main consequence of climate change. Nowadays, the caused drought by global warming plays a main role in destroying the living environment, as it is recognized as an important factor in collapsing some societies and causing massive protests. On the other side, some concerns such as dependency on fossil fuels and instability of this kind of energy source have persuaded policymakers and researchers in finding and introducing alternative energy resources to overcome the caused disasters by fossil fuels. The goal of the researchers in this field is to improve engine performance characteristics and reduce exhaust emissions as shown in Fig. 1. In this figure, the upward and downward arrows show the increasing and decreasing trends of engine characteristics, respectively.

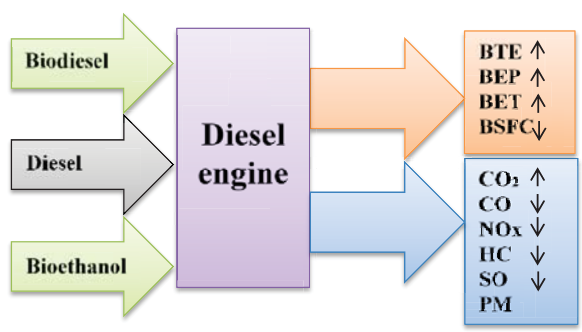

Fig. 1. The input-output diagram of diesel engines. The increasing and decreasing trends of the characteristics were shown by upward and downward arrows, respectively.

The effect of engine emissions on the environment depends on engine construction technology and the used fuels (Shi et al., 2008). As adapting the engine construction for a newly introduced fuel is extremely expensive, matching the alternative fuel to the engine construction is much more cost-effective and crucial to achieving the fundamental goals like improving the engine performance and reducing the emissions (Subbaiah et al., 2010). The main factors for choosing an alternative fuel include exhaust emissions, fuel stability, application and fuel distribution ability and its effect on engine life (Pinto et al., 2005; De Menezes et al., 2006). Accordingly, mixtures of biodiesel, ethanol and diesel fuel attracted great attention as an alternative fuel for the diesel engine. Biodiesel and ethanol are considered as clean alternative fuels with the capability to reduce environmental pollution and dependency on fossil fuels. Ethanol and biodiesel blends are well recognized as appropriate alternative fuels for diesel engines. The oxygen atoms in the molecular structures of biodiesel and ethanol improve the quality of the combustion in the engine chamber, reducing exhaust pollutions. Besides, dienestrol is considered as zero net CO_2 exchange, which points out to the fact that CO_2 produced in the combustion of biofuels is in equilibrium with CO_2 absorbed through photosynthesis by the plants that can be converted to biofuels (Pereira et al., 1999; Ramadhas et al., 2005; Lapuerta et al., 2007; Agarwal, 2007; Demirbas, 2007; Pang et al., 2008).

Biodiesel has attracted much attention as one of the alternative fuels in recent years in terms of the technical, environmental, accessibility, economic and competitive aspects. Currently, the blend containing 20% biodiesel and 80% diesel fuel is used in many countries. United States, Brazil, Indonesia, Malaysia, France, Germany, Italy and other European nations use the same blends practically in diesel engines (Sharma and Singh, 2009). Fueling the engine by ethanol was started in 1826 and 1876 by Samuel Murrey and Nicholas Otto when vehicle engine was invented (Demirbas et al., 2009). Ethanol was solely applied for starting the car when Henry Ford constructed the first car in 1896. After that a car was constructed in 1908 (model: T Ford), which had ability to be fueled by ethanol, gasoline or ethanol-gasoline blends (Solomon et al., 2007). United States and European Union expanded using ethanol in 1900. The demand for ethanol was declined after World War I because the production process of ethanol was much more expensive than fossil fuels. Ethanol acquired a special popularity in General Motors and Dupont companies due to its anti-caking effect (high octane) and the possibility of replacing with fossil-based fuels (Solomon et al., 2007 Balat and Balat, 2009; Demirbas et al., 2009). Nowadays, the ethanol production is simple and is applied with blending of fossil diesel to be used in diesel engines because of lower cost and high content of oxygen (34.8%) (Lapuerta et al., 2007). The diestrol is vastly used for fueling diesel engines in researches to study the effects of diestrol and its sources, components, and usage conditions on the engines. Some findings by the researchers were in contrary with each other. High importance of biodiesel and ethanol and those effects on engine performance and emissions on one hand and the opposite results due to different variables on the other hand emphasis a comprehensive review in this regard. Hens the goal of the research is to review the usage of biodiesel and ethanol in diesel engine at different engine conditions. The benefits and limitations of diesel engines fueled by diestrol were investigated. As biodiesel and alcohol shares must be properly adjusted in blending with diesel, the optimization process to find optimum percentage of the biofuels was reviewed.

2. CURRENT STATUS: GEO-THERMAL ENERGY FOR BANGLADESH

This section contains three subsections to describe biodiesel, then review the effects of biodiesel in diesel blends on the performance and emission characteristics of the diesel engine.

2.1. Biodiesel fuel

One of the interesting features of biodiesel is their sources, as waste oils, vegetable oils and animal fats (Ribeiro et al., 2007; Shi et al., 2008). Biodiesel has some properties similar to those of fossil diesel. Biodegradability and lubricity are among advantageous properties of biodiesel as an alternative fuel to be used in combustion engines. Demirbas (2008) reported that methyl esters have high lubricity causing an increment in the lubrication properties of the blended fuels containing biodiesel. For this, biodiesel reduces the engine wear. Lubrication property of biodiesel is about 66% better than that of fossil diesel. However, improvement of oxidation stability of biodiesel is important to prevent the deteriorating when stored over long time. To be used as an alternative fuel in diesel engines, pure biodiesel or biodiesel blends need to be tested in terms of its physicochemical properties according to the biodiesel international standard specifications (ASTM 6571, 3-EN 14214). Some physicochemical properties of biodiesel required to be tested comprise heating value, cetane number, viscosity, density, distillation range, pour points, cloud points, flash point, free glycerin content, total glycerin content, copper corrosion, sulfur content, ash content, carbon residue, and acid value. The similarity of the physicochemical properties of biodiesel and diesel fuel has made biodiesel more attractive to researchers, industry leaders and policymakers

(Sharma and Singh, 2009). Dube et al. (2007) reported that biodiesel is an ideal fuel even in sensitive environments, such as forests, marines and national parks because it has low emission profile compare with fossil diesel. Biodiesel as oxygenated matter for fueling diesel engines is obtained from different sources from vegetables' oils to animal fats. The main sources of those are cotton, soya, rapeseed and palm oil (Fig. 2) (Ejaz and Younis, 2008; Boey et al., 2009). Molecular compounds of vegetables' oils and animal fats mainly consist of triglycerides, which can be converted to biodiesel in a process called transesterification (Costa and Piazzullo, 2018; Khoobbakht et al., 2020a, b).

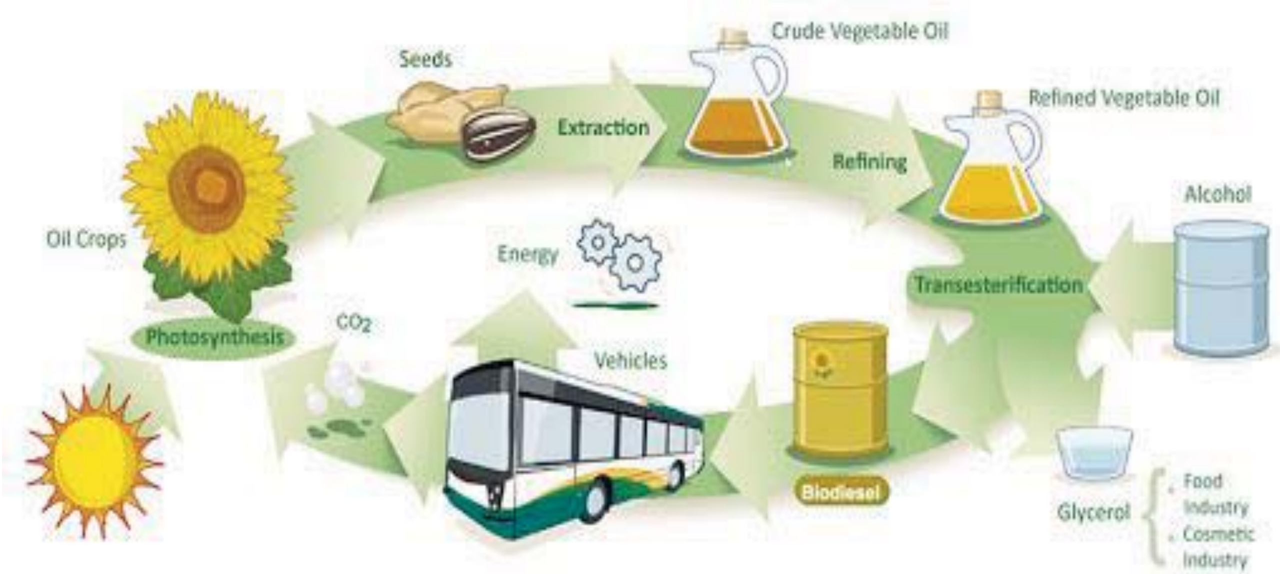

Fig. 2. Biodiesel production cycle (Anonymous, 2020).

Biodiesel is a clean fuel and doesn't contain carcinogenic matters. The sulfur content in biodiesel is low and so sulfur exhaust of diesel engines fueled by biodiesel or diesel-biodiesel blends decreases in comparison with that of diesel fuel. Despite the many benefits, there are limitations to using biodiesel. Biodiesel derived from vegetable oils or animal fats have high density and viscosity in comparison with diesel fuel, which is considered as the main drawback feature for fueling diesel engine by pure biodiesel. Also low biodiesel volatility is another limitation to using it as unblended fuel for diesel engine. The fatty acid methyl esters, biodiesel compounds, have low flash point value in comparison with vegetable oils but they still have higher flash point value comparing with fossil diesel causing to upgrade the safety in storing, handling and fueling in the engine (Demirbas, 2008). Also it has low engine power due to low calorific value and ignition temperature properties that leading to emit low NOx emissions (Kegl, 2008).

Many sources of biodiesel were successfully used in diesel engines such as rapeseed and safflower (Bettis et al., 1982), sunflower (Bettis et al., 1982; Kapilan et al., 2009), linseed (Agarwal and Das, 2001), tobacco seed (Usta, 2005), palm (Lin et al., 2006), soybean (Lapuerta et al., 2008b; Azad et al., 2018), poppy seed (Uyumaz et al., 2020), and algae (Khoobbakht et al., 2021). This fact shows the high accessibility of different biodiesel types to be used in diesel engines. The effects of biodiesel on characteristics and emissions of diesel engines were evaluated by many researchers. These effects are investigated in the following subsections.

2.2. Performance of the diesel engine fueled by biodiesel-diesel blends

The researchers evaluated the effects of biodiesel blends on the performance of diesel engine. The performance characteristics consist of brake engine power (BEP), brake engine torque (BET), brake thermal efficiency (BTE) and brake specific fuel consumption (BSFC). Biodiesel causes to decline thermal efficiency of the diesel engines. Lin et al. (2006) observed the trend for palm-oil biodiesel. But BTE improved by biodiesel in some cases (Demirbas, 2009) especially for lower load conditions (Agarwal and Das, 2001). Biodiesel leads to enhance BEP and BET reported in some researches. Usta (2005) observed an engine torque and power increase for 17.5% tobacco seed biodiesel in the diesel engine fueled by biodiesel blends. Adding 25% biodiesel to fossil diesel improved engine power and torque

(Zenouzi et al. 2008). This improvement could be described by the fact that a nearly full combustion could be achieved in the diesel engine thanks to the high oxygen content of biodiesel, leading to enhancing combustion efficiency. Some researches ended by same power generation of the diesel engines fueled by the biodiesels derived from rapeseed, safflower and sunflower in comparison with the engines fueled by fossil diesel (Bettis et al., 1982). The researchers attributed the power similarity to low long-term durability of biodiesels due to their carbonization effects. Biodiesel could reduce BEP (Kapilan et al., 2009) and BET (Uyumaz et al., 2020; Simsek and Uslu, 2020) of diesel engines. Kaplan et al. (2006) observed more power loss at high engine rotational speeds (10%) compared to low engine rotational speed (5%). BSFC has incremented in the engines fueled by biodiesel (Lin et al., 2006; Kapilan et al., 2009; Demirbas, 2009; Singh et al., 2020; Uyumaz et al., 2020). Aydin (2020) reported that biodiesel obtained from animal fats, vegetable and microalgae oils has enhanced BSFC in comparison with fossil diesel. This is due to low calorific value and low energy content of biodiesel in comparison with pure diesel (Uyumaz et al., 2020). Simsek and Uslu (2020) compared the effects of biodiesel resources like animal fats and vegetable oils, canola, safflower and waste vegetable oils. They observed an increase in BSFC for all the resources of biodiesel in comparison with diesel fuel, whilst biodiesel derived from the resources of vegetable oils had better results than biodiesel from animal fats.

Higher BSFC in the engine fueled by biodiesel compared to that of diesel fuel is because of lower content of biodiesel heating value (Zhu et al., 2011) resulted to consume more weight of biodiesel fuel to generate a same BEP. Reversely, Isik and Aydin (2019) analyzed the blends containing 10-50% safflower biodiesel with fossil diesel on diesel power generator characteristics and observed growth of engine performance, especially BSFC. Zenouzi et al. (2007) found that 5% biodiesel (B5D95) in terms of performance and B25D75 blend in terms of fuel combination were the best ones. This subsection shows non-similar effects of biodiesel-diesel on the diesel engine performance characteristics. The non-similar findings are due to the differences in biodiesel sources and different biodiesel-diesel ratios.

2.3. Emissions of the diesel engine fueled by biodiesel-diesel blends

Air pollutions corresponded to diesel engines comprise CO, NOx, Particulate matters (PM), smoke and sulfur. The results of some researches showed that adding oxygenate agents to fossil diesel can significantly reduce the amount of these pollutants (Ghobadian et al., 2009; Wang et al., 2016; Khoobbakht et al., 2021). Many researchers indicated that biodiesel can dilute PM and CO portion in the exhaust emissions (Wang et al., 2000; Sharp et al., 2000; Cardone et al., 2002). In comparison with fossil diesel, the combustion of biodiesel in diesel engines emits less CO, HC and PM and more NOx and NO_2 (Zhu et al., 2011).

Kannan and Anand, (2011) stated that fossil diesel released more CO, NOx, Unburned hydrocarbons (UHC) and smoke emissions than biodiesel at all load conditions while CO emission of the biodiesel increased in heavier engine load conditions. At full engine load conditions, biodiesel had the lowest UHC and smoke emission. Also, they recorded a lower NOx emission for biodiesel (485 ppm) and a higher NOx emission for fossil diesel (578 ppm) at full engine load condition. Helwani et al. (2009) reported a diminution in ability of pure biodiesel to reduce emissions such as PM, CO, and UCH by 66.7, 46.7, and 45.2%, respectively.

Dube et al. (2007) reported that CO_2 released by the engine fueled by biodiesel was more than that of diesel fuel, which is not considered a negative characteristic, but is a sign of burning more complet of biodiesel. Besides, the exhaust CO_2 can be captured by the biological organs through photosynthesis process by the plants which are cultured for biofuel production in the next cycle (Shi et al., 2006). In a contradictory result, Kannan and Anand (2011) reported a lower level of CO_2 released by the engine fueled by biodiesel in comparison with that of diesel fuel, which can be attributed to the interactions of the other variables like load and speed of the engine. In comparison with diesel fuel, Tsolakis (2006) reported that biodiesel led to a reduction in PM due to more complete combustion process. Fernando et al. (2006) concluded that high temperature, prolonged rise in temperature, and abundance of oxygen molecules in combustion chamber led to form NOx. High oxygen content in the molecular composition of biodiesel is the main reason in the reduction of the exhaust emission of diesel engines fueled by biodiesel (Corporan et al., 2005; Kapilan et al., 2009). Smoke reduction in biodiesel combustion is attributed to lower aromatic content (Corporan et al., 2005). Zheng et al., (2008) concluded the reduction in THC, PM and CO present in the exhaust emissions of the compression-ignition engines fueled by biodiesel may be attributed to the high oxygen content of biodiesel. Combustion of biodiesel emits almost no SO2 emissions (Kapilan et al., 2009). In another research, biodiesel blend of B20 in fossil diesel declined THC, PM and CO emissions by 20%, 20% and 13%, respectively (Anonymous, 2002). Najafi et al. (2006) reported 67 and 2% diminution of CO and UHC respectively for B20 in comparison with pure diesel fuel. Aydin (2020) evaluated biodiesel obtained from animal, vegetable and microalgae oils and reported that HC and CO emissions decreased whereas NOx and CO_2 increased compared to fossil diesel. Uyumaz et al. (2020) also observed decrease of CO and increase of NOx of diesel engine fueled by poppy biodiesel. Some researchers reported that biodiesel increases NOx emission (Anonymous, 2002; Lapuerta et al., 2008a; Zheng et al., 2008; Simsek and Uslu, 2020) whereas Rakopoulos et al. (2006) and Najafi et al. (2006) reported the opposite trend, a slight dilution of NOx portion in the exhaust emission by biodiesel. As reported by the researchers, biodiesel blends with fossil diesel can reduce all exhaust emissions of diesel engines except for NOx, although in some cases biodiesel reduces NOx emission, as well. This section indicates the valuable ability of biodiesel to decrease diesel engine emissions. Biodegradability and nontoxicity properties of biodiesel are considered as the effective factors in decreasing emissions such as HC, CO, PM. Commercial biodiesel causes to dilute exhaust emissions by 75-83% compared to those of fossil diesel (Demirbas, 2009).

3. ETHANOL-DIESEL BLENDS

Ethanol is introduced as fuel in the first subsection. Analyzing ethanol-diesel blends in diesel engine and its effects on engine performance and emission characteristics are reviewed in the next subsections.

3.1. Ethanol fuel

Ethanol is derived from renewable bio-resources including sugar-contained crops such as sugar beet and sugarcane, and starch-contained crops such as corn, cassava, maize, and red seaweed (Fig. 3).

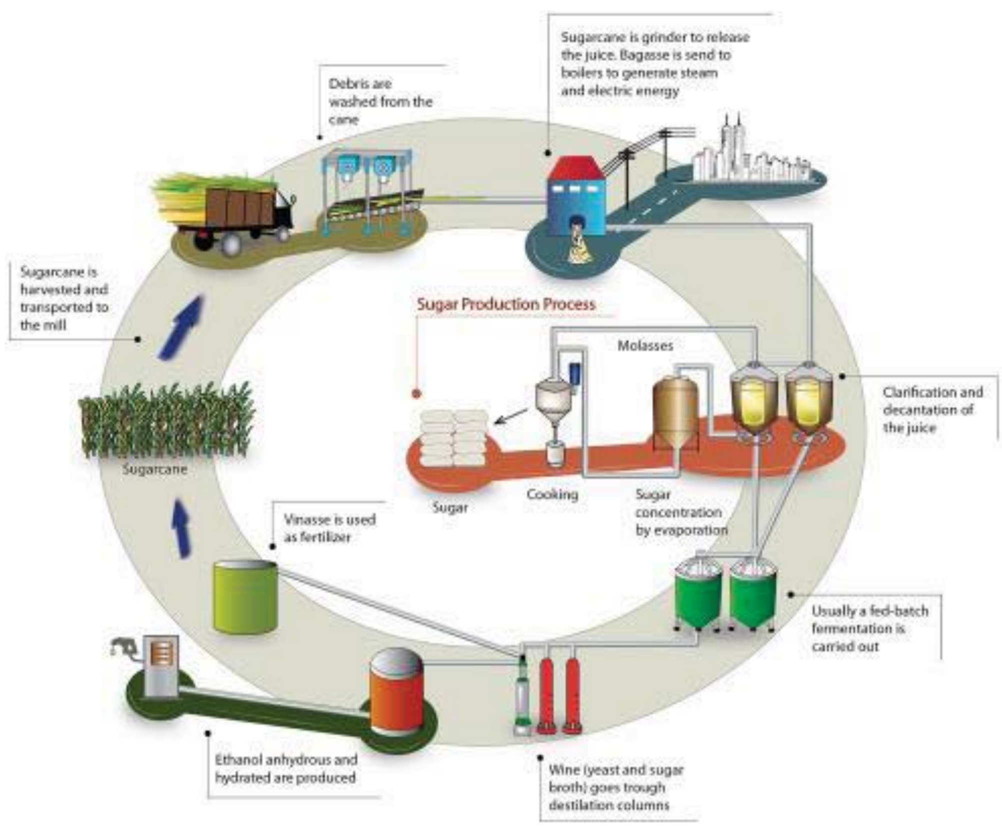

Fig. 3. Bioethanol production cycle of (Bergmann et al., 2018).

Combustion of pure ethanol in gasoline engines causes a reduction in the carbon emissions up to 80% (Lashinky and Schwartz, 2006). Ethanol also makes a reduction in PM and SOx emissions and toxic gases (Ajiv et al., 2000; Fernando and Hanna, 2004). Replacing fossil fuels by ethanol reduces CO_2 released in the combustion through capturing it by the plants cultured for ethanol production. The energy value of ethanol is less than that of crude oil, by 68% (Krylova et al., 2008). In comparison with fossil diesel with cetane number of 45-55, ethanol has low cetane number as less than 12 (Houghton-Alico, 1982). Low enrgy value and low cetane number are recognized as considerable obstacles for ethanol as a combustible, renewable and clean agent, to be purely used for fueling diesel engines (Almeida and Silva, 2006; Bai et al., 2008). However, ethanol can be blended with fossil diesel or/and biodiesel and then used in the conventional diesel engines (Ali et al., 1995a). In the diesel engine, ethanol-diesel blends can be ignited with no significant reformation in the engine structure. Applying ethanol in diesel fuel causes a significant reduction in the exhaust emissions. However, there is limitation in ethanol portion of ethanol-diesel blends to prevent notable changes in the blends' properties. The fuels used in the diesel engine should be appropriate in terms of lubricity, viscosity, volatility, stability, cetane number and energy content. Ethanol solubility in the blends, furthermore, is another determining factor for the applicability of ethanol-diesel blends, which depends on the composition, water content and temperature of the fuel.

Ethanol-diesel blends can be applied for fueling diesel engines (Ecklund et al., 1984), however, these blends have some disadvantages including low lubrication, low viscosity, low combustion ability and reducing cetane number, high volatility and low mixing capability (Hansen and Lyne, 2001; Satge de Caro et al., 2001; Li et al., 2005), which may lead to increase in exhaust emission of UCH (Merritt et al., 2005).

3.2. Performance of the diesel engine fueled by ethanol-diesel blends

Ethanol-diesel blends are considered as an alternative for fossil fuel in different diesel vehicles and engine powered equipment (Abu-Qudais et al., 2000; Hansen et al., 2005). The performance of engines has been tested using ethanol as an additive fuel. Kass et al. (2001) reported 8% BEP growth by blending 10-15% ethanol in fossil diesel whereas Hansen and Zhang (2003) reported that ethanol-diesel blends reduced BEP by 7-10%. Ethanol-diesel blends can increase BTE, though in interactions with other effective variables, ethanol may make a negative effect on BTE. Ethanol-diesel blends with 10-15% ethanol increased BTE up to 3% (Hansen and Zhang 2003; Li et al., 2005). Cheung et al. (2008) reported that ethanol did not change BTE. Rakopoulos et al. (2008b) observed that BTE of the diesel engine fueled by ethanol-diesel blends with 5-10% ethanol was equal to or slightly higher than that of pure diesel fuel. However, Huang et al. (2009) reported a reduction in BTE for ethanol-diesel blends with 10-30% ethanol, which can be attributed to the fact that a high ethanol portion in the blends can reduce temperature of the combustion chamber leading to an incomplete combustion and subsequently a reduction in BTE. Most researches in this field have reported an increase in BSFC of the diesel engine fueled by ethanol-diesel blends (Li et al., 2005; Rakopoulos et al., 2008b; Cheung et al., 2008; Rekoplas et al., 2008b). In general, it can be concluded that ethanol-diesel blends can increase BTE and BSFC. However, BEP and BET may even decrease in the blends with a high portion of ethanol, owing to a lower calorific heating of the alcohol in comparison with that of fossil diesel.

3.3. Emissions of the diesel engine fueled by ethanol-diesel blends

Ethanol-diesel blends reduced the engine emissions especially at higher ethanol portions (Li et al. 2005). Ahmed (2001) observed 27-41% diminution of PM by blending 10-15% ethanol with fossil diesel. Blending ethanol into fossil diesel reduces the smoke (Kowalewicz, 2004; Rekoplas et al. 2008b), SO2 (Can et al. 2004), PM (Lapuerta et al. 2008b), and CO (Rekoplas et al., 2008b; Huang et al., 2009). Lapuerta et al. (2008b) reported that ethanol increased HC and CO, though the increment was not significant. Rekoplas et al. (2008b) and Huang et al. (2009) also observed a HC increase in the exhaust emissions under the effects of ethanol. Comparing with fossil diesel, Li et al. (2005) reported that HC of ethanol-diesel blends increased up to 40%. HC increment caused by ethanol present in diesel fuel can be attributed to decreasing temperature of the combustion chamber because of low heating value of ethanol, leading to incomplete combustion and increasing unburned hydrocarbons. Li et al. (2005) reported NOx reduction up to 4.2% arising from blending 10-15% ethanol into fossil diesel. Rekoplas et al. (2008b) reported that NOx emission corresponded to ethanol-diesel blends was same or slightly lower comparing with fossil diesel. However, there are contradictions in the researchers' findings on the effects of ethanol-diesel blends on NOx emission. Some researchers observed that ethanol increases NOx (Can et al. 2004; Lapuerta et al., 2008b). Ahmed (2001) reported 4-5% increase of NOx present in the exhaust emissions corresponded to ethanol-diesel blends with 10-15% ethanol. It seems these contradictions arise from the interactions of other significant variables like load and speed of the engine. CO emitted by the combustion of ethanol-diesel blends increased at low and medium engine loads, while at high and full loads CO emission decreased (Li et al., 2005). Cheung et al. (2008) reported the same results in case of CO and

HC emissions. Low heating value of ethanol causes a significant reduction in temperature of the combustion chamber especially in a low engine load leading to incomplete combustion and increasing CO and HC emissions. However, at high engine loads, temperature of the combustion chamber reaches in an optimal level and, furthermore, the high oxygen content of ethanol makes a reduction in CO and HC emissions. Cheung et al. (2008) also observed slight decrement of NOx at low-medium load conditions due to the lower temperature of the combustion chamber, while an increase in NOx occurred at higher engine loads. It should be noted that NOx synthesis in the combustion chamber occurs in higher temperature. They also observed a reduction in PM with increasing ethanol portion in ethanol-diesel blends especially at high engine loads, which is attributed to the high oxygen content of ethanol.

4. BIODIESEL-ETHANOL BLENDS

Biodiesel-ethanol blends are considered as an altrnative for fossil diesel. Some functional information about biodiesel-ethanol blends were provided in this section and their effects on engine performance and emission characteristics are reviewed in the following two subsections. Ethanol-diesel blend is considered as an alternative for the use in the diesel engine with a slight modification in the engine structures (Ajav and Akingbehin, 2002), though blending ethanol into fossil diesel is a drawback (Kwanchareon et al. 2007). The problem can be solved by an additive to improve mixing capability of the ingredients. As another disadvantage, ethanol-diesel blends cannot be mentioned as good lubricant compositions. Here in the fuel blends, biodiesel acts as a good additive due to the high lubricity property and it also improves stability of ethanol-diesel blends (Gerdes and Suppes, 2001).

Temperature reduction facilitates the phase separation of ethanol-diesel blends. The phase separation problem can be solved by adding an emulsifier to reduce surface tension of the liquids or adding a co-solvent to improve the solvency power of the liquids (De Menezes et al., 2006; Lapuerta et al., 2007). Among the co-solvents, esters have attracted particular attention as an appropriate co-solvent in ethanol-diesel blends. Esters have the physicochemical properties similar to diesel fuel that allow them to be blended in a wide range of proportions. It is a solvent that allows blending more percentages of ethanol in the blends, allows existing higher water content in the blends, enhances the stability of fuel blends and prolongs the capability of storage time. Biodiesels have higher cetane numbers resulting in improving the cetane number of the blends and so adjusting the fuel combustion in the engines. Besides, existence of oxygen in esters causes to gain high the oxygen level of the blend, which can be considered as another factor in the improvement of the combustion process. Also, biodiesel improves the lubricating properties of the BE blends (Ribeiro et al., 2007; Shi et al., 2008). Previous researches showed that biodiesel increased The stability of biodiesel-ethanol blends so that the blends are stable below zero temperatures (Fernando and Hanna, 2004; Makareviciene et al., 2005). Different researches have been conducted to study the effects of biodiesel-ethanol (BE) blends on the performance and emissions of diesel engines as shown in Table 1. These effects on diesel engines are more explained in the following two subsections.

4.1. Performance of the diesel engine fueled by biodiesel-ethanol blends

Biodiesel-ethanol blends were evaluated by Ali et al. (1995a) and Kumar and Raj (2016). The researchers stated the performance features of the diesel engine fueled by BE were similar to that of fossil diesel fuel, except for BSFC which intensified in the diesel engine fueled by BE. BSFC increase corresponds to BE fuels was reported by Zhu et al. (2011), Aydin and Ilkilic (2010), Zhu et al. (2010), and Yilmaz and Sanchez (2012). Yilmaz and Sanchez (2012) recorded lower BSFC for biodiesel-ethanol compared to biodiesel-methanol. They believed lower BSFC was due to the higher vaporization heat of methanol compared with that of ethanol. Aydin and Ilkilic (2010) reported that BSFC at medium engine speed was the optimum value due to higher temperatures and consequently higher efficiency. Yilmaz and Sanchez (2012) did not observe any significant change in exhaust temperature under the effect of ethanol, but Aydin and Ilkilic (2010) measured higher exhaust gas temperature of B80E20 for all tested engine rotational speeds among other blends because of higher flaming speed and so shortening the combustion time and then improvement of the combustion process. Blending ethanol into biodiesel causes to growth thermal efficiency (Zhu et al. 2010). Zhu et al. (2011) observed an increase in BTE when 5% ethanol was added into biodiesel but did not record significant difference of BTE for 10-15% ethanol. Aydin and Ilkilic (2010) reported that B80E20 had greater BTE in comparison with diesel fuel, especially at high rotational speeds because of more completeness of combustion process and better lubricant property. Aydin and Ilkilic (2010) reported that engine torque associated to B80E20 was 1.3% and 1.2% higher than that of B20D80 and pure diesel fuel, respectively. Prbakaran and Viswanathan (2016) evaluated B90E10, B70E30 and B50E50 blends and showed that BTE of the blends was higher than that of pure diesel fuel. BTE reached to a maximum value for B50E50 which was 8% bigger compared to pure diesel. Only at low loads, BSFC was higher for the tested blends in comparison with pure diesel.

Table 1. The effect of BE blends on diesel engine charactristics.

Ref.	Engine	Fuel	Condition	Increase	Decrease
Zhu et al. (2011)	4C, DI, NA, WC	BE5-15, PD	5 loads at 1800 rpm	HC, CO BSFC BTE	HC, CO PM, NO_x
Aydin and Ilkilic (2010)	1C, DI, AC, NA	BE20, B20, DF, PB	1000-3000 rpm at Full load	NO_X, BET, BTE, BSFC	CO
Zhu et al. (2010)	4C, DI, NA	PB, BE5-15	5 loads at 1800 rpm	BSFC,BTE,CO	HC, CO, NO_x PM
Yilmaz and Sanchez (2012)	2C, DI, WC,	B85E15, B, PD	3000 rpm at full load	BSFC CO, HC	NO
Subbaiah et al. (2010)	1C, DI, WC	BE10-30, B20	1500 rpm, at different loads	BTE, NO, CO_2	Smoke, CO, HC
Prbakaran and Viswanathan (2016)	1C, DI, AC	B90E10, B70E30, B50E50	1500 rpm, at different loads	BTE BSFC	CO, HC NO_x, smoke
Labeckas et al. (2014)	4C, NA, DI	E5-15, E15B15	1400, 1800 and 2200 rpm	BSFC	NO_x, HC
Saleh and Selim (2017)	4C, DI,	B5-25, B10E10, PD, D95B10-E5, B10-E15, B10-E20	1500 rpm, at different loads	BTE NO_x	NO_x, HC, CO, smoke HC, CO, smoke
Kumar and Raj (2016)	1C, DI, NA, WC	BE0-10	Variable speed at full load	BSFC, BE0	SFC BTE BSFC CO, HC, NO_x
Tongroon et al. (2019)	4C, DI, WC	B7, B3E5, B7E5, B10E10	1400-3200 rpm	HC, BSFC, NO_x	BET and BEP

Blending biodiesel and ethanol for fueling diesel engine caused to increase BTE due to more completeness of combustion process resulted from higher oxygen content and lower engine power losses because of higher lubricant property of biodiesel (Aydin and Ilkilic, 2010). BE blends, in general, have high calorific value (Zhu et al., 2011; Aydin and Ilkilic, 2010; Zhu et al., 2010), high viscosity (Ali et al., 1995a; Aydin and Ilkilic, 2010) and high crystallization (Ali et al., 1995a).

4.2. Emissions of the diesel engine fueled by biodiesel-ethanol blends

BE blends significantly decline emissions such as CO and PM but intensify NOx emissions in comparison with fossil diesel (Starr, 1997; Ali et al., 1995b; Durbin et al., 2000). Kass et al. (2001) found 20-30% emission reduction under the effect of 10-15% ethanol. Chen et al. (2007) reported 25-50% PM decrease relative to the blends containing 10-20% ethanol. Shudo et al. (2007) found that higher ratio of ethanol in the blends caused to an increase in the heat releasing rate through the premixed combustion phase leading to a reduction in smoke emission because of improvement in the premixed combustion phase. They reported that PM emission decreased thanks to the presence of ethanol in the blends, as ethanol can decrease blends' density and viscosity resulting in an appropriate fuel atomization in the combustion chamber. At low engine loads, PM emission augments due to the cooling effect of ethanol. Bhale et al. (2009) and Zhu et al. (2011) reported that the blends containing 10-15% ethanol caused an increase in HC and CO emissions especially at light-medium engine loads resulting from cooling effects and high oxygen content of ethanol in the blends. Zhu et al. (2010) reported that HC and

CO emissions correspond to the blends containing 10-15% ethanol were greater than those of pure biodiesel and pure diesel, while those emissions decreased in the combustion with decreasing ethanol portion up to 5% in the blends. Comparing with pure diesel, NOx emission was intensified with biodiesel, while blending ethanol into biodiesel caused a reduction in NOx emission. PM emission related to pure biodiesel and the blends were lower in comparison with those of pure diesel fuel. The more ethanol portion in the blends, the lower the PM at medium-high engine loads. They concluded that 5% ethanol can reduce HC and CO, while increasing ethanol portion in the blends caused to more decrease in NOx and PM. Kumar and Raj (2016) introduced two trends for NOx of BE, i.e. ethanol additive caused a reduction in the exhaust emissions at low-medium rotational speeds and an increase in the exhaust emissions at higher rotational speeds of the diesel engine.

Aydin and Ilkilic (2010) stated that CO emitted from B80E20 blend was lower in comparison with pure diesel due to the high oxygen content of ethanol and biodiesel in the blends. Oxygen atoms in the molecular structure of ethanol and biodiesel cause to rise CO oxidation during combustion process. NOx increased due to high content of oxygen in ethanol increasing combustion efficiency leading to an improvement in the combustion and an increase in the combustion temperature resulting in more NOx synthesis. These factors lead to prolong the ignition time delay and presence more fuel-air gas mixture which cause an increment in the heat releasing rate of the combustion and raising the combustion temperature. Zhu et al. (2011) reported that BE blends had lower NOx and higher NO_2 emissions, compared to those of biodiesel at low engine loads, while there was non-significant difference at medium-high engine loads. PM emission of BE blends decreased compared to that of pure biodiesel and pure diesel. Canakci (2005) and Lapuerta et al. (2008b) concluded the presence of oxygen atoms in ethanol and methanol can increase NOx emission. As those additives have low cetane number, the blends containing these additives lead to extend ignition time and consequently an increase in burning fuel in the premixed combustion phase leading to an increase in NOx synthesis. The cooling effect of ethanol and methanol has greater influence on NOx formation. As the cooling effect at higher engine load conditions. diminishes, the difference in NOx portion of the exhaust emissions of the blends becomes insignificant. Yilmaz and Sanchez (2012) measured the exhaust emissions of the diesel engine fueled by B85E15, B85M15, pure biodiesel, and pure diesel. They observed that BM and BE dilute exhaust NOx and, in this point, the influence of BE blends were higher compared to BM. They reported that BE caused an increase in CO and UHC at engine loads up to 70% in comparison with those of pure diesel and pure biodiesel and recommended using additional treatments such as preheating entrance air to reduce the emissions at low-medium engine loads. They did not record any significant difference at higher engine load conditions between the fuels in terms of CO and HC, which can be attributed to the fact that alcohols need more energy to be vaporized. The needed vaporization energy of alcohols cannot be rapidly provided at low engine load conditions, due to colder operating of the engines. Thus, incomplete combustion in this case leads to intensify CO and HC. Hence, the emission formation relative to BE blends depends on the engine operation conditions as exerted load on the engine, temperature of entrance air to combustion chamber and alcohol portion in the blends. Regard to HC, Kumar et al. (2003) recorded lower emission of BM blends compare to pure Jatropha biodiesel. Lapuerta et al. (2008b) stated that methanol cooling effect reduces the combustion temperature and correspondingly decreases NOx formation because of lower heating value and higher requirement evaporation energy. Cheng et al. (2008) believed that cooling effect is very low when 5% alcohol is used but in this case the combustion improvement because of better spray features and atomization property of methanol lead to decrementing CO and HC. BM emits more CO and HC compared to BE, due to high evaporation energy requirement of methanol (1178 kJ/kg) compared to that of ethanol (840 kJ/kg).

5. BIODIESEL-ETHANOL-DIESEL BLENDS

Diestrol has positive effects on the exhaust oxygen fraction, equivalence ratio and water and oil temperature of the diesel engine (Torkian Boldaji et al. 2011), which reduce the emissions in combustion process (Singh et al., 2020). Besides reducing exhaust emissions, great attention in this regard is due to biodegradability, nontoxicity and bio-accessibility of biodiesels that are produced from different vegetable and animal sources. In this section some information about biodiesel-bioethanol-diesel blends are provided. In the following two subsections the effects of using these blends in the diesel engines are reviewed. Esters were used primarily as a co-solvent. Because of the similarity of esters to pure diesel fuel, they can be blended with pure diesel with no limitation. Reduction of diesel engine emissions such as HC, CO, and PM caused by biodiesel has been approved in many researches, except for NOx (Zheng et al., 2006; Pradeep and

Sharma, 2007; Avinash et al., 2009; Qi et al., 2009; Cengiz and Sehmus, 2009). Biodiesel also facilitates blending more portion of ethanol into diesel fuel, correspondingly raises stability and endurance for more water content, so the blends can be stored for a long time. High cetane number of biodiesels can compensate the decreasing effect of ethanol on cetane number and in this way it improves the engine ignition process. The esters increase oxygen level of biodiesel-ethanol-diesel (BED) blends and in addition, improve the engine lubricity due to high lubricating ability. Similar to ethanol, biodiesel causes to reduce exhaust emissions. The limitations of biodiesel are high viscosity and pure point values, and low volatility magnitude in comparison with fossil diesel fuel. High viscosity or poor flow property of biodiesel is a limitation especially in cold weather (Geller and Goodruml, 2004; Joshi and Pegg, 2007; Sarin et al., 2009). Also, these properties act as diminution factors of thermal efficiency of biodiesel compared to that of pure diesel (Devan and Mahalakshmi, 2009). It is believed that ethanol improves flow characteristics of the BED blends. The oxygen content in the blends is a PM reduction factor and this property is more important than others such as volatility or chemical composition. So, the diesel engine is fueled by BED for goal of decreasing exhaust pollutions (Pang et al., 2008).

Comparing BED (diestrol) with pure diesel fuel, beside lower energy content of BED, environmentally friendly characteristics as well as higher lubricant properties and renewability are of the main feature of biofuels. These properties have attracted researchers to evaluate BED influences on the diesel engine (McCormick and Parish, 2001). Biodiesels provide a condition to add more ethanol in BEDs and allow higher water content and higher stability and better storing property. High biodiesel cetane number compensates low alcohol cetane number, so biodiesel is considered as ignition improvement factor. Also biodiesels increase oxygen content of BED. Additionally, high lubricant property of biodiesels is a beneficent factor for diesel engines. Biodiesel and ethanol are same regard to emission reduction when the blends are burned in diesel engines, especially for PM reduction (Ribeiro et al., 2007). Using biodiesels is due to their similarity to diesel fuel so any proportion of BD blends can be used. However different percentages of biodiesel and ethanol in diestrol have been evaluated in diesel engine. In some research, BEDs improved the combustion efficiency of diesel engines due to presence of the oxygenate biofuels in the blends. It was not observed a significant difference in CO emission by blending ethanol and diesel into biodiesels derived from soybean, castor and residual oil (Guarieiro et al., 2009). In examining BEDs, Fernando and Hanna (2004) reported good stability even in temperatures under zero degrees Celsius and same or better properties compared to pure diesel. Cetane number, lubricant ability, and energy content of BEDs can be adjusted by the fuel components although these properties of ethanol are low. Barabas and Todorut (2009) investigated on the characteristics of BEDs containing 5-15% ethanol and 20-30% biodiesel. They concluded that the BED blends have viscosity and density values same as or close to those of fossil diesel and the blend with 5% ethanol has very close characteristics to fossil diesel fuel. Rahimi et al. (2009) examined the physicochemical properties of the blended fuels containing ethanol derived from potato remnants and methyl ester from sunflower seeds. They expressed that ethanol is main factor for adjusting the BED flash point. They recorded 16 ˚C as flash point reduction in the result of blending 3% ethanol in sunflower biodiesel and diesel blend. Also this ethanol percentage decreased viscosity of BED. Ethanol and sunflower biodiesel have very lower sulfur content (0 and 15 ppm, respectively) than that of fossil diesel (500 ppm), as worth mentioning that BE, in general, have sulfur content lower than 20 ppm. The effects of BEDs on performance and emissions' characteristics of diesel engines were summarized in Table 2. In the following two subsections, the effects of diestrol were more described.

5.1. Engine performance of BED

Some researchers observed that the engine performance of the diesel engine fueled by fossil diesel is higher than the BE and BD blends (Aydın and Ogut, 2017). Qi et al. (2011) reported that blending 5% diethyl ether into fossil diesel enhanced performance characteristics of the diesel engine compared to blending 5% ethanol into fossil diesel and the BD blends. Compared with fossil diesel, the BEDs caused a reduction in BTE of the diesel engine (Kannan and Anand, 2011) because of lower energy equivalent value of diestrol. However, some researchers reported an inverse result (Subbaiah et al., 2010; Kannan et al., 2012; Geo et al., 2017). Al-Hassan et al. (2012) reported that BTE increased with increasing ethanol portion in the blends up to 10% and then begins to decrease with more increasing over 10% ethanol portion. Krishna et al. (2019) expressed that D78B17E5 blend had a same BTE as fossil diesel (27%) whereas a lower BTE was observed for the DBE7, BDE8, BDE9 blends.

Table 2. The influence of BEDs on diesel engine.

Reference	Engine	Fuel	Condition	Increase	Decrease
Kwanchareon et al. (2006)	1C, DI, NA, AC	D90B10-B5E5-E10, D85B15-B10E5-E15, D80B15E5-B10E10-B5E15, PD, PB, PE	0, 30, 60 & 100% load	NO_x	HC, CO
Pang et al. (2006)	4C, DI	D75B20E5	1800 rpm at varying load	BSFC, NO_x	PM, BEP and BET
Shi et al. (2005)	4C, DI	D80B16E4-B20, D85B12E3	1000-3600 rpm at full load	NO_x , HC	Smoke, PM, CO
Kannan and Anand (2011)	1C, DI, NA, WC	PD, B100, D10B70E20, D20B60E20	Different loads at 1500 rpm	SFC, BTE	CO, HC, NO CO_2
Barabas et al. (2010)	4C, DI	PD, D85B10E5, D80B10E10, D70B25E5	0-40%, 40-80% & >80% load	CO_2, BSFC NO_x	CO, BTE HC
Hulwan and Joshi (2011)	3C, DI,	D50E40B10-E30B20, D70E20B10	1200 & 1600 rpm, low & high load	CO, SFC, BTE, NO	smoke
Kannan et al. (2012)	1C, DI	B20E5D75, E5D95, B95E5, PB, PD	1500 rpm, all load	BTE, BSFC NO_x	CO, THC, Smoke
Al-Hassan et al. (2012)		PD, DBE5, DBE10, DBE15, DBE20	800-1600 rpm, constant load	BSFC BTE	BEP, BTE
Khoobbakht et al. (2016)	4C, DI, WC	BED	1000- 2800 rpm, all load	CO_2, NO_x	CO, HC, Smoke
Mofijur et al. (2015)	4C, DI	BDE3, BDE5, BDE15, BDE25	All load	BSFC	NO_x, HC, PM, CO, smoke
Paul et al. (2017)	1C, DI, NA, WC	D, D45E5B50, D40E10B50, D35E15B50, D30E20B50	20-120% load at 1500 rpm	BTE, BSEC, NO_x	HC, CO
Aydın and Ogot (2016)	1C, DI, NA, WC	D100, D95B2.5M2.5, D90B5M5, D92.5B5M2.5, D92.5B2.5M5	Varying speeds at full load	BTE, BEP, PET	CO, CO_2, HC, O_2, SO_2, NO_x
Krishna et al. (2019)	4C, DI, NA, WC	D100, D78B17E5, DBE6, DBE7, DBE8, DBE9	Varying load at 1600 rpm	BTE, NO_x, CO_2, BSFC	CO
Kandasamy et al. (2019)	1C, DI, NA,	D95B5, D75B5E20	Full load at 10 speeds	BEP, BET, BSFC, HC, NO_x	Smoke, CO HC, NO_x
Radelle et al. (2019)	2C, DI, NA, WC	DB7E0, DB15E0, DB15E5, DB15E10, DB15E15, DB15E20	Varying load at 1500-2100 rpm	BSFC, BTE	BET
Rahimi et al. (2009)	2C, DI, NA, AC	PE, PB, PD, D95E3B2, D90E6B4, D85E9B6, D78E12B8, D89.5E0B10.5, D79E0B21, D68E0B32, D58E0B42,	1200-3600 rpm at full load	BSFC	BEP and BET HC, CO, PM, NO_x, smoke
Kim and Choi (2010)	4C, DI, NA, WC	D, D85E15, D95B5, D80B20, D80B15E5	2100 & 3800 rpm at 25-100% load	NO_x	HC, CO, Smoke PM
Yilmaz et al. (2014)	2C, DI, WC	BDE25, BDE15, BDE5, BDE3		CO, HC	HC, NO
Kwanchareon et al. (2006)	1C, DI, NA, AC	D90B10-B5E5-E10, D85B15B10E15-E15, D80B15E5-B10E10-B5E15, PD, PB, PE	0-100% load	NO_x	HC, CO
Barabas et al. (2010)	4C, DI,	PD, D85B10E5, D80B10E10, D70B25E5	0-40, 40-80 & >80% load	CO_2, BSFC NO_X	CO, BTE HC
Geo et al. (2017)	1C, DI,	BED, PD	at 25%, 50%, 75% & full load	BTE, Smoke HC, CO, NO_x	Smoke
Parthasarathy et al. (2015)	1C, DI	BED, PD, PE,	Full load, 1500 rpm	BTE, CO_2,	CO, NO_x, HC, Smoke

The BED blends reduce engine brake power (Rahimi et al., 2009; Al-Hassan et al., 2012; Kandasamy et al., 2019) and torque (Rahimi et al., 2009; Kandasamy et al., 2019; Pradelle et al., 2019). Some researchers observed growth of BEP by the BED blends at high engine loads compared to fossil diesel (Hulwan and Joshi, 2011).The BED blends increase BSFC (Rahimi et al. 2009; Subbaiah et al., 2010; Kannan and Anand, 2011; Hulwan and Joshi, 2011; Kannan et al., 2012; Mofijur et al., 2015; Labeckas et al., 2014). Pradelle et al. (2019) recorded that the blends with 5% ethanol amplifies BSFC by 2%. Tongroon et al. (2019) used BED blend fuels to analyze the effects on fuel heat release rate and engine performance. They stated that engine performance characteristics relative to ethanol were worse than those of fossil diesel. This reduction in performance of the diesel engine fueled by the blends containing ethanol is because of decreasing air proportion to fuel in the engine combustion chamber and low calorific value of the blends (Al-Hassan et al., 2012). Some researchers observed an insignificant difference in BSFC of the BEDs in comparison with that of fossil diesel (Shi et al. 2005). Also an increment in engine loads causes to decrease in BSFC (Kannan and Anand, 2011; Hulwan and Joshi, 2011). Some additives in diestrol may improve the engine performance characteristics. Singh et al. (2020) used butanol as additive in biodiesel-diesel blends and reported a slight increase in BEP and BSFC whereas BTE decreased.

Generally, can be told that increasing the portions of ethanol and biodiesel in the BED blends causes to decrease BTE and BEP due to low heat value of both biodiesel and ethanol, higher density and viscosity of biodiesel, high latent heat of evaporation of ethanol and low ethanol cetane number. However, the blends with an optimal portion of biodiesel and ethanol partially offset the revers effects of each other, so low ethanol portion in the blends can moderate low biodiesel atomization feature. Also, higher biodiesel cetane number modulates the cetane number of the biofuel-fossil blends and makes these properties of the blends almost same as those of fossil diesel. Increasing the volumetric percentages of biodiesel and ethanol in the blends augments BSFC for the mentioned reasons because more fuel must be consumed in the combustion chamber to achieve a same BEP.

5.2. Emissions of the diesel engine fueled by biodiesel-ethanol-diesel blends

Recent researches indicated that BEDs substantially rebate CO (Ali et al., 1995b; Kowalewicz, 2004; Shi et al., 2006; Lebedevas et al., 2009; Bhale et al., 2009), HC (Cardone et al., 2002; Shi et al., 2005; Pang et al., 2006; Prbakaran and Viswanathan, 2016), smoke (Hulwan and Joshi, 2011; Prbakaran and Viswanathan, 2016), PM (Hansen et al., 2005; Chen et al., 2007; Kim and Choi 2010; Mofijur et al., 2015), but increase NOx emission (Shi et al., 2005; Hulwan and Joshi, 2011; Qi et al., 2011). Qi et al. (2010) reported that HC, NOx, CO, and smoke emissions of BMDs decreased compared to those of BD blends.
Lower combustion temperature resulted from shorter ignition delay due to higher cetane number of biodiesel in one side and nonaromatic content of biodiesel in another side prevent NOx forming (Rakopoulos et al., 2008) but presence of oxygen atoms in biodiesel is a more effective factor in increasing NOx emission. Oxygen content of the blends causes to have excess hydrocarbon oxidation and hence the combustion temperature increases in the engine chamber leading to NOx synthesis (Raheman Ghadge, 2007; Ahmet et al., 2009). CO decreasing is because of high content of oxygen in BEDs (Shi et al., 2005). Tongroon et al. (2019) reported that higher heat release rate in cases of higher ethanol percentages augmented exhaust NOx. PM forming mainly occurred in the parts of combustion chamber with higher fuel concentration and consequently higher temperature. These local areas are mainly close to fuel injection zone. PM decreased due to oxygenates effects of biofuels on more complete combustion (Shi et al., 2005). The blends can provides required oxygen atoms to the pyrolysis zone resulting in more complete combustion (Wang et al., 2000; McCormick and Parish, 2001).

Shi et al. (2006) stated that CO emission depends on operating conditions. Kwanchareon et al. (2007) reported that blending oxygenate biofuels with fossil diesel at higher load conditions caused a significant CO reduction, while it was observed a slight reduction at low-medium conditions of engine load. Hulwan and Joshi, (2011) observed CO increasing of BEDs at low conditions of engine load and slight decreasing at high engine load conditions compared with fossil diesel. Barabas et al. (2010) observed that CO was diluted at low-medium engine load conditions and it decreased at high engine loads and had a significant difference with pure diesel fuel. Kwanchareon et al. (2007) stated that HC emission was lower at medium load than that of low or high loads. Kannan et al (2012) stated that BEDs reduced CO, THC and smoke at high load conditions whereas CO, THC and smoke emissions were high at low loads because of high BED latent vaporization heat and high viscosity feature. The smoke was high (about 54%) at low-medium engine load conditions compared with pure diesel fuel. THC emissions were high only for the blends containing high biodiesel portion at low engine loads. Kwanchareon et al. (2007) reported that NOx emissions increased at low to high engine loads compared to pure diesel. Kannan et al (2012) observed that NOx increased at high engine load conditions because of higher content of oxygen in BED, while it decreased at low engine load conditions because of low BED flame temperature. Krishna et al. (2019) stated that NOx emission of the BED blends were more than that of pure diesel at high engine load conditions and decreased by decreasing the engine load. This is due to increasing the combustion pressure and heat release rate caused by increase in the engine load (Uyumaz et al., 2020). Regarding CO, PM, THC, and NOx, Cardone et al. (2002) reported that an increase in the rotational speed caused a diminution in the exhaust emissions. They also stated that CO, CO2, and THC decreased with amplifying the exerted load on the diesel engine. They concluded that the dependency between emissions and engine load was because of air/fuel ratio which makes an effect on efficiency of the combustion process. Yilmaz et al. (2014) stated that ethanol caused an increase in HC at low engine load, while made a reducing effect on HC emission at over 50% engine load. Labeckas et al (2014) reported that CO emission of the blends at low engine rotational speed was low while at medium and high speeds was high in comparison with fossil pure diesel. Smoke of the blends at low and high speeds was lower while at medium speed was higher compared with fossil pure diesel.

Kowalewicz (2004), Lebedevas et al. (2009), Bhale et al. (2009), Hulwan and Joshi, (2011), Mofijur et al. (2015) and Prbakaran and Viswanathan (2016) reported that the blends reduced NOx. Yilmaz et al. (2014) reported that CO of the blends incremented in comparison with that of pure diesel fuel while NOx decreased. Chen et al. (2007) stated that NOx reduction was more significant due to the presence of ethanol. Ethanol in the fuel blends can reduce NOx emissions because of decreasing the combustion temperature resulting in higher heat of evaporation and so suppressing NOx emissions (Hansen et al., 2006; Ren et al., 2008). Park et al. (2011) concluded that ethanol caused a reduction in NOx emissions due to low energy content and high needed evaporation heat. The research reported by Jha et al. (2009) showed that increasing ethanol portion in BEDs caused to reduce NOx for the modified diesel engine.

Shi et al. (2005), Bhale et al. (2009), Park et al. (2011), Qi et al. (2011) and Tongroon et al. (2019) reported that the BED blends increased HC. Pang et al. (2006) stated that the BEDs can relatively augmented the carbonyls portion in the exhaust emissions. Jha et al. (2009) reported CO increased with increasing ethanol portion in the BED blends. Park et al. (2011) stated that the high required evaporation heat of ethanol causes to reduce temperature in combustion process, considering that it dominants the higher oxygen molecules corresponded to ethanol portion in BEDs, and act as opposite factor in oxidation of CO to CO_2. Kumar et al. (2006) reported that NOx emissions of BEDs had decreasing trend for lower engine load conditions. CO and HC values had reverse trend for same conditions but changed to decreasing trend in high engine load conditions. Isik and Aydin (2019) reported that NOx decreasing was significant but reversely CO and HC emissions slightly intensified. Aydin and Ogut (2017) analyzed the effects of different safflower biodiesel-methanol-diesel blends on engine emissions and reported that B2.5M5D92.5 fuel was the best compared to pure disel, B2.5M2.5D95, B5M5D90, B5M2.5D92.5 to reduce CO, CO_2, SO_2, NOx, and HC emissions in the diesel engine. In determining exhaust emissions of BEDs, Tongroon et al. (2019) observed that higher ethanol portions caused to retard the combustion and so promoted the UHC forming because of longer ignition time. Recently using additives in diestrol is investigated in diesel engines. Singh et al. (2020) showed that adding 5-14% butanol in biodiesel-diesel blends reduced NOx emission due to cooling effect of butanol. Whereas they recorded increase of NOx as the effect of burning PB and BD in diesel engine.

In general, increasing the concentrations of biodiesel and ethanol in BED blends reduces CO emission because biodiesels and alcohols contain high oxygen content and consequently cause to completeness improvement of the combustion process. Also, higher biodiesel cetane number lengthens ignition time delay and provides longer combustion time and more complete combustion. At high percentages of biodiesel and ethanol, CO emission increases because of higher biodiesel viscosity causing to poor fuel atomization, high ethanol cooling property (latent evaporation heat), low fuel ignition temperature and low probability of CO oxidation converting to CO_2.
Increase in biodiesel and ethanol portions in the blends intensifies CO_2 emission because of high cetane number of biodiesel and high oxygen contents of both biodiesel and ethanol. In higher concentrations of biodiesel and ethanol, CO_2 decreases because of high biodiesel viscosity preventing optimal combustion and the high latent heat of evaporation and low cetane number of ethanol. The highest CO_2 emission is obtained in the

mid-volume percentages of biodiesel and ethanol, but low temperature and delayed ignition at high percentages of biodiesel and ethanol disrupt the oxidation process, although sufficient oxygen molecules are available for fuel ignition in combustion chamber.
HC emission decreases with increasing biodiesel and ethanol portions in the blends, because they provide high oxygen content for fuel ignition in the chamber and thus improve the combustion process. HC emission increases at high percentages of biodiesel and ethanol due to their low energy content value, high density and viscosity, low atomization property and low volatility feature of biodiesel as well as high cooling property and latent evaporation heat of alcohol which put down the blends combustion efficiency. Another reason of high HC portion at high ethanol percentages is the fact that ethanol easily evaporates and it slowly enters into the combustion chamber and so it is weakly distributed in the chamber.

As volumetric portion of biodiesel and alcohol in the blends rises, NOx emissions increment because of the presence of high oxygen molecules and high biodiesel cetane number. The increase of these factors improves combustion completeness and raises the temperature of combustion chamber. Another reason for NOx increasing is the devaluation of cetane number with increasing ethanol because the low cetane number value amplifies the ignition time delay and accumulates high fuel-air mixtures in local zones and releases a great heat when fuel combusted in the chamber. For high biofuel shares in the blends, due to high viscosity and poor atomization of biodiesel and cooling effect of ethanol and so non suitable combustion process cause to NOx reduction.
The blends of BED decrease the amount of smoke due to high oxygen content and creating favorable conditions for CO oxidation as well as absence of carbon and sulfur in biodiesel and ethanol that cause to reduce these elements in the blends.

6. OPTIMIZATION OF DIESTROL COMPONENTS

In the literature, BEDs declined PM while different trends reported for CO and NOx. Some studies indicated that BEDs decreased CO. In some researches BEDs did not significantly change NOx but increasing trend for CO was reported in different studies. Similar to CO, same trends have not been recorded for NOx under the effects of BEDs in the previous researches. Also some researches indicated the effect of engine age on NOx trends.

Beside the importance of the above emissions due to environmental impacts, the BSFC of diesel engine is very important because of economic aspects and also resource depletion. In many researches it was reported that diesel engines consume more BD, ED and BED blends than fossil pure diesel. Some researchers (Senatore et al., 2000; da Silva Fernando et al., 2003; Ramadhas et al., 2005; Choi et al., 2006; Hasimo Glua et al., 2008; Lapuerta et al., 2008; Ozsezen et al., 2009; Karabektas, 2009; Fontaras et al., 2009; Armas et al., 2010) believe that an increase in BSFC is proportion to low energy content of biofuels in comparison with that of fossil pure diesel. Armas et al. (2010) reported that BSFC of biodiesel with 12.9% lower heating value than that of B15D85, increased approximately up to 12% compared to the B15D85. Lin et al. (2009) compared 8 kinds of biodiesel and reported that those amplified BSFC by 9.45-14.65 in comparing with that of fossil pure diesel. Luján et al. (2009) stated that the mass BSFC of biodiesel was higher than that of pure diesel. Godiganur et al. (2010) observed increasing trend of fuel consumption of a diesel engine as biodiesel percentage increased in the tested blends from 10 to 100%. Reyes and Sepúlveda (2006) recorded minimum BSFC for B40 among other tested blends form B10-100. Ghobadian et al. (2009) found that the mean BSFC of 10-50% biodiesel for many engine speeds belonged to B40 as 2.2% lower than that of fossil pure diesel. Mahanta et al. (2006) recorded BSFC of 15 and 20% of pongamia biodiesel were slightly lower than that of diesel and that of B20 had minimum value. In evaluation of jatropha, karanja and polanga biodiesels, Sahoo et al. (2009) recorded that BSFC values of JB100, KB100, and PB100 were 12.37, 13.31%, and 13.31%, respectively, more respect to that of pure diesel.

The most important characteristics of biodiesel on fuel consumption are low caloric value and high density and viscosity (Xue et al., 2011). Karabektas (2009) found that a four-stroke diesel engine turbocharged biodiesel had fuel consumption meanly 17.7% lower than that of the engine without turbocharger. Pal et al. (2010) evaluated thumba biodiesel percentages, B10-30 and observed that BSFC sharply rebated by increasing engine rotational speed up to 2000 rpm. After constant value to 4000 rpm, BSFC augmented sharply again. Carraretto et al. (2004) in studying the effects of engine injection time recorded BSFC decreasing trend with decreasing of injection advance. This trend is due to optimization of combustion process and so improvement of engine performance especially at low-medium engine rotational speeds.

The different trends of the influence of diestrol on performance and emissions of diesel engines emphasis importance of the optimization of ethanol and biodiesel percentages in diestrol. Shirneshan et al. (2016) used Artificial Bees Colony Algorithm and Anwar et al. (2020) applied statistical modeling and analysis of variance to optimize biodiesel percentages, engine load and rotational speed on engine emissions. Khoobbakht et al. (2016) optimized the percentages of the diestrol components to decrease the exhaust emissions of the engine. They recorded that BEDs diluted CO, HC, and smoke emissions whereas increased CO_2 portion in the exhaust gases in results of more completeness of combustion process. They presented a predictive model to find optimum diestrol ingredient to reach minimum engine emissions. The researchers applied desirability approach in response surface methodology to optimize the diestrol percentages at different engine loads and rotational speeds to minimize CO, THC, NOx, and smoke and maximize CO_2. They recorded the optimal condition with 74% desirability as B26E11D63 at 80% engine load and 2800 rpm rotational speed. The emissions of the optimal point were 0.013%, 41 ppm, 643 ppm, 12%, and 7.3% for CO. HC, NOx, smoke, and CO_2, respectively. Khoobbakht et al. (2019) modeled and optimized the effect of BED blends on the diesel engine performance characteristics at different engine load and rotational speed conditions using central composite design in response surface methodology. They observed that low percentages of bioethanol and biodiesel can improve BTE compared to fossil pure diesel but the trend reversed for high percentages of biodiesel and bioethanol. The highest BEP value reported at 2800 rpm rotational speed and engine full load for fossil pure diesel. The highest value of BTE was recorded for D83B12E5 fuel at 1900 rpm engine rotational speed and 80% load. The minimum BSFC was observed for pure diesel at engine full load and 2453 rpm rotational speed. Also the response surface method was used by Mirbagheri et al. (2020) to optimize the engine characteristics under the effects of diestrol.

7. FUTURE TRENDS OF DIESTROL FUEL IN DIESEL ENGINE

Based on the results in the literature of diestrol fuels in diesel engines, positive and negative impacts of those on the engine characteristics, performance and emissions, have different trends due to different bio-sources types of ethanol and biodiesel. Many types and models of diesel engines equipped with different mechanical parts made from different companies are another reason. Also they are influenced by engine parameters and conditions such as rotational speed, load percentage (Khoobbakht et al., 2019) and injection pressure and injection timing (Gnanasekaran et al., 2016). These caused to have increasing trend in one testing condition and decreasing trend in another condition.

Magnusson et al., (2002) believed that as the engine rotational speed raised, the completeness of combustion process increased because air-fuel proportion improved and accordingly CO, THC, PM, and NOx emissions decreased. Lapuerta et al. (2008b) reported that the advanced injection of the blended fuels caused an increase in NOx formation, even more than that of pure diesel fuel. Kannan and Anand, (2011) stated that NOx increased by load rising for all the tested fuels. Singh et al., (2020) also recorded positive effects for compression ratio, injection pressure and timing on BTE increase and BSFC decrease in the diesel engine fueled by biodiesel.

Modifying diesel engine structure or equipping the engine may help in improvement of the engine performance and emissions. Jagtap et al. (2020) studied the effect of coating of piston, cylinder head and valves by 250 µm thick mullite material (Metco 6150) and using jatropha biodiesel in a diesel engine. They reported that the coating caused to decrease emissions and BTE in comparison with non-coating status and adding 5% anhydrous ethanol caused to more decrease in NOx and increase in BTE. Sun et al. (2020) and Ayhan et al. (2020) investigated the effect of biodiesel on the exhaust gas recirculation (EGR) equipped diesel engine. They observed a decrease in NOx and an increase in CO, HC and PM as the effect of EGR. These non-similar results due to the above reasons show the necessity of conducting more researches to reach lower engine emissions with increase or without decrease in engine performance characteristics. For specific bio-sources of ethanol and biodiesel, engine type and operation conditions are needed to find lower emissions and better performance. Some researches should be conducted to find new bio-sources and new additives that decrease engine emissions and enhance the performance of the engines. Liu et al (2017) observed that engine performance with adding an additive to biodiesel causes to improve the diesel engine performance. Fangsuwannarak et al. (2016), Dueso et al. (2018) and Kolli et al. (2019) approved the positive effect of additives in reducing NOx emission. Devarajan (2019) reported that adding di-methyl-carbonate to biodiesel blends can decrease diesel engine emissions. Also Yang et al. (2017) observed the positive effect of additives on reduction of some emissions but not all of them. Gad and Jayaraj (2020) reported that adding nano-additives to Jatropha biodiesel-diesel blends caused to improve the performance and emissions of diesel engine. Also above non-similar finding, show the necessity of optimization of component percentages of diestrol to find the optimum diesel engine characteristics at each operation condition of the engine, i.e. finding optimum performance and emissions for engine load, rotational speed, and injection pressurize and timing. As, literature relieved that the influence of diestrol components was optimized in point of engine emissions (Khoobbakht et al., 2016) or engine performance (Khoobbakht et al., 2019) individually, here it is recommended to optimize both engine performance and emission together to find the optimal percentages of diestrol in point of both engine performance and emissions' characteristics. Using new analytical approaches such as numerical methods (Li et al., 2018) for optimization of the diestrol components can help to reach better engine performance characteristics and lower emissions. Also optimization of additive types and amounts can be benefit in this regard.

8. CONCLUSION

According to the presented results of investigations in the field of the effects of blending biofuels into fossil diesel on the engine performance characteristics (BTE, BEP, BET, and BSFC) and exhausted pollutions (CO, CO_2, HC, NOx, and smoke), the effects of ethanol and biodiesel fuels on the characteristics of diesel engines are different due to biofuel sources, type, age and healthiness of diesel engine, as well as working operation that cause to observe different trends in the tests. Because of different trends of diesel engine characteristics with increasing ethanol and biodiesel portions in the blend fuels, optimization of the fuel components as an important subject recently has been researched. The simultaneous optimization of both engine performance and emission characteristics is recommended.

In general, increasing the portions of biodiesel and ethanol reduces the smoke and sulfur. From the low to mid-volume of biodiesel and ethanol in BED blends, CO and HC decrease whereas CO_2 and NOx increase. However, there are reverse trends at high portions of biodiesel and ethanol. These finding limits using high percentages of biodiesel and ethanol in the BED blends that emphasizes on more researches in this field to solve the problem. Using high percentages of biodiesel and ethanol may necessitate some required modifications in the structure of diesel engine, equipping the engine with some facilities, or finding optimal parameters of engine to reach lower emissions and better performance.

Abbreviations

BA	Biodiesel-alcohol	ED	Ethanol-diesel
BD	Biodiesel-diesel	HC	Hydrocarbons
BE	Biodiesel-ethanol	MD	Methanol-diesel
BED	Biodiesel-ethanol-diesel	NO_x	Nitrogen oxides
BEP	Brake engine power	NO_2	Nitrogen dioxide
BET	Brake engine torque	PB	Pure biodiesel
BM	Biodiesel methanol	PE	Pure ethanol
BMD	Biodiesel-methanol-diesel	PD	Pure diesel
BSFC	Brake specific fuel consumption	PM	Particulate matters
BTE	Brake thermal efficiency	SO_X	Sulfur oxides
CO	Carbon monoxide	THC	Total hydrocarbons
CO_2	Carbon dioxide	UHC	Unburned hydrocarbons

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