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A Review Study on the Using of Diethyl Ether in Diesel Engines: Effects on CO_2 Emissions

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Keywords：Diesel engines, CO_2 emissions, fuel additives, diethyl ether blends.

ABSTRACT

Vehicle and other fuel combustion emissions can change the composition of the atmosphere, increasing its ability to trap heat. Gases that are effective in trapping heat are called greenhouse gases and include all of the gases in vehicle emissions. The major component of greenhouse gases emissions is carbon dioxide (CO_2). Reduction of CO_2 emissions has become a concern worldwide. Introduction of biofuels to fueling of automotive engines is the one method to decrease emissions of greenhouse gases. The CO_2 from biofuels, is emitted during combustion and absorbed during growth of tree end plants. These biofuels can be applied as blends or sole fuels. The most researches declare that the best way to reduce greenhouse emissions is the use of various biofuels. Therefore, it is very important that the results of various studies on alternative fuels or fuel additives are evaluated together to practice applications. On the other hand, diesel cars are also helping to reduce CO_2 emissions. For these reasons, this study especially focuses on the use diethyl ether in diesel engines as fuel or fuel additive in various diesel engine fuels. This review study investigates the effects of diethyl ether addition on the CO_2 emissions.

INTRODUCTION

Diesel engines are widely used in both light and heavy duty vehicles (Manikandan and Sethuraman, 2014). They are reliable, robust and the most efficient internal combustion engines (Londhekar and Kongre, 2017). However, they are suffer from their high emission drawbacks like particulate matters (PM), total gaseous hydrocarbons (THC), nitrogen oxides (NOx), sulfur oxides (SOx) and smoke (Hagos et al, 2017; Patil and Marlapalle, 2016). It is seemed that the most suitable way to reduce of these emissions is the using of alternative fuels made from renewable sources instead of commercial fuels (Geng et al, 2017). operational and technical limitations (Kumar and Saravanan, 2016). The fuel side modification techniques such as blending, emulsification and oxygenation are the easy way for emission reduction without any modification on the engine hardware. Modification of diesel fuel to reduce exhaust emission can be performed by increasing the cetane number, reducing fuel sulphur, reducing aromatic content, increasing fuel volatility and decreasing the fuel density to have the compromise between engine performance and engine out emissions, one such change has been the possibility of using diesel fuels with oxygenates (Patil and Taji, 2013). Among different alternative fuels, oxygenated fuel is a kind of alternative fuel. Diethylene glycol dimethyl ether (DGM), dimethoxy methane (DMM), dimethyl ether (DME), methyl tertiary butyl ether (MTBE), dibutyl ether (DBE), dimethyl carbonate (DMC), methanol, ethanol and diethyl ether (DEE) have played their role to reduce diesel emissions (Patil and Taji, 2013; Senthilkumar et al, 2012; Saravanakumar et al, 2014). These fuels can either be used as a blend with conventional diesel fuel or pure. These additives can also be used in combination with biodiesel (Jawre et al, 2016). The presence of oxygen in the fuel molecular structure plays an important role to reduce PM and other harmful emissions from diesel engines. However, NOx emissions can be reduced in some cases and be increased depending on the engine operating conditions (Chauhan et al, 2016; Valipour, 2014). Especially, DEE is a suitable fuel for diesel engines due to it is a cetane improver besides an oxygenated fuel (Krishnamoorthi and Malayalamurthi, 2016). Therefore, this review study is devoted to use of DEE in diesel engines as fuel or fuel additive in various diesel engine fuels.

PROPERTIES OF DIETHYL ETHER

Diethyl ether is the simplest ether expressed by its chemical formula CH3CH2-O-CH2CH3, consisting of two ethyl groups bonded to a central oxygen atom as seen in Fig. 1. Diethyl ether (DEE) is regarded as one of the promising alternative fuels or an oxygen additive for diesel engines with its advantages of a high cetane number and oxygen content. DEE is liquid at the ambient conditions,

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which makes it attractive for fuel storage and handling. DEE is produced from ethanol by dehydration process as seen in Fig. 2 so it is a renewable fuel (Bailey et al, 1997).

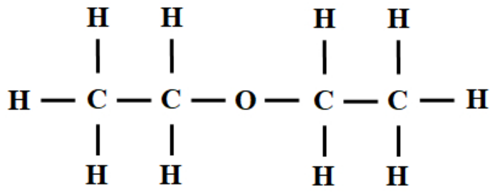


Fig. 1. Diethyl ether chemical composition (Hagos et al, 2017)

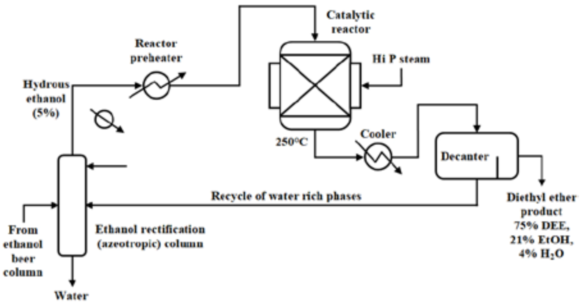


Fig. 2. Production of diethyl ether from ethanol (Bailey et al, 1997)

As shown in Table 1, DEE has several favorable properties, including exceptional cetane number, reasonable energy density, high oxygen content, low autoignition temperature and high volatility. Therefore, it can be assist to improving of engine performance and reducing the cold starting problem and emissions when using as a pure or an additive in diesel engines (Bailey et al, 1997; Sezer, 2011).

Table 1. The main fuel properties of diesel and DEE

Property	Diesel	DEE
Chemical formula	C_xH_y	$C_4H_{10}O$
Molecular weight	190-220	74
Density of liquid at NTP* (kg/L)	~0.84	0.71
Viscosity at NTP* (cP)	2.6	0.23
Oxygen content (wt %)	-	21
Sulfur content (ppm)	~250	-
Boiling temperature (°C)	180-360	34.6
Autoignition temperature in air (°C)	315	160
Flammability limit in air (vol %)	0.6-6.5	1.9-9.5
Stoichiometric air-fuel ratio (AFR_s)	14.6	11.1
Heat of vaporization at NTP* (kJ/kg)	250	356
Lower heating value (MJ/kg)	42.5	33.9
Cetane number (CN)	40-55	125

*NTP: Normal temperature and pressure

There are some challenges with DEE such as storage stability, flammability limits and lower lubricity. Storage stability of DEE and DEE blends are of concern because of a tendency to oxidize, forming peroxides in storage. It is suggested that antioxidant additives may be available to prevent storage oxidation. Flammability limits for DEE as seen in Table 1 are broader than those of many fuels, but the rich flammability limit of DEE is in question (Bailey et al, 1997).

STUDIES ON DIETHYL ETHER

There are a number of studies in literature on the use DEE in diesel engines as a fuel or fuel additive in various diesel engine fuels. For example; as pure (Mohan et al, 2017), with diesel fuel (Rakopoulos et al, 2012; Rakopoulos et al, 2013, Patil and Thipse, 2016; Rathod and Darunde, 2015; Karthik and Kumar, 2016; Banapurmath et al, 2015; Lee and Kim 2017; Saravanan et al 2012; Ibrahim, 2016; Likhitha et al, 2014; Kumar and Nagaprasad, 2014, Balamurugan and Nalini, 2016; Madhu et al, 2017; Danesha and Manjunath, 2016; Prasadarao et al, 2014; Cinar et al, 2010), with diesel-ethanol blends (Iranmanesh, 2013; Sudhakar and Sivaprakasam, 2014a; Sudhakar and Sivaprakasam, 2014b; Sudhakar and Sivaprakasam, 2014c; Paul et al, 2015; Paul et al, 2017; Lukhman et al, 2016; Kumar and Reddy, 2015), with diesel-ferric chloride blends (Patnaik et al, 2017), with diesel-kerosene blends (Patil and Thipse, 2015), with diesel-acetylene gas dual fuel (Mahla et al, 2012), with biogas (Sudheesh and Mallikarjuna, 2010), with liquefied petroleum gas (Jothi et al, 2007), with diesel-natural gas dual fuel (Karabektas et al, 2014), with ethanol (Polat, 2016; Mack et al, 2015), with various biodiesel fuels (Pranesh et al, 2015; Rakopoulos 2013; Rakopoulos et al, 2016; Rakopoulos et al, 2014; Krishna et al, 2014; Singh and Sahni, 2015; Jawre and Lawankar, 2014a; Jawre and Lawankar, 2014b; Rao and Reddi, 2016; Babu et al, 2012; Sivalakshmi and Balusamy, 2013; Ali et al, 2013; Ali et al, 2014; Kumar and Prasad, 2014; Satyanarayanamurthy, 2012; Rajan et al, 2016; Geo et al, 2010; Hariharan et al, 2013; Devaraj et al, 2015; Kaimal and Vijayabalan, 2016), with biogas-biodiesel blends (Barik and Murugan, 2016), with water-biodiesel emulsion fuel (Sachuthananthan and Jeyachandran, 2007), with various biodiesel-diesel blends (Krishnamoorthi and Malayalamurthi,2017; Roy et al, 2016; Kumar et al, 2015; Kumar, 2017; Ganesha and Chethan, 2016; Srihari et al, 2017; Karthick et al, 2014; Satya et al, 2011; Abraham and Thomas, 2015; Firew et al, 2016; Prasad et al, 2012; Biradar et al, 2011; Manickam et al, 2014; Channe and Kulkarni, 2015; Nagdeote and Deshmukh, 2012; Vadivel et al, 2015; Mallikarjun et al, 2013; Sudhakar and Sivaprakasam, 2014; Krishnamoorthi, 2015; Sathiyamoorthi et al, 2017; Imtenan et al, 2015a; Akshatha et al, 2013; Kumar and Rao, 2014; Annamalai et al, 2014; Ali et al, 2016a; Ali et al, 2015; Ali et al, 2016b; Imtenan et al, 2014; Imtenan et al, 2015b; Varaprasad and Rao, 2017; Muneeswaran et al, 2016; Samuel et al, 2016; Pugazhvadivu and Rajagopan, 2009; Muneeswaran and Thansekhar, 2015; Navaneethakrishnan and

Vasudevan, 2015; Tudu et al, 2016; Murugan et al, 2017; Krishnamoorthi and Natarajan, 2015; Senthil et al, 2015), with ethanol-biodiesel-diesel blends (Venu and Madhavan, 2017a; Venu and Madhavan, 2016; Qi et al, 2011; Venu and Madhavan, 2017b) and methanol-biodiesel-diesel blends (Venu and Madhavan, 2017b).

EFFECTS ON CO_2 EMISSIONS

Sezer (2011) declared that CO_2 with DEE was lower than diesel fuel for all conditions due to simpler chemical structure and lower carbon content of DEE. Karthik and Kumar (2016) declared that percentage of DEE was increased in the blends, the amount of CO_2 decreased as seen in Fig. 3. Diesel fuel showed the highest CO_2; where as DEE20 showed the least. The amount of CO_2 also increased, when percentage of EGR increased.

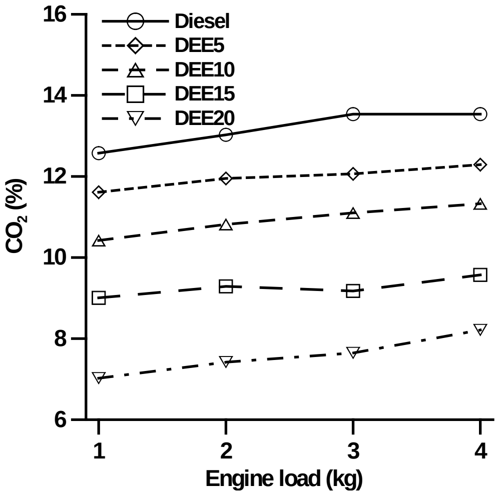


Fig. 3. Effect of DEE addition on CO_2 emissions of diesel fuel (Karthik and Kumar, 2016)

Prasadarao et al (2014) declared that pure biodiesel produced lower CO_2 emissions than diesel fuel as seen in Fig. 4. The blending 5% DEE with biodiesel and diesel fuels gave the same CO_2 emissions for all engine load conditions. The highest CO_2 emissions were obtained with the BD80DEE5 blend, while the BD15DEE5 blend presented the lowest CO_2 emissions at all engine loads. This was due to biodiesel was a low carbon fuel and had a lower elemental carbon to hydrogen ratio than diesel fuel.

Patnaik et al (2017) declared that CO_2 emission decreased by DEE15 blend about 0.3% compared to diesel at full load as seen in Fig. 5. The decrease in CO_2 emission could be related to lower of molecular carbon in DEE which leading to decrease in CO_2.

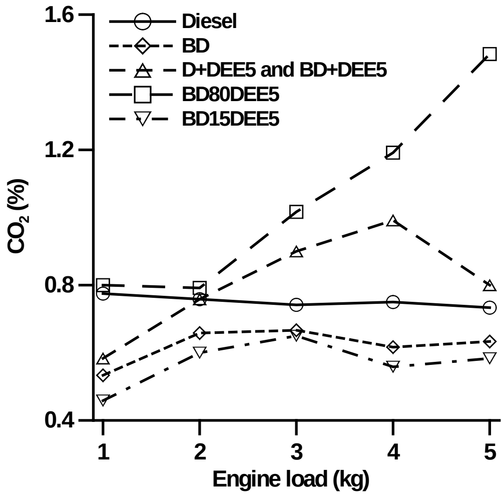


Fig. 4. Effect of DEE addition on CO_2 emissions of biodiesel fuel (Prasadarao et al, 2014)

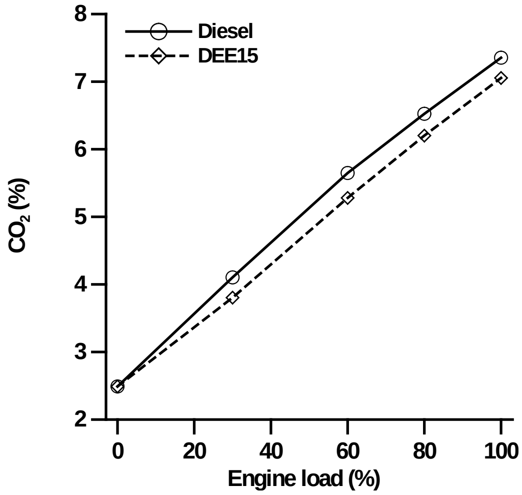


Fig. 5. Effect of DEE addition on CO_2 emissions of diesel fuel (Patnaik et al, 2017)

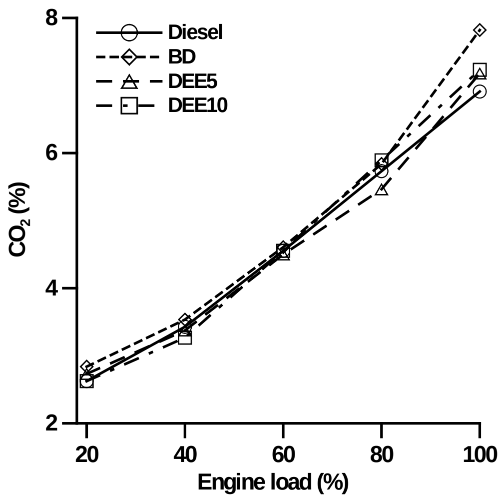


Fig. 6. Effect of DEE addition on CO_2 emissions of biodiesel fuel (Devaraj et al, 2015)

Devaraj et al (2015) declared that for diesel, CO_2 emission was 2.6% at 20% load and 6.9% at full load as seen in Fig. 6. For biodiesel, it was 2.87% at 20% load and 7.8% at full load. For DEE5 and DEE10, it was 2.8% and 2.6% at 20% load and at full load it reached 7.2% for both. From this, it could be observed that CO_2 emission was increasing in case of biodiesel, when compared to diesel. But for DEE5 and DEE10 the values were not changing at higher loads. This indicated that the increase in the amount of DEE beyond a certain limit did not affect the formation of CO_2 at higher loads due to the presence of reduced amount of carbon to hydrogen ratio and excess oxygen.

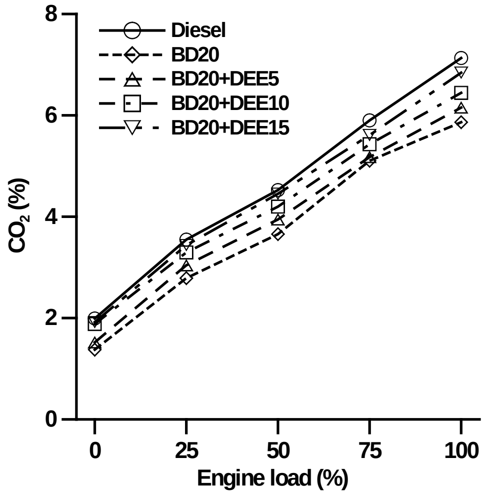
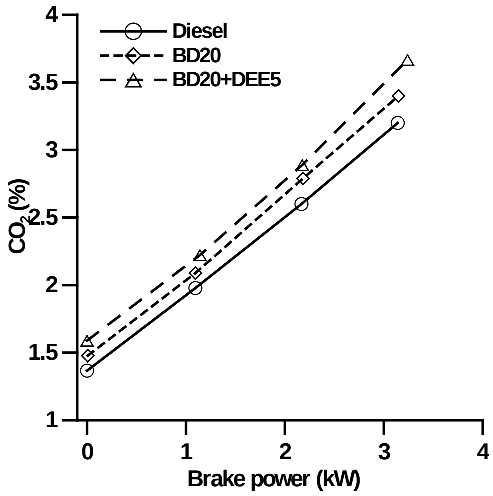


Fig. 7. Effect of DEE addition on CO_2 emissions of diesel-biodiesel blends (Kumar et al, 2017)

Kumar et al (2017) declared that the percentage of CO_2 by volume of diesel and BD20 blend are 7.1, and 5.6% respectively as seen in Fig. 7. But, adding DEE the result for BD20DEE5, BD20DEE10 and BD20DEE15 blends are 6.2, 6.4 and 6.8% respectively. The percentage decrease of CO_2 with respect to diesel and BD20 is 16.9% and 9.81% viz. with respect to diesel and BD20DEE10 blends by volume basis. Abraham and Thomas (2015) declared that CO_2 emission in the exhaust of internal combustion engine is indication of better combustion of fuel. CO_2 emission of BD20 and DEE5 blends is higher than that of diesel fuel due to complete combustion of fuel taking place because of the extra availability of oxygen as seen in Fig. 8.

CO_2 emission increases by increasing load, as seen in Fig. 9. With increase in DEE percentages in the blend, CO_2 emission is also increased. More amount of CO_2 in exhaust emission is an indication of the complete combustion of fuel. Combustion of fossil fuels will be producing carbon dioxide and which will be accumulated in to the atmosphere and leads to many of the environmental problems. Though, combustion of the biofuels produces carbon dioxide, oil-yielding crops are readily absorbing these and hence carbon dioxide levels are kept balance (Varaprasad and Rao, 2017).



(b)

Fig. 8. Effect of DEE addition on CO_2 emissions of diesel-biodiesel blends (Abraham and Thomas, 2015)

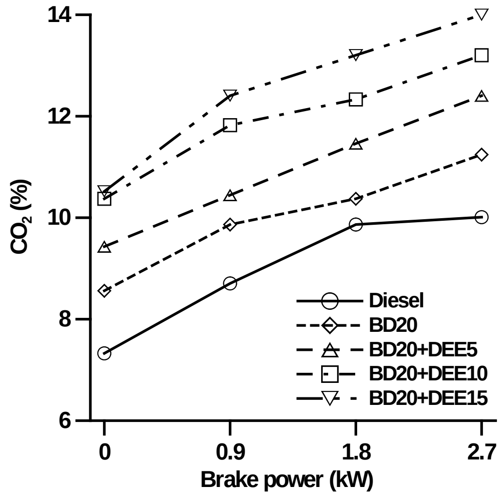


Fig. 9. Effect of DEE addition on CO_2 emissions of diesel-biodiesel blends (Varaprasad and Rao, 2017)

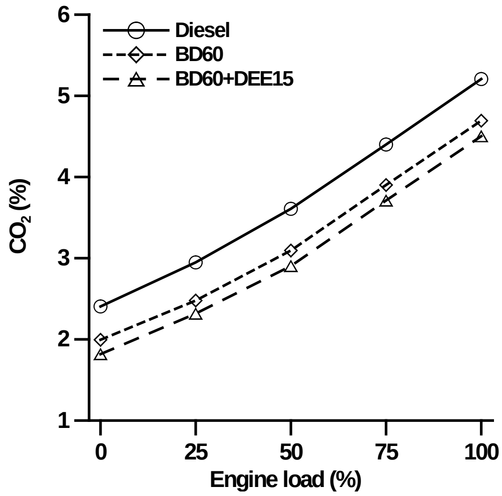


Fig. 10. Effect of DEE addition on CO_2 emissions of diesel-biodiesel blends (Samuel et al, 2016)

CO_2 emissions are lesser at lesser loading and went on increasing till full load for all the fuels tested.

Lesser concentration of oxygen at lesser loading, and increasing oxygen concentration at higher loads may be the reason for the variation in CO_2. This larger quantity of carbon at higher loads is oxidized to CO_2 have resulted in higher CO_2 emissions at higher loads. It is also noticed from Fig. 10 that the diesel fuel is having higher CO_2 emissions when compared with other biodiesel blends at all varying conditions. Higher oxygen content in biodiesel is the reason for lesser CO_2 emissions. Thus it is found that addition of diethyl ether to biodiesel blend has significantly reduced a CO_2 emission which is lowest for the fuels tested (Samuel et al, 2016).

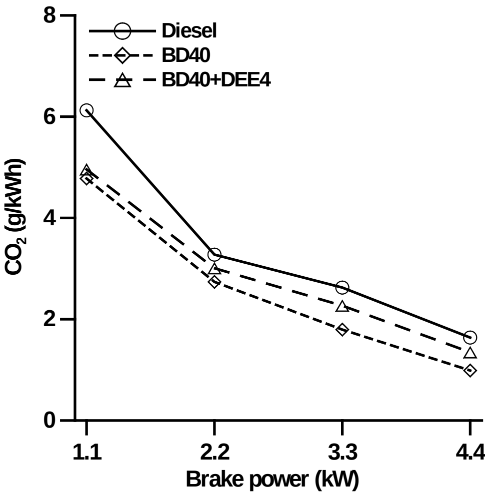


Fig. 11. Effect of DEE addition on CO_2 emissions of diesel-biodiesel blends (Tudu et al, 2016)

CO_2 emission indicates the complete combustion, due to sufficient amount of oxygen being available in the air-fuel mixture, or sufficient time in the cycle for complete combustion. It can be seen from Fig. 11 that diesel fuel produces the highest CO_2 emission among all fuels tested, as a result of more complete combustion of fuel. The carbon to hydrogen ratio is one of the important parameters and their nature of bonding determines the energy characteristics and combustion nature of hydrocarbon fuels. CO_2 in the exhaust will decrease when the carbon to hydrogen ratio deceases in the fuel. Higher density and lower volatility of BD40 result in lower CO_2 emission in comparison with the diesel operation. When DEE is added to the BD40 blend, the CO_2 emission is increased in the entire load spectrum. The oxygen present in the DEE may promote the combustion of the DEE4 blend, and hence, marginally higher CO_2 is produced than that of BD40. The CO_2 emission for DEE4 is approximately about 18% lower compared to that of diesel, and about 22% higher than that of the BD40 blend at full load (Tudu et al, 2016).

Fig. 12 depicts the variation of carbon dioxide with brake power. Carbon dioxide which is a chief inhibitor of greenhouse gases forms an important role in combustion of oxygenated blends. DEE blends exhibit slightly increased CO_2 emissions which indicate that the DEE blends enhance the combustion. CO_2 and water vapor (H_2O) are the products of complete combustion. CO_2 for DEE5 and DEE10 were lower at lower loads. As the engine load increases, CO_2 emissions for DEE blends increases, indicating improved combustion with addition of DEE. Higher the rate of combustion is, higher the formation of CO_2 is. Thus, 1.3% increase in CO_2 for DEE5 and 6.8% increase in CO_2 for DEE10 is noticeable at 100 % engine loads (Venu and Madhavan, 2017a).

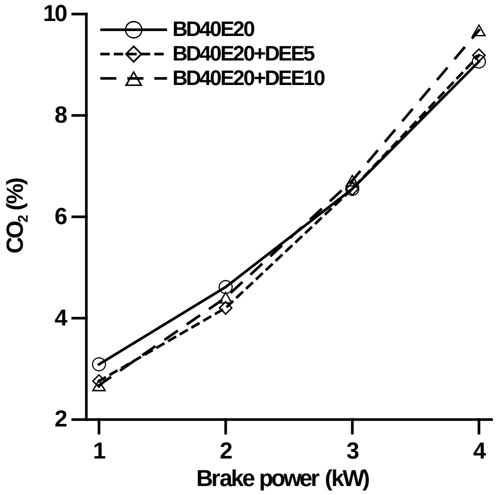


Fig. 12. Effect of DEE addition on CO_2 emissions of diesel-biodiesel blends (Venu and Madhavan, 2017a)

CONCLUSIONS

The effect of diethyl ether addition to various diesel engine fuels is investigated on CO_2 emisions in this review study. The following conclusions can be summarized as results of the study.

- Diethyl ether is regarded as one of the promising alternative fuels or an oxygen additive for diesel engines with its advantages of a high cetane number and oxygen content. DEE is produced from ethanol by dehydration process so it is a renewable fuel.
- Carbon dioxide is indicator of the complete combustion in the internal combustion engines. However, CO_2 emission is a chief inhibitor of greenhouse gases so the reduction of CO_2 emission is very important for global warming.
- The addition of diethyl ether to various fuels and fuel blends generally results in the reduction in CO_2 emissions due to simpler chemical structure and lower carbon content (carbon to hydrogen ratio) of diethyl ether. In the some studies (Abraham and Thomas, 2015; Varaprasad and Rao, 2017), CO_2 emission of diethyl ether blends is higher due to complete combustion of fuel taking place because of the extra availability of oxygen.
- The combustion of fossil fuels will be producing carbon dioxide and which will be accumulated in to the atmosphere and leads to many of the environmental problems. However, combustion of the biofuels produces carbon dioxide, oil-yielding crops are readily absorbing these and hence carbon dioxide levels are kept balance.

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