STUDY ON THE COMBUSTION CHARACTERISTICS OF A DIESEL ENGINE WITH EGR USING DEE AND BIOFUEL BLENDS

Dr. PRADIPTA KUMAR DAS
Associate Professor , Dept. of Mechnical Engineering, AryanInstitute of Engineering & Technology, Bhubaneswar
MANORANJAN PANDA
Department of Mechanical Engineering,Raajdhani Engineering college,Bhubaneswar, Odisha
Dr. BHARAT CHEDE
Department of Mechanical Engineering, NM Institute of Engineering and Technology,Bhubaneswar , Odisha

Abstract - The combustion and emission characteristics of compression-ignition engine with EGR using diethyl ether and biofuel blends are studied. A four-stroke single cylinder compression ignition engine is used for the experiment. The experiment is carried out at bothconstant and variable enginespeed conditions. The alternative fuels used for the study are DEE and butanol.Butanol isa biofuel that can be produced by alcoholic fermentation of the biomass feedstocks. Itis highly miscible in diesel than other alcohol based fuels and also a high energy density. Diethyl Ether(DEE) also has high miscibility in diesel. DEE has a high cetane number and oxygen content and hence a superior combustion quality. The blends used are neat diesel(D100), Diesel-90% Butanol-10%(D90B10) and Diesel-80% butanol-15% DEE-5%(D80B15DEE5). EGR system is also used in the simulations for studying the effects on emissions. The exhaust emission levelsof HC, CO and $NO_x$are observed. Other engine parameters such as indicated power, brake power, indicated specific fuel consumption and brake specific fuel consumption are analyzed. The D80B15DEE5 blend showed significantly lower emissions with minimal compromise of performance of the engine.

Keywords - Combustion, Butanol-diesel blend, Exhaust Gas Recirculation, Emissions.

I. INTRODUCTION

Fossil fuels play an important role in power generation. Fuels like gasoline, diesel etc. are synthesized from crude oil. Diesel is one of the most extensively used fuels in the world.It is used mainly due to its high thermal efficiency for both internal and external combustion engines. However, there are some drawbacks for using diesel as a fuel. One of the main reasons is the environmental pollution caused due to the emission of compounds likeNO_x, CO, HC and soot. The other reason is its limited availability, it is estimated that at the current rate of usage, crude oil will not last more than 60 years from now. The emission of NO_x, CO and HC may lead to the damage of ozone layer and thus global warming. The emissions from vehicles contain harmful substances which cause a range of pulmonary diseases in people. The combined effects of environmental pollution and non-renewability gives rise to the need of alternative fuels that can lower harmful emissions and still keep up the engine performance characteristics.

Diethyl Ether(DEE) of formula $(C2H5)_2O$ is one of the most prominent renewable fuels. It is very effective due to its high volatility and oxygen content. It also has low autoignition temperature. With a very high cetane number DEE is a great alternative fuel. It is easily synthesized by the dehydration process of ethanol. DEE can be handled easily due to its presence in liquid state at room temperature. It can be easily injected by portable injector due to its low viscosity. Storage of DEE is a concern due to its tendency to form peroxide during room temperature[6].

Butanol is a highly effective alternative fuel because of its high energy density and excellent emission characteristics. Butanol is better than other alcohol based fuels like ethanol and methanol as a fuel[11]. It can be synthesized by fermentation of algae, corn and other materials containing cellulose. Butanol can blend with diesel easily due to its low volatility and ignition temperature[7]. Butanol is a major factor in reducing NO_x emissions[10]. Due to its high energy density the performance of the engine is also not hindered by its use. Fuels like ethanol causes a major performance loss.Also, the oxygen content in butanol helps decrease the CO and soot emissions.

Usage of blended fuels doesn't give the best results forNO_x emissions due to the oxygen content in the compounds. An effective method to furtherdecrease NO_x is exhaust gas recirculation (EGR).Exhaust gas recirculation is a highly effective and efficient strategy to control NO_x emissions from diesel engines. The EGR reduces NO_xformation by lowering the oxygen concentration in the cylinder. It also helps inheat absorption in the combustion chamber. It is a low costand very reliable method to decrease the NO_x emissions. The basic block diagram of a conventional EGR system is shown in figure 1.

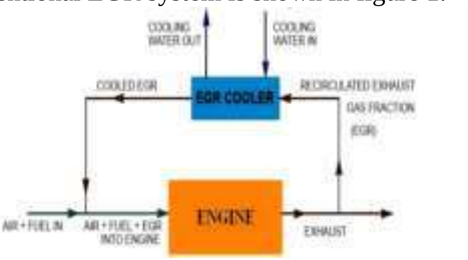

Figure 1: EGR Block Diagram

The alternative fuels used in the blends can be synthesized naturally. Butanol can be procured from biomass feedstocks and is also produced during fermentation by solvent producing bacteria in the ABE fermentation process. Ethanol is produced by vapor-phase hydration of ethylene to make ethanol. DEE is produced as a by-product during this process. DEE is produced on an industrial scale by acid-ether synthesis. A major source of ethylene, from which DEE is synthesized, is organic waste like fruits peels etc. Thus, butanol and DEE naturally produced biofuels with chemical properties that support their use as alternative fuels[9].

The reserves of crude-oil are very limited and the usage level all over the world is increasing rapidly. In the past decade, the price gap shrink between the petrol and diesel indicates the increase in demand for diesel especially in the automobile industry. The emissions from the increasing use of vehicles is a major contributor to Global climate change. The transition to Electric Vehicles is the best solution to these problems, but this transition can be achieved only in a long term. Also, the sudden change to EVs is not feasible in developing and under-developed countries. The process of transition can be made much more efficient by the use of alternative fuels. These fuels reduce the use of diesel and hence the demand for it. They also reduce emissions of harmful gasses to help inhibit climate change on a global scale.

II. SELECTION OF BLENDS

The addition of butanol and DEE to diesel helps decreasing emissions only when these are blended in appropriate proportions. The blend must be such that the emissions are controlled and the engine performance is not diminished. Thus, the importance of selection of the correct blend ratio is paramount. The fuel properties of diesel, Butanol and DEE are shown in Table 1.

Butanol is the best choice for an alternative fuel when compared to other alcohol based fuels like ethanol, propanol etc. A 20% blend of butanol with diesel showed the lowest emissions of NO_x at most of the engine loads when compared to ethanol, heptanol and other alcohol blends[1]. Also, the brake thermal efficiency was higher in the 10% butanol blend.Butanol has a lower calorific value and cetane number than diesel but a very high latent heat of vaporization. Thus, an excess amount of butanol in the blend leads to a lower overall calorific value of the fuel blend thus leading to a higher brake specific fuel consumption(BSFC). Due to its high latent heat of vaporization, butanol absorbs the heat in the cylinder during combustion due to which the in-cylinder temperature decreases. A lower cylinder temperature leads to reduced NO_x emission at the exhaust.

The HC emissions was observed to be increasing with butanol content in diesel[2]. The 20% butanol blend showed the highest HC emission level. This is because of the high carbon content in butanol resulting in hydrocarbon emission at the exhaust. These results show the limiting factors of the use of butanol.

S.No.	Properties	Diesel	Butanol	DEE
1	Calorific value(kJ/kg)	43500	33100	33483
2	Density @ 20°C(kg/m3)	815	808	714
3	Flash point(°C)	70	35	-45
4	Viscosity @40°C(mPa s)	2.95	2.63	0.22
5	Latent heat of evaporation(kJ/kg)	250	716	460
6	Cetane number	52	35	96

Table 1: Fuel Properties

DEE is a prominent alternative fuel because of its excellent combustion qualities. The high cetane number and energy density make it a good fuel[8]. It is reported that NOx emissions are reduced for 5%DEE and 19% ethanol blends in diesel at all engine loads[3]. The CO emissions reduces for the DEE blend at medium and higher engine loads. BSFC is also slightly lower for DEE blend when compared to biodiesel-ethanol blend indicating an improvement in performance. It is observed that the BSFC is lower for70%diesel, 25%biodiesel, 5% DEE than the blend with 20%biodiesel and 10%DEE[4]. This is because of the lower calorific value and high enthalpy of vaporization of DEE. The 5% DEE blend also gave the best brake thermal efficiency for most of the engine loads. This is because of its excellent combustion properties. Thus, excess DEE in the fuel blend can deteriorate engine performance.

EGR is an effective method in reducing emissions and also helps enhance fuel efficiency[5]. As seen in [3], when an ethanol and diesel blend is tested by varying the EGR rate, the NO_x emissions are reduced significantly as the EGR rate is increased from 0 to 40%. An increase in CO and HC emissions with EGR rate is also observed. The CO and HC emissions increase significantly only after 30% recirculation rate. The decrease in NO_x is because the mixing of exhaust gases with inlet air reduces combustion temperature which leads to reduced formation of NO_x. The increase in CO and HC emissions is due to the carbon content in the exhaust gases which are recirculated. Thus, there is a tradeoff between NO_x and CO, HC emissions.

The effects of butanol and DEE on engine performance and emissions are taken into account and are used nominally with diesel for simulations. The EGR rate is also varied appropriately to give the best emission and performance results.

III. SIMULATION SETUP

The simulations are done on RicardoWave-2019.1 software. The fuel files of Butanol and DEE were created using the required properties. The simulation parameters were also set. The diesel engine used in the simulations have a bore diameter of 80mm and stroke length of 85mm with a compression ratio of 22. The simulations are done for the three blendswithout the EGR system. The simulations are also done for the D80B15DEE5 blend with EGR system in place. The block diagram of the engine setup with EGR system and the required sensors is shown in figure 2.

The block diagram shows the engine components required for the simulations in the required configuration. The EGR system is also attached to the engine setup. A fuel injector is also fixed to the engine. The inlet and exhaust gas flow rates are measured using flow rate sensors.
The flow rate output is fed to a function which calculates the recirculation rate for EGR. The rate output is then fed to a PID controller which is connected to an actuator. The actuator controls the orifice diameter for EGR system. The orifice thus acts as an EGR valve based on the inlet and exhaust flow rates.

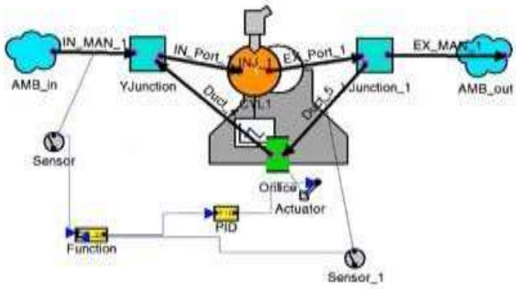

Figure 2: Engine setup block diagram

The simulations are performed for neat diesel(D100), Diesel-90% Butanol-10%(D90B10) and Diesel-80% butanol-15% DEE-5%(D80B15DEE5). The performance parameters measured are brake power, indicated power, BSFC and ISFC. The emission levels of NO_x, CO and HC are also measured. The EGR rate is varied from 0% to 25% for the simulations.

IV. SIMULATION RESULTS – WITHOUT EGR

The simulation results without installing the EGR system is shown in Table2. The simulations were performed for both constant speed and variable speed. The results for simulations at constant engine speed 3000rpm are shown in Table 2.

Engine and emission parameters	Units	At 3000rpm		
		Pure diesel	D90B10	D80B15DEE5
Indicated Power	kW	18.17	18.165	17.77
Brake Power	kW	11.53	11.64	11.354
CO	ppm	1180.34	613.03	497.821
NO_x	ppm	3891.8	3067.8	2851.28
HC	ppm	68.49	66.57	64.674
BSFC	kg/(kW.h)	0.219	0.2174	0.223
ISFC	kg/(kW.h)	0.187	0.1868	0.191

Table 2 : Results – without EGR

Table 2 shows that the decrease in Indicated and brake power is less than 3% for both the blends when compared to pure diesel. The increase in fuel consumption(ISFC and BSFC) is also less than 3% when compared to pure diesel. The NO_x emissions decreased by more than 20% for the blends D90B10 and D80B15DEE5 when compared to diesel. The decrease in CO emissions is observed to be around 50%. There is an increase of less than 5% in HC emissions for both the blends compared to pure diesel. The simulations were performed for the three fuels with varying engine speed from 1999rpm to 3999rpm. The brake power, BSFC, NO_x, CO and HC emissions were measured for the varying speed.

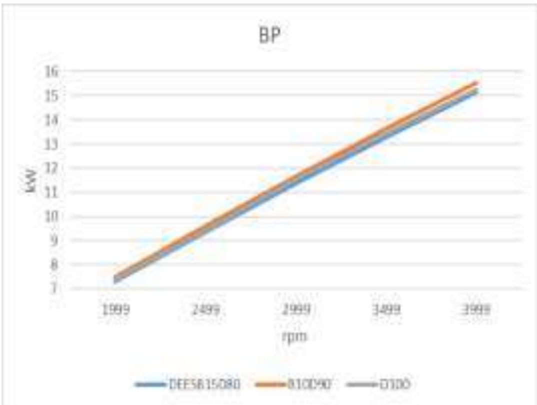

Figure 3: BP vs Engine Speed

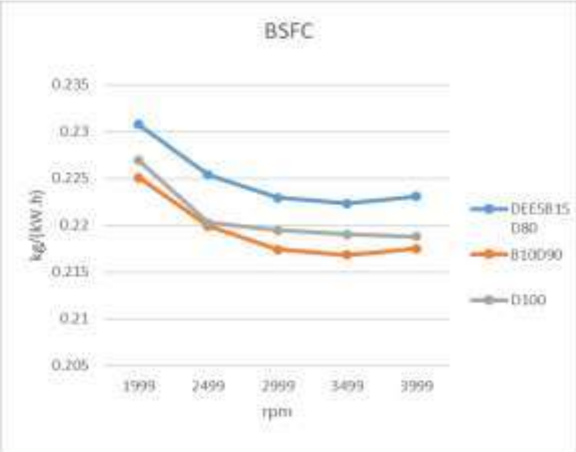

Figure 4: BSFC vs Engine Speed

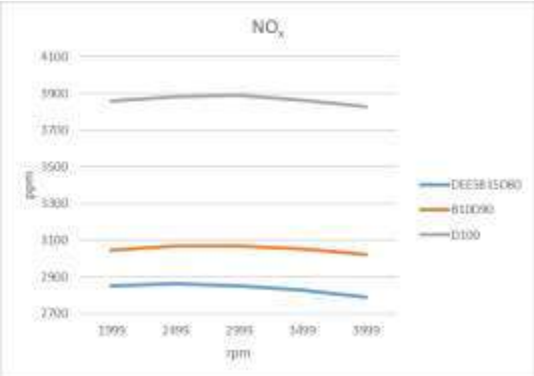

Figure 5: NO$_x$ vs Engine Speed

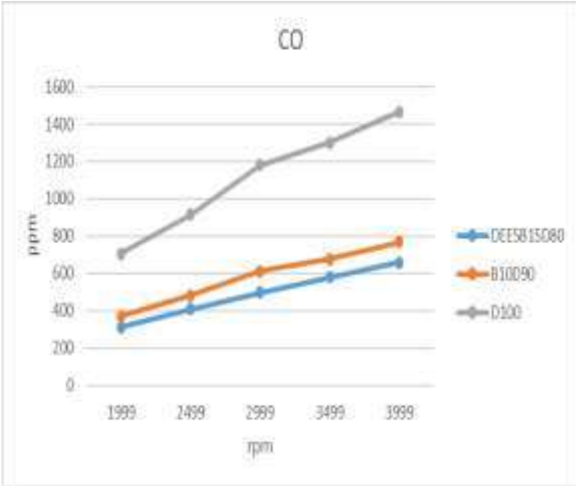

Figure 6: CO vs Engine Speed

Figure 3 shows that there is a small difference in brake power for the three tested fuels. Figure 4 shows that the fuel consumption is highest for D80B15DEE5 for all engine speeds. The Figures 5 and 6 show the NO_x and CO emissions for different engine speeds. The NO_x and CO emissions in D80B15DEE5 blend is significantly lower compared to pure diesel.

The D90B10 blend also showed lower NO_x and CO emissions. It is also observed that the HC emissions is lowest for D80B15DEE5. The HC emissions is almost constant for all engine speeds in all the 3 fuels tested.

V. SIMULATION RESULTS – WITH EGR

.

The simulation is performed with an EGR system in place for the blend D80B15DEE5. The EGR rate is varied from 0 to 25% and the parameters are measured over 5 cases. In case-1 the EGR rate is 0% whereas at case-5 the EGR rate is 25%. The 5 cases are equally distributed over 0 to 25%. The performance parameters measured are brake power, indicated power, BSFC and ISFC. The emission levels of NO_x, CO and HC are also measured. The engine speed is 6000rpm.

Table 3 shows that the brake power and indicated power decreased gradually with the increase in recirculation rate. The decrease in power from 0 to 25% EGR is about 30%. The brake specific fuel consumption increases by about 10% with the increase in EGR rate from 0-25%. The increase in ISFC is observed to be less than 0.5%.

Parameters	Units	D80B15DEE5 at 6000rpm				
		Case-1	Case-2	Case-3	Case-4	Case-5
Brake Power	kW	19.59	18.15	16.68	15.20	13.75
Indicated Power	kW	25.63	24.12	22.58	21.03	19.50
BSFC	kg/(kW.h)	0.26	0.268	0.273	0.279	0.29
ISFC	kg/(kW.h)	0.20	0.201	0.2014	0.202	0.2021
CO	ppm	944	640.99	416.77	260.51	155.63
HC	ppm	63.47	59.88	56.31	52.66	49.12
NO_x	ppm	4684.5	3621.8	2410.74	1345.3	648.1

Table 3 : Results – with EGR

The NO_x emissions decreased rapidly with increase in EGR rate. The decrease is observed to be 85%. The CO emissions also decreased by a great amount due to EGR. The decrease is observed to be 80%. There is a 20% decrease in HC emissions as the EGR rate increased from 0 to 25%.

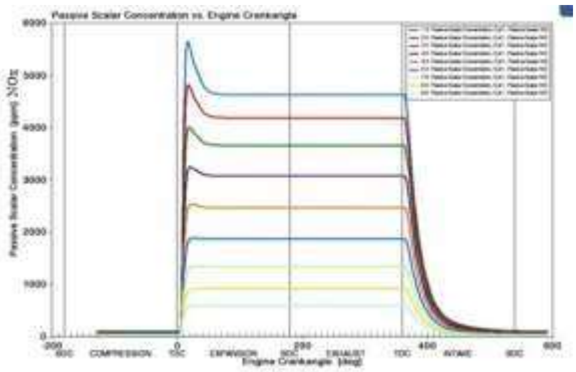

Figure 7: NO_x conc. vs Engine Crank angle

Figure 7 shows the graph plotted between NO_x concentration at the exhaust manifold and the engine crank angle for 9 cases of EGR rate from 0 to 25%. The NO_x concentration is highest near the TDC during combustion. And is almost constant during the expansion stroke. The NO_x concentration is lowest at a recirculation rate of 25%.

Figure 8 shows the graph plotted between brake power and the EGR rate from 0 to 25%. The Brake power linearly decreases with increase in recirculation rate.

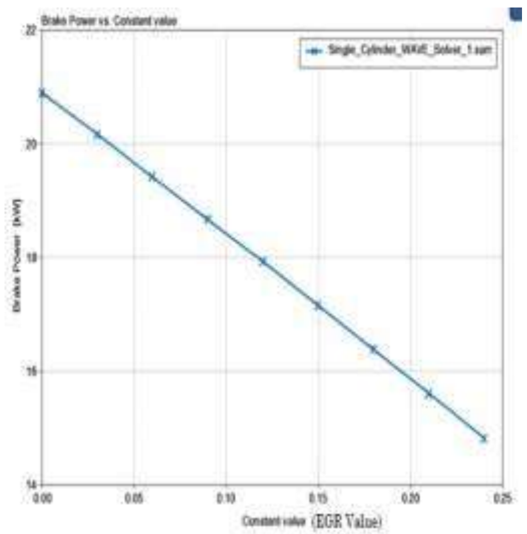

Figure 8: Brake Power vs EGR rate

VI. CONCLUSION

The simulation are done for the blends D100, D90B10 and D80B15DEE5. There is a decrease in brake power with the addition of butanol due to its lower calorific value. With increase in butanol the brake power further decreases but the emission levels are highly favorable. The addition of DEE improves the combustion quality of the fuel due to its high cetane number, volatility and oxygen content. This helps in avoiding a significant decrement in performance of the engine. DEE, being a cleaner fuel than diesel, further helps decrease emissions. The increment in BSFC is also attributed to the lower calorific values of butanol and DEE.

The butanol blend shows significantly lower emissions of NO_x and CO and further less emissions with DEE addition. Butanol and DEE have very high enthalpies of vaporization due to which the heat in the cylinder is absorbed by the two fuels. The lower cylinder temperature leads to a diminished NO_x formation. The NO_x emissions doesn't vary much with engine speed because it is a function of cylinder temperature. CO emissions are due to the incomplete combustion of fuels. The significant decrease in CO emissions in butanol and DEE blends is due to the oxygen content which helps in complete combustion. The high cetane number of DEE also helps complete combustion. The increase in CO emissions with engine speed is due to the more fuel combustion at higher speeds. There's only a small decrement in HC emissions with the blends because of the high carbon content in DEE and butanol.

The introduction of EGR helps reduce NO_x and CO emissions significantly. This also causes brake power to decrease and BSFC to increase. This is due to the reduced oxygen and flame temperature in the cylinder. The brake power decreases significantly as the recirculation rate increases and a EGR rate of 25% gave the lowest brake power. The 25% recirculation rate also recorded the lowest NO_x, CO and HC emissions. For obtaining low emissions without compromising much on engine performance, the EGR rate must be maintained between 10% and 20%. Thus, the D80B15DEE5 blend gives the best results in terms of performance and emissions

REFERENCE

[1] Mohamed Nour, Ali M.A. Attia, Sameh A. Nada , "Combustion, performance and emission analysis of diesel engine fuelled by higher alcohols (butanol, octanol and heptanol)/diesel blends", Energy Conversion and Management 185 (2019) 313–329

[2] Mingzhang Pan , Yuke Wang , Weiwei Qian , Changkun Wu , Haozhong Huang , Hao Li , Xiaorong Zhou, "Experimental and numerical study on flow, combustion and emission characteristics of CI engine fueled with n-butanol/diesel blends under post-injection strategy", Fuel 292 (2021) 120267

[3] Márcio Carvalho , Felipe Torres , Vitor Ferreira , Júlio Silva , Jorge Martins and Ednildo Torres, "Effects of Diethyl Ether Introduction in Emissions and Performance of a Diesel Engine Fueled with Biodiesel-Ethanol Blends" , Energies 2020, 13, 3787; doi:10.3390/en13153787

[4] Amr Ibrahim, "An experimental study on using diethyl ether in a diesel engine operated with diesel-biodiesel fuel blend", Engineering Science and Technology, an International Journal 21 (2018) 1024–1033

[5] Jichao Liang , Quanchang Zhang , Zheng Chen, Zunqing Zheng , Chao Yang, Qixin Ma, "The combustion and emission characteristics of diesel-ethanol blends with THF as

cosolvents in a diesel engine operating with EGR", Fuel 298 (2021) 120843

[6] Senthilkumar D. and Dr. Thirumalini S., "Investigation onEffect of Split Injection and Retarded Injection Timing on the Performance Characteristics of engines with Cashew nut shell biodiesel Blends", International Journal of Ambient Energy, 2020.

[7] S. P. M. Vignesh, Srihari S., and Dr. Thirumalini S., "Effectof dual fuel injection on the emission characteristics of a single cylinder ci engine using alcohol diesel blends with preheated air", International Journal of Engineering and Advanced Technology, vol. 8, no. 5, pp. 1395-1402, 2019.

[8] Ismet Sezer ,2018,"A Review Study on the Using of Diethyl Ether in Diesel Engines: Effects on NOx Emissions", International Journal of Automotive Engineering and Technologies ,e-ISSN: 2146 – 9067

[9] Srihari S., Chaitanya, B., and Dr. Thirumalini S.,"Experimental study on influence of diphenyl ether and diethyl amine on exhaust emissions of diesel engine", Materials Today : Proceedings., 2020

[10] Srihari S. and Dr. Thirumalini S., "Investigation on reduction of emissionin PCCI-DI engine with biofuel blends", Renewable Energy, vol. 114, pp. 1232 - 1237, 2017.

[11] Xudong Zhen , Yang Wang , Daming Liu,2020, "Bio-butanol as anew generation of clean alternative fuel for SI (spark ignition) and CI (compression ignition) engines", ELSEVIER, Vol. 147,pp. 2494-2521.