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Effect of Injection Timing and cold EGR on Performance and Emission Characteristics of a Stationary Single Cylinder DI-Diesel Engine Fueled with n-Butanol/Diesel Blends

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Abstract: Increasing road transport of automobile has increased its share on environmental pollution also usage of non renewable petroleum based fuels could cause energy crisis in near future. Hence to curtail the tailpipe emissions and to overcome the energy need, public bodies across the globe slowly enforcing the usage of renewable fuels. Utilization of renewable alcohols as fuel grabbed the attention of the researchers as they can be extracted from lignocellulosic bio-mass. In the present work the influence of EGR rate and injection timing on the performance and emission characteristics of a single cylinder, four stroke, direct injection diesel engine has been experimentally investigated using D70B30 (70% diesel and 30% butanol) blend as fuel. To conduct this study, we recorded the combustion and emission characteristics under nine operating conditions at three EGR rates (i.e. 10%, 20% and 30%) and three injection timings (i.e. 21°CA bTDC, 23°CA bTDC and 25°CA bTDC) under peak load at 5.3 bmep. Results indicate that there is increase in brake thermal efficiency for D70B30 blend upto 20% EGR and increasing the EGR rate there is a decline in the BTE when compared to neat diesel. With same EGR rate and injection timing D70B30 blend show 15% and 20% reduction in NO_x and smoke density respectively. When the EGR rate is increased there is a significant reduction in NO_x emission with heavy penalty in smoke emission. Advancing the injection timing reduced the smoke emission by 60% and 22% increase in NO_x concentration also gave better combustion behavior due to prolonged ignition delay. It may be concluded that n-butanol can be an excellent substitute for fossil diesel and long term durability tests have to be carried out for its commercial usage in the conventional diesel engines.

Keywords: n-butanol, engine, Injection Timing, Exhaust Gas Recirculation

Abbrevations

B(A)TDC	-	Before (After) Top Dead Centre
HRR	-	Heat Release Rate
CAS	-	Chemical Abstract Service
CO	-	Carbon monoxide
DI	-	Direct Injection
ULSD	-	Ultra low sulfur diesel
BTE	-	Brake Thermal Efficiency
D70B30	-	70% Diesel + 30% n-butanol blend by vol.
HC	-	Hydrocarbons
NO_x	-	NitrogenOxides
EGR	-	Exhaust gas recirculation

I. INTRODUCTION

Diesel engines are indispensable equipment in public transportation, heavy duty machinery, power generation, agricultural and industrial equipment owing to their higher fuel-conversion efficiency, higher power output, higher torque capacity, higher durability and higher reliability than gasoline engines[1]. Conventional fossil fuel reserves are not only limited but also nonrenewable in nature and as such they may deplete completely or may lead to a considerable world crisis when the demand exceeds supply, also associated stringent emission protocols compel the research community to explore alternative renewable fuels for diesel engines. The use of fossil diesel in diesel engines produces high NOx (nitrogen oxides) and soot emissions that are detrimental to both environmental and human health [2, 3]. To avoid the problems associated to fossil fuels, it becomes necessary to use cleaner and renewable energy sources. According to EPA regulations transportation fuel sold in the U.S. must contain a minimum volume of renewable fuel to reduce greenhouse gas emissions and the use of petroleum fuels.

Recently renewable energy sources have grabbed the attention of the researchers; few are bio-gas, bio-alcohol and bio-diesel. Biogas requires high pressure for its use in automobile and its leakage can be hazardous. Biodiesel from edible vegetable oil can cause shortage in food supply. Non-edible oil sources require large scale cultivation which can take up the land resources meant for food crops. In order to circumvent the competition between food and fuel, the next generation biofuels, or the second generation biofuels, are produced from non-food feedstock (e.g. lignocellulose feedstock) and/or food crops that have already fulfilled the food purpose (e.g. vegetable oil waste), which separates them from the first generation bio fuels and enables the potential for sustainable, affordable, and environmental friendly fuel supply short chain alcohols, such as methanol and ethanol have been investigated widely as an additive of biodiesel or diesel due to their more mature production technology[4]. Their high volatility, low viscosity and high oxygen content also could improve fuel spray combustion characteristics and bring down emissions. However, some disadvantages, such as high latent heat of vaporization, low cetane number and low heating value, prevent their large percentage of the application as fuel in diesel engines. In addition, the problem about phase separation would lead to a low engine performance and high emissions at low temperatures when short-chain alcohols were blended with diesel[5].

From the safety perspective, lower alcohols have low flash point (FP) and are classified as Class I liquids (FP below 37.8 °C) along with gasoline by the National Fire Protection Association (NFPA) in the US. Meanwhile, diesel fuel is classified under Class II liquids (FPabove37.8 °C). But addition of lower alcohols to diesel lowers the flash point and would make the blend to fall under Class I liquids, consequently requiring the same infrastructure as gasoline for storage and handling[3].

Butanol is deemed as one of the next generation biofuels for transportation and combustion engine applications which is a 4-carbon straight chain alcohol that canbe produced from biomass (bio-butanol) as well as fossil fuels(petro-butanol). Nevertheless both have same chemical properties and produce similar effects when used in engines, hence it could be considered as a good alternative fuel for diesel engines and it provides several advantages over the lower alcohols like methanol and ethanol, such as higher energy density, higher cetane number, higher heating value, better miscibility, and blend stability with diesel fuel[6, 7].Low cetane number property of n-butanol prevents its direct usage in an unmodified compression ignition engine. Diesel/butanol blends are one of the several possibilities that can be utilized to make diesel technology compatible with alcohols, as a consequence of its lower polarity exhibits better miscibility characteristics with diesel unlike lower or short chain alcohols. However when blended with diesel, butanol lowers the cetane number of the blends which brings about deterioration of auto- ignition characteristics and a longer ignition delay, also it is worth to note that cetane number cannot provide a reasonable indication of ignition delay. In other words, it is necessary to pay attention on the effect of n-pentanol on spray ignition from both physical mixing and chemical reaction aspects[5]. Rajesh Kumar et al,[5] reviewed the effects of butanol/diesel blend in diesel engines and concluded that butanol can replace upto 40% of diesel fuel without any major modifications in the existing engine infrastructure. Damodharan et al,[8]prepared three ternary blends (D50-WPO40-B10, D50-WPO30-B20 and D50-WPO20-B30) and the effect of n-butanol addition on performance and emission characteristics of a DI diesel engine was investigated, results indicated that BTE of the engine increased with increasing n-butanol fraction in the blends when compared to WPO. D50-WPO40-B10 and D50-WPO30-B20 blends delivered better performance than WPO. BTE of D50-WPO20-B30 was found to be even better than baseline diesel operation. Tuccar G et al, investigated emission and performance characteristics of the engine fueled with diesel/microalgae biodiesel blends and found that engine power and torque output reduced slightly when butanol was added to the MB–diesel blends and the exhaust emission tests revealed that CO and NOx emission and smoke opacity values improved with butanol addition. Choi et al, (2015)[9] investigated the effect of diesel fuel blend with n-butanol on the emission of turbocharged common rail direct injection (CRDI) diesel engine and to compare the results with the neat diesel fuel operation case. The blend component was designated as 5%, 10% and 20% by vol. Experimental results shown that for the BU5 blend, the normalized total mass of PM decreased by 70–90% as compared with the D100 and lower amount of nano-sized PM under 50 nm emitted. While the reduction of the total PM mass for the BU10, BU20 were 60–80% and 30–60% respectively, and higher amount of nano-sized PM under 50 nm were emitted. Therefore the BU5 blend could be a better option to reduce the PM mass and the emissions of nano-sized PM under 50 nm.

Thermal NOx is considered to be the dominant origin for NOx emissions from diesel locomotives which depends highly on temperature. EGR is widely used as the main method to depress NOx emissions from diesel engines. Currently, EGR is also used as the basic method to control ignition timing and the burn rate of HCCI combustion. Brijesh et al, (2015)[10] optimized various parameters like injection parameters, compression ratio and amount of ultra-cooled exhaust gas recirculation has been done for a variable compression ratio engine, to achieve low-temperature combustion, with an objective to reduce both NOx and soot simultaneously. Taguchi analysis showed CR and EGR were dominant factors compared to the injection parameters. Result indicated a simultaneous reduction in NOx (98%) and PM (60%) was achieved with an increase in BTE (5%) by combining the moderate rate of ultra-cooled EGR with retarded injection timing and moderate CR. Huang et al, (2016)[11] studied the particle emissions under different EGR ratios on a diesel engine fueled by blends of diesel/gasoline/n-butanol. The in-cylinder pressure peak decreases and heat release is delayed for the combustion of each fuel as the EGR ratio increases. As the EGR ratio increased, the total particle number concentrations for the four blends decreased at first, and then increased. As the EGR ratio increased, the soot emissions during the combustion of four fuels also increased, and the ratios of the number concentrations of the sub-25 nm particles to the total particle number concentrations decreased for all the investigated fuels. Nwafor, (2004)[12] investigated the effect of injection timing on emission characteristics of diesel engine running on biofuel. The test results show that the lowest carbon monoxide (CO) and CO, emissions were obtained with the advanced injection unit. The hydrocarbon (HC) emissions of the engine running on vegetable oil fuels were significantly reduced compared to the test results on baseline diesel fuel. The advanced injection system showed a slight increase in fuel consumption. The exhaust temperatures were high and delay period was reduced with the advanced injection unit. Rajesh Kumar and Saravanan, (2015)[13] in this work, the effects of blending n-pentanol, a second generation biofuel with diesel on the performance and emission characteristics of a diesel engine under exhaust gas recirculation (EGR) conditions are investigated. Tests were performed on a single-cylinder, constant-speed, un-modified, direct-injection diesel engine using four n-pentanol/diesel blends: 10%, 20%, 30% and 45% (by volume). The possibility of using a high pentanol/diesel blend (45%) was also explored with an objective to maximize the renewable fraction in the fuel. Three EGR rates (10%, 20% and 30%) were utilized with an intention to reduce the high nitrogen oxides (NOx) that were prevalent at high engine loads using these blends. It was found that simultaneous reduction of NOx and smoke emissions can be achieved using the combination of pentanol/diesel blends and a medium EGR rate (20–30%) with a small drop in performance.

Studies have indicated that n-butanol/diesel blend is a suitable fuel for DI diesel engines. Even though the advantages of using n-butanol/diesel blend in CI engines have been well known, the current work focuses on the optimum parameter with which this renewable fuel serves better performance and low emissions when fueled in diesel engines. Motivated by the above, this work focuses on effectively utilizing renewable n-butanol in diesel engine in the DI mode under the influence of various cold EGR and injection timings.

II. MATERIALS AND METHODS

A. Test fuels

Table 1 shows the main properties of diesel, n-butanol and test blend for this study. The ultra-low sulfur diesel was procured from Bharath Petroleum; Chennai with a cetane number of 54 is used as the baseline fuel. From baseline tests, it has been observed that neat diesel produces high NOx and smoke emissions due to lack of oxygen during the combustion process. Hence in order to enhance the combustion process high oxygenated n-butanol(CAS NO: 71-36-3) certified to the purity of 98% was used as an additive which was procured from Merck Millipore. D70B30 (70% diesel, 30% butanol) were prepared at the mixing ratio of volume. Mixing lower volatility n-butanol to higher volatility diesel could promote the evaporation of the blend.

Table 1 Properties of test fuels

Properties	Test method	ULSD	n-butanol	D70B30
LHV (MJ/kg)	ASTM D240	41.82	34	39.474
ν at 30°C (mm^2/s)	ASTM D445	3.80	2.2	3.334
ρ (kg/m3)	ASTM D4052	838	810	829.6
Cetane number	ASTM D4737	54	-	-
Flash point (°C)	ASTM D93	70	36	59.8

LHV – low heating value; ν – kinematic viscosity; ρ – density; CCI – calculated cetane index; B – n-butanol; ULSD-diesel

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B. Test engine and facilities

Tests were carried out in a single cylinder, 4 stroke, water-cooled, direct injection diesel engine whose layout is in Fig.1.

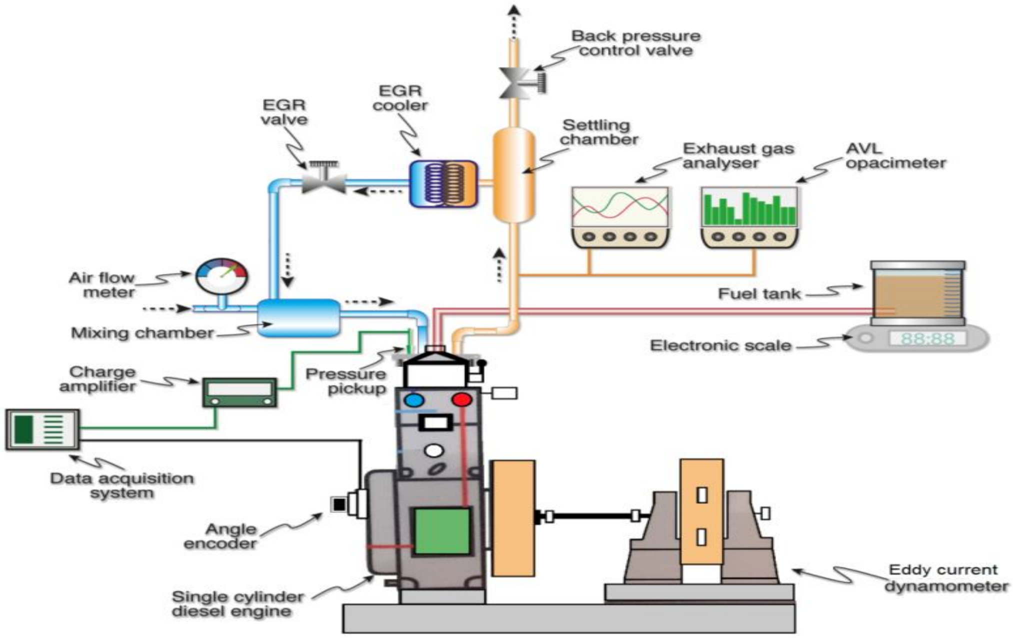

Fig.1 Layout of the experimental setup[14]

The specifications of the engine are presented in Table 2.

Table 2 Engine specifications

Make and model	Kirloskar, TV1 make, 4-Stroke Diesel
Number of cylinders	One
Combustion chamber	Hemispherical open type
Cooling system	Water-cooled
Lubricating oil	SAE40
Piston	Shallow Bowl-in type
Bore, mm	87.5
Stroke, mm	110
Connecting rod length, mm	238
Swept volume, cm3	661
Clearance volume, cm3	38.35
Compression ratio	17.5:1
Rated power, Kw	5.2
Rated speed, rpm	1500
Injection type	Direct Injection
Fuel injection pump	MICO inline, with mechanical governor
Injection pressure, bar	210
Number of Nozzle holes	3
Spray-hole diameter, mm	0.25
Spray cone angle, °	110
Needle lift, mm	0.25
Valve diameter, mm	34.2
Maximum valve lift, mm	10.1

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The instrumentation facility attached to the engine for measuring critical parameters is briefly listed in Table 3. The range, accuracy and uncertainties of the instruments were given in Table 4.

Table 3 Details of the Engine Instrumentation

#	Instrument	Make and Model
1	Dynamometer	Technomech, TMEC-10, Eddy current type, 7.5kW, 1500-6000rpm. Water-cooled.
2	Dynamometer loading unit	Apex, AX-155, Constant speed type
3	Load sensor	SensotronicsSanmar6000, Load cell, Strain gauge type , S beam, Capacity 0-50 kg
4	Pressure transducer	PCB Piezotronics, HSM111A22, Range 5000 psi. with low noise cable
5	Data acquisition system	National Instruments - USB-6210 Bus Powered M Series. 16-bit, 250kS/s, Piezo powering unit Model AX-409.
6	Crank angle encoder	Kubler-Germany 8.3700.1321.0360, Dia: 37mm. Crank angle sensor - Speed 5500RPM with TDC pulse
7	Fuel flow transmitter	Yokogawa, EJA110-EMS-5A-92NN, Calibration range 0-500 mm of H2O
8	Air flow transmitter	Pressure transmitter, Range 0- 250 mm of H2O
9	Resistant temperature detector	PT100 – Range 0 to 100°C
10	Thermocouple	Type K - Range 0 to 1200°C, O/P 4–20mA
11	Gas analyser (NO, CO and HC)	AVL 444N
12	Smoke meter	AVL 437C

Table 4 Range, accuracy and percentage uncertainties of instruments

Instrument	Measured Quantity	Range	Accuracy	Uncertainties, %
Gas analyzer	NOx	0 - 5000 ppm	<500ppm: ±50 ppm	±5
	HC	0 - 20000 ppm	<200ppm: ±10ppm >200ppm: ±5%	±5
	CO	0 - 10%	<0.6% vol: ±0.03% >0.6% vol: ±5%	±5
Smoke meter	Smoke density	0 – 1000 mg/m^3	±0.1 mg/m^3	±1.0
Pressure pickup	Cylinder pressure	0 – 250bar	±0.1 bar	±0.1
Crank angle encoder	Crank angle	0 - 360°	±1°	±0.2

C. EGR setup

EGR method is an efficient method used for reduction of high NO_x emission from diesel engines. In this study cooled EGR technique is adopted owing to its advantages over hot EGR, usage of greater proportion of EGR is achieved as cooling increases the density of the re-circulated exhaust gas.

The required quantity of exhaust gas is directed to the EGR cooler which acts as a heat exchanger, where cooling of hot exhaust gases is achieved by the surrounding cooling water which was maintained at a constant temperature. In this study, temperature drop in exhaust gas is achieved upto 36°C. EGR rate is controlled by an EGR valve. Orifice meter is used for measuring the flow rate of exhaust gas. Re-circulated exhaust gas and incoming air is mixed well in a mixing chamber before they inducted inside the combustion chamber. EGR quantity was determined using the relation,

$$\% = \left[\frac{(\quad _2)}{(\quad _2) \quad _h}\right] \times 100 \qquad (1)$$

The quantity of CO_2 in the exhaust was measured by the AVL 444N gas analyzer by adjusting the control valve to vary the flow rate of the exhaust until the quantity of CO_2 in the intake reaches the desired value. The similar method was used in author's previous work (De Poures et al. 2017[14], Rajesh kumar &Saravanan 2015[15]) to determine the EGR rates.

D. Error Analysis

The errors associated with various measurements and calculations of parameters are computed in this section. The maximum possible errors in calculations were estimated using the method proposed by Moffat [16]. Errors were estimated for minimum values of the output and accuracy of the instrument. If an estimated quantity S, depends on independent variables like (x_1, x_2, x_3… x_n), then the error in the values of S is calculated by using the equation,

$$\frac{\ }{\ } = \left\{ \left(\frac{_1}{_1}\right)^2 + \left(\frac{_2}{_2}\right)^2 + \cdots + \left(\frac{\ }{\ }\right)^2 \right\}^{\frac{1}{2}} \qquad (2)$$

Where$\left(\frac{_1}{_1}\right)$, $\left(\frac{_2}{_2}\right)$ etc, are the errors in the independent variables. $_1$ is the accuracy of the measuring instrument and X_1 is the minimum value of the output measured during the experiment.

Since brake thermal efficiency (BTE) is calculated from fuel consumption, errors associated with it can be represented by equation (3) as follows,

$$\left(\frac{\ }{\ }\right) = \left\{ \left(\frac{\ }{\ }\right)^2 + \left(\frac{\ }{\ }\right)^2 + \left(\frac{\ }{\ }\right)^2 \right\}^{\frac{1}{2}} \qquad (3)$$

As per equation (3), the maximum possible error in the calculation of BTE and BSFC was determined to be 0.33%. Similarly, the errors associated with the measurements of temperature, cylinder pressure and the crank angle was determined to be 0.5%, 1.35% and 2% respectively. This method of error analysis was adopted in author's previous study (Rajesh Kumar &Saravanan 2016b).

E. Test procedure

Experiments were performed under steady-state condition and at peak load, which corresponds to a brake mean effective pressure of 5.3 bar. Combustion and emission characteristics of the test engine were recorded at nine operating conditions by progressively increasing the three cold EGR rates (i.e. 10%, 20% and 30%) and three injection timings (i.e. 21°CA bTDC, 23°CA bTDC and 25°CA bTDC), whereas injection pressure is held constant at 21 Mpa. The fuel blend ratio was designated as W70P30 and was kept in observation for 90 days before conducting this study to ensure that there is no phase separation. The tests were conducted on the same day and almost at same environmental conditions, repeatability of the experimental observations is ensured by averaging the results which is repeated of two times. The baseline tests were conducted with neat diesel and waste plastic oil at same operating conditions as stated above. The injection timing was advanced or retarded by 2°CA bTDC by adding or removing the shim respectively which is located in between the engine and fuel pump. The EGR rate and injection timing were varied for each trial and the recordings were made.

III. RESULT AND DISCUSSION

The performance, combustion and emission characteristics of the engine fueled with D70B30 blend were discussed with reference to baseline engine fueled with diesel operated under the influence of various injection timing and EGR rates.

A. Performance Analysis

1). Brake Thermal Efficiency (BTE): Fig.2 predicts brake thermal efficiency at various EGR rates and injection timing at peak load condition. At same operating conditions D70B30 blend shown a better performance than neat diesel upto 20% EGR, further escalating the EGR rate has shown drop in performance for the blend this may be due to the dominance of fall in combustion temperature over the oxygen content of the blend. At low EGR rates addition of n-butanol to diesel increased the ignition delay period of the blend and gives ample of time for fuel-air mixing which plays a significant role in increased engine performance[17], also presence of intrinsic oxygen dominates over the low heating value of the blend resulting in higher BTE over baseline diesel.

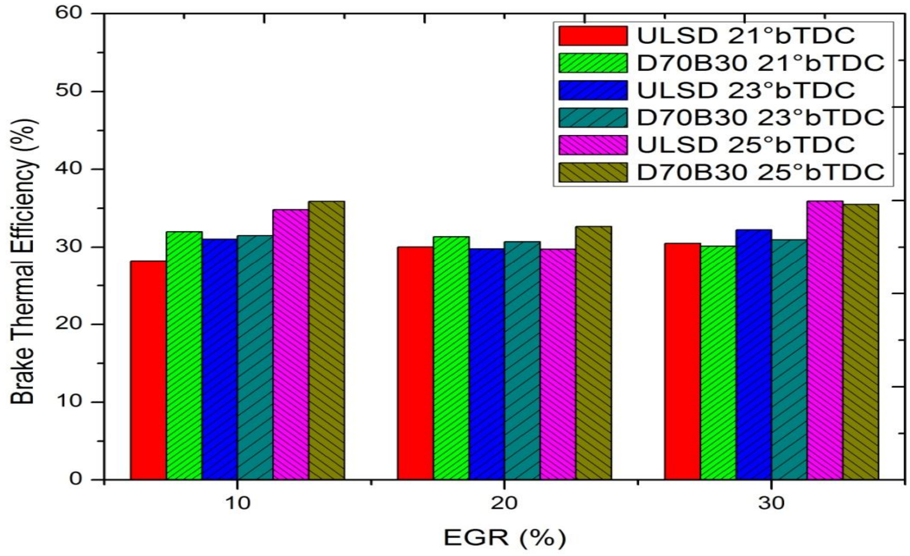


Fig.2 EGR vs BTE at 5.3 bmep

From the plots it may be noted that for diesel BTE varies from a maximum value of 35.94% at 30% EGR and 25 °bTDC to a minimum value of 28.21% at 10% EGR and 21 °bTDC. For D70B30 it varies from 35.8% to 30.13% respectively at same operating conditions. Advancing the injection timing increases the BTE, this is because of increased combustion temperature assisted by prolonged ignition period of the test fuels thereby increasing the BTE.

2). Brake Specific Fuel Consumption (BSFC): Fig.3 depicts brake specific fuel consumption at various EGR rates and injection timings at peak load. At same operating conditions the BSFC in case of D70B30 blend was higher compared to diesel, due to its lower heating value resulting in more discharge of fuel for same displacement of the plunger in injection pump, thereby increasing BSFC[18]. As the EGR rate is increased the BSEC increased; the reason can be attributed to the dilution of the fresh air with exhaust gas causing incomplete combustion, and also a drop in available torque. As a consequence the engine governor supplies more fuel to maintain the constant speed operation of the engine .

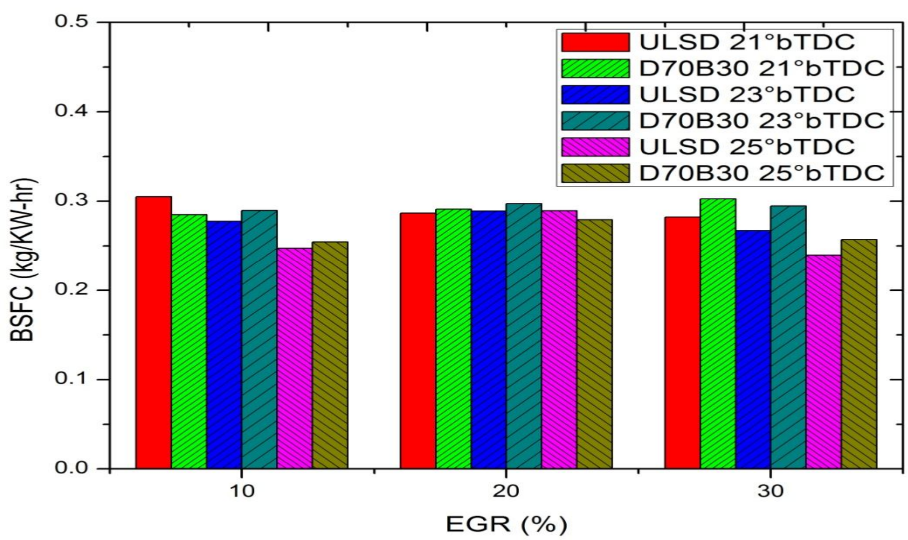


Fig.3 EGR vs BSFC at 5.3 bmep

B. Emission Analysis

1). Oxides of Nitrogen: Fig. 4 depicts the NOx emission at a varying EGR rate and injection timing. Maximum NO_x is observed for ULSD, which is 1314 ppm at 10% EGR, 25°CA bTDC and minimum NO_x is observed for D70B30, which is 499 ppm at 30% EGR, 21°CA bTDC. For the same injection timing and EGR rates D70B30 blend exhibit lower NO_x emission than that of diesel due to shorter combustion period, which results in lower in-cylinder temperature with subsequent reduction in NOx concentration.

As the EGR rate is increased from 10% to 30% there seen a significant reduction in NOx emission for any given injection timing, this may due to EGR gas results in a temperature drop in the burning zone due to a dilution effect, thermal, and chemical effects. The EGR dilutes the oxygen concentration of the intake fluid. Concurrently, the EGR increases the specific heat capacity of the working fluid, thereby reducing the flame temperature[19].

Furthermore, the endothermic dissociation of the EGR constituents such as H_2O may contribute to the reduction in flame temperatures. The NO_x emission is in increasing trend as the injection timing escalates from 21°CA bTDC to 25°CA bTDC at any given EGR rate, this may be due to advancement in injection timing increase the delay period for both the fuels which in turn increases peak cylinder pressure and temperature with subsequent increase in NO_x emission.

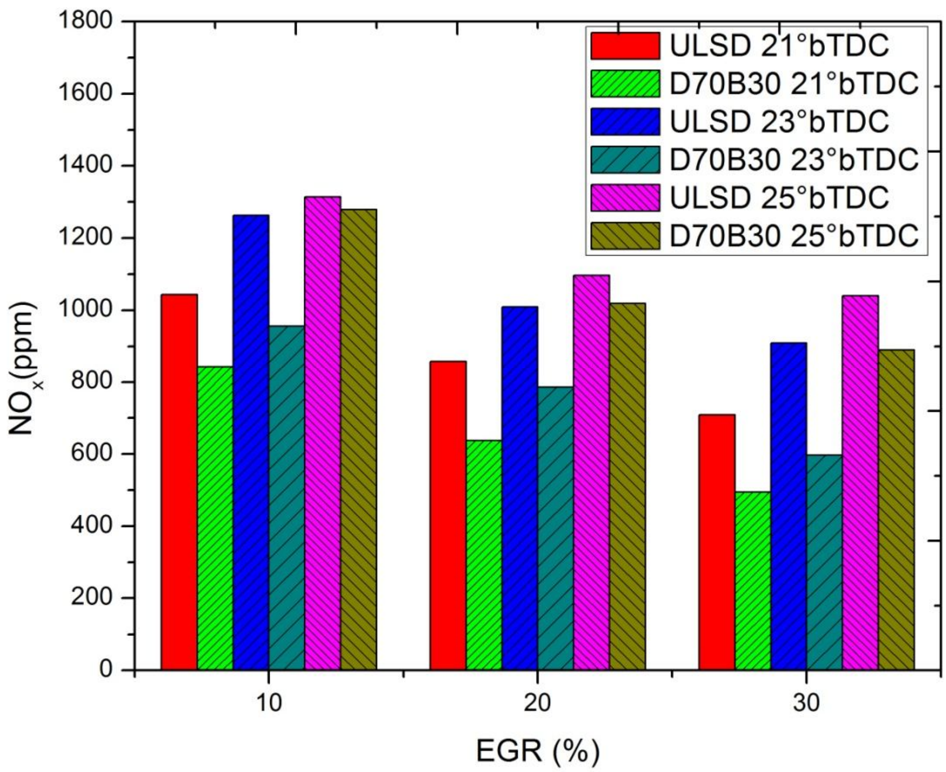


Fig.4 EGR vs Oxides of Nitrogenat 5.3 bmep

2). Smoke Density : Fig. 5 depicts the smoke density with varying injection timing and EGR rates. The maximum smoke emission was observed for ULSD, which is 249 mg/m^3 at 21°CA bTDC, 30% EGR and minimum smoke density is observed for ULSD, which is 27 mg/m^3 at 25°CA bTDC, 10% EGR. For the same injection timing and EGR rates D70B30 blend significantly reduced the smoke concentration at tailpipe this may be due to oxygen content present in the blend which enhances the combustion behavior resulting in high premixed combustion and diffusion phase when compared to diesel.

Increasing the EGR rate from 10% to 30% increases the smoke emissions this due to the fact that recirculation of exhaust gas contain suspended soot particles and during combustion process part of these soot particles do not take part in combustion due to lack of oxygen concentration inside the combustion chamber, hence smoke emission increases with EGR and increasing the EGR percentage multiplies the smoke emissions[14]. There is a general decrease in smoke emission as injection timing increases from

21°CA bTDC to 25°CA bTDC. It has been observed that advancement in injection timing reduced the smoke emission to a greater extent even though EGR ratio increases, this is because the advancement of injection timing provides ample of time for combustion as the fuel is injected earlier into the combustion chamber, this leads to better combustion and reduces carbon soot particles.

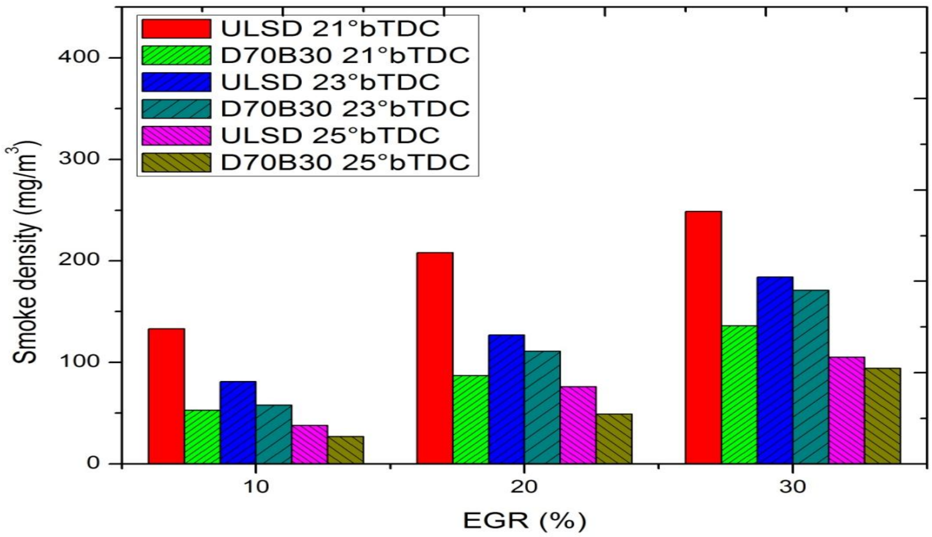


Fig.5 EGR vs Smoke density at 5.3 bmep

3). Carbon Monoxide: Fig. 6 shows the variation of CO emission versus EGR rates under the influence of different injection timings. The maximum CO emission is observed with D70B30 blend, which is 0.25 % volume at 21°CA bTDC, 30% EGR rate and lowest with ULSD, which is 0.02% at 25°CA bTDC, 10% EGR. For the same injection timing and EGR rates D70B30 blend exhibit higher CO emission, this is because the main combustion events of blend-fuel are accomplished during the expansion stroke because of the delay in ignition timing; this leads to a decrease in the in-cylinder gas temperature[20]. As a result, CO emissions could not be further oxidized completely which results in increased carbon monoxide emission.

As the EGR rate is varied from 10% to 30% at any given injection timings CO emission increases this may be due to oxygen availability for combustion decreases as exhausted gas is recalculated which prevents the oxidation process which eventually results in increased CO emission There is a general decrease in CO emission when injection timing is varied from 21°CA bTDC to 25°CA bTDC. Advancing the injection timing more fuel is inducted causing increased combustion temperature and ample of time is available for oxidization of the fuel which curtails the CO emission.

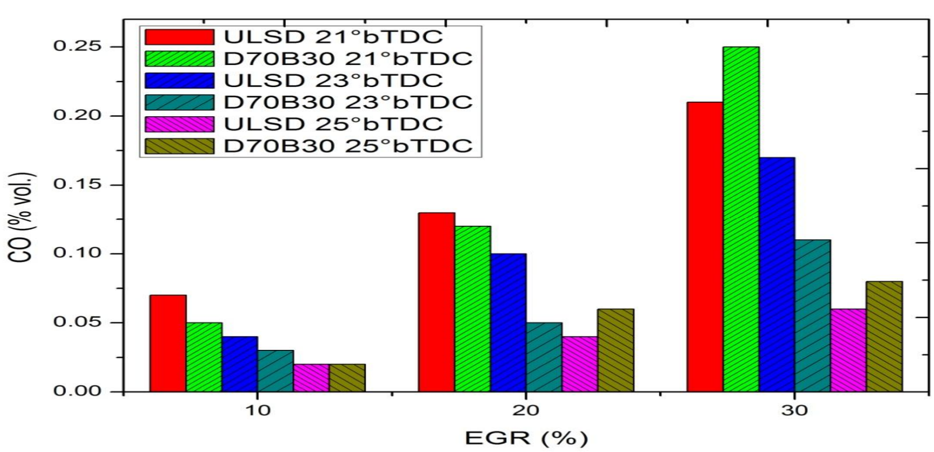


Fig.6 EGR vs Carbon monoxide at 5.3 bmep

4). Unburned Hydrocarbon: Fig.7depicts hydrocarbon emission versus EGR rate. Hydrocarbon emission is the consequence of incomplete combustion of the hydrocarbon fuel, which is a useful measure of combustion inefficiency [21-23]. It presents the unburned hydrocarbon emission versus EGR rates at different injection timing. The maximum hydrocarbon emission was observed for D70B30 blend, which is 32 ppm at 21°CA bTDC, 30% EGR and minimum for both ULSD, which is 12 ppm at 25°CA bTDC, 10% EGR. For the same injection timing and EGR rate, D70B30 blend shows higher UHC than that of diesel this is because D70B30 blend have lower calorific value which increases the ignition delay period causing more fuel to take part in combustion process thereby increasing hydrocarbon concentration at the exhaust wall quench layer of the combustion chamber, ring-crevice storage, and the absorption-desorption of fuel from oil layers and surface deposits also plays a significant role[24].

As EGR rate escalates from 10% to 30% there is an increase in UHC for both the fuel, this is because the increase in the EGR rate reduces the flame temperature available for combustion thus reducing the combustion efficiency thereby resulting in high UHC emission. Injection timing plays a major part in controlling UHC, from the plot it is evident that advancing the injection timing, reduce the UHC significantly. The advancement in injection timing leads to more complete combustion of the fuel as combustion temperature increases and more time is available for braking hydrocarbon chains in the fuel.

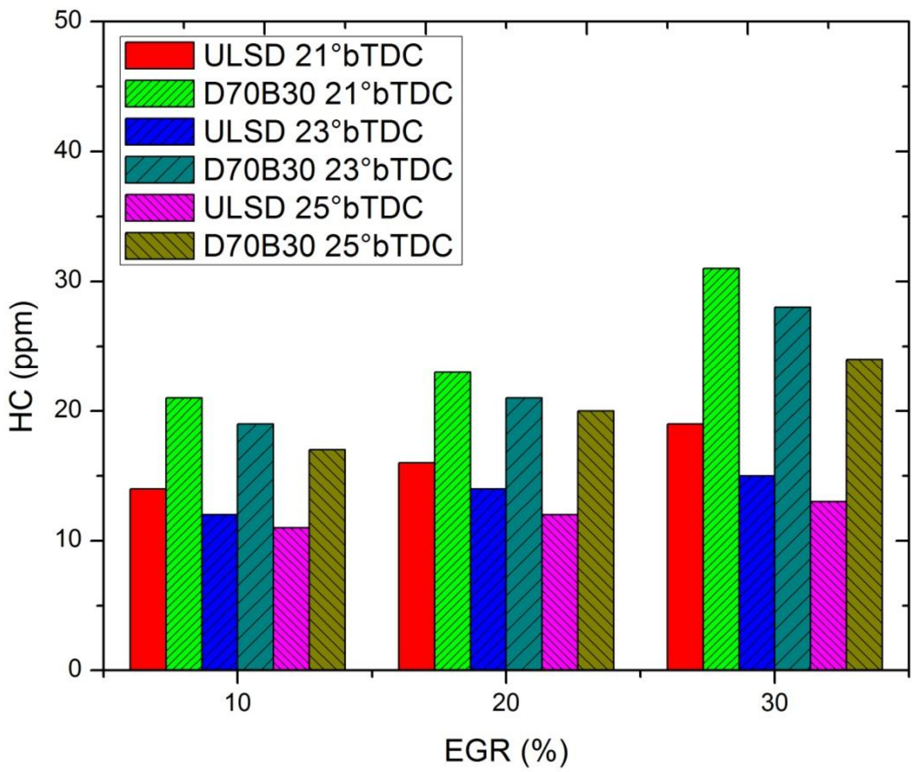


Fig.7 EGR vs Hydrocarbon at 5.3 bmep

IV. CONCLUSION

The combined effect of the exhaust gas recirculation and injection timing on performance and emission characteristics of diesel engine that use D70B30 blend were investigated under nine operating conditions at three EGR rates (i.e. 10%, 20% and 30%) and three injection timings (i.e. 21°CA bTDC, 23°CA bTDC and 25°CA bTDC) under peak load at 5.3 bmep. The following conclusions were arrived from the study.

There is increase in brake thermal efficiency for D70B30 blend upto 20% EGR and increasing the EGR rate there is a decline in the BTE when compared to neat diesel. Under the same EGR rate and injection timing. It has been observed from the results that with D70B30 blend a simultaneous reduction in both NO_x and smoke emission was achieved about 15% of NO_x emission and 20% of smoke density was achieved. When the EGR rate is increased from 10% to 30%, except NO_x concentration all other emission concentration increases. When the injection timing was advanced from 21°CA bTDC to 25°CA bTDC except NO_x concentration, all other emission concentration decreased. It may be concluded that n-butanol can be an excellent substitute for fossil diesel and long term durability tests have to be carried out for its usage in the conventional diesel engines.

REFERENCES

[1] J. M. Bergthorson and M. J. Thomson, "A review of the combustion and emissions properties of advanced transportation biofuels and their impact on existing and future engines," Renewable and Sustainable Energy Reviews, vol. 42, pp. 1393-1417, 2015/02// 2015.

[2] A. Elfasakhany, "Investigations on performance and pollutant emissions of spark-ignition engines fueled with n-butanol–, isobutanol–, ethanol–, methanol–, and acetone–gasoline blends: A comparative study," Renewable and Sustainable Energy Reviews, vol. 71, pp. 404-413, 2017/05// 2017.

[3] P. Geng, E. Cao, Q. Tan, and L. Wei, "Effects of alternative fuels on the combustion characteristics and emission products from diesel engines: A review," Renewable and Sustainable Energy Reviews, vol. 71, pp. 523-534, 2017/05// 2017.

[4] B.-Q. He, "Advances in emission characteristics of diesel engines using different biodiesel fuels," Renewable and Sustainable Energy Reviews, vol. 60, pp. 570-586, 2016/07// 2016.

[5] B. Rajesh Kumar and S. Saravanan, "Use of higher alcohol biofuels in diesel engines: A review," Renewable and Sustainable Energy Reviews, vol. 60, pp. 84-115, 2016/07// 2016.

[6] B. Rajesh Kumar and S. Saravanan, "Effect of iso-butanol addition to diesel fuel on performance and emissions of a DI diesel engine with exhaust gas recirculation," Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy, vol. 230, pp. 112-125, 2016/02/01/ 2016.

[7] B. Rajesh Kumar, S. Saravanan, D. Rana, V. Anish, and A. Nagendran, "Effect of a sustainable biofuel – n-octanol – on the combustion, performance and emissions of a DI diesel engine under naturally aspirated and exhaust gas recirculation (EGR) modes," Energy Conversion and Management, vol. 118, pp. 275-286, 2016/06// 2016.

[8] D. Damodharan, A. P. Sathiyagnanam, D. Rana, B. Rajesh Kumar, and S. Saravanan, "Extraction and characterization of waste plastic oil (WPO) with the effect of n-butanol addition on the performance and emissions of a DI diesel engine fueled with WPO/diesel blends," Energy Conversion and Management, vol. 131, pp. 117-126, 2017/01// 2017.

[9] B. Choi, X. Jiang, Y. K. Kim, G. Jung, C. Lee, I. Choi, et al., "Effect of diesel fuel blend with n-butanol on the emission of a turbocharged common rail direct injection diesel engine," Applied Energy, vol. 146, pp. 20-28, 2015/05// 2015.

[10] P. Brijesh, A. Chowdhury, and S. Sreedhara, "The Simultaneous Reduction of NO _x and PM Using Ultra-Cooled EGR and Retarded Injection Timing in a Diesel Engine," International Journal of Green Energy, vol. 12, pp. 347-358, 2015/04/03/ 2015.

[11] H. Huang, C. Zhou, Q. Liu, Q. Wang, and X. Wang, "An experimental study on the combustion and emission characteristics of a diesel engine under low temperature combustion of diesel/gasoline/n-butanol blends," Applied Energy, vol. 170, pp. 219-231, 2016/05// 2016.

[12] O. M. I. Nwafor, "Effect of advanced injection timing on emission characteristics of a diesel engine running on biofuel," International Journal of Ambient Energy, vol. 25, pp. 115-122, 2004/07// 2004.

[13] B. Rajesh Kumar, S. Saravanan, D. Rana, and A. Nagendran, "Combined effect of injection timing and exhaust gas recirculation (EGR) on performance and emissions of a DI diesel engine fuelled with next-generation advanced biofuel – diesel blends using response surface methodology," Energy Conversion and Management, vol. 123, pp. 470-486, 2016/09// 2016.

[14] D. P. Melvin Victor, A. P. Sathiyagnanam, D. Rana, B. Rajesh Kumar, and S. Saravanan, "1-Hexanol as a sustainable biofuel in DI diesel engines and its effect on combustion and emissions under the influence of injection timing and exhaust

[15] B. Rajesh kumar and S. Saravanan, "Effect of exhaust gas recirculation (EGR) on performance and emissions of a constant speed DI diesel engine fueled with pentanol/diesel blends," Fuel, vol. 160, pp. 217-226, 2015/11// 2015.

[16] R. J. Moffat, "Using uncertainty analysis in the planning of an experiment," ASME, Transactions, Journal of Fluids Engineering(ISSN 0098-2202), vol. 107, pp. 173-178, 1985 1985.

[17] N. Jamsran and O. Lim, "Effects of EGR and boosting on the auto-ignition characteristics of HCCI combustion fueled with natural gas," Journal of Natural Gas Science and Engineering, vol. 35, pp. 1015-1024, 2016/09// 2016.

[18] J. Devaraj, Y. Robinson, and P. Ganapathi, "Experimental investigation of performance, emission and combustion characteristics of waste plastic pyrolysis oil blended with diethyl ether used as fuel for diesel engine," Energy, vol. 85, pp. 304-309, 2015/06// 2015.

[19] M. Mani, G. Nagarajan, and S. Sampath, "An experimental investigation on a DI diesel engine using waste plastic oil with exhaust gas recirculation," Fuel, vol. 89, pp. 1826-1832, 2010/08// 2010.

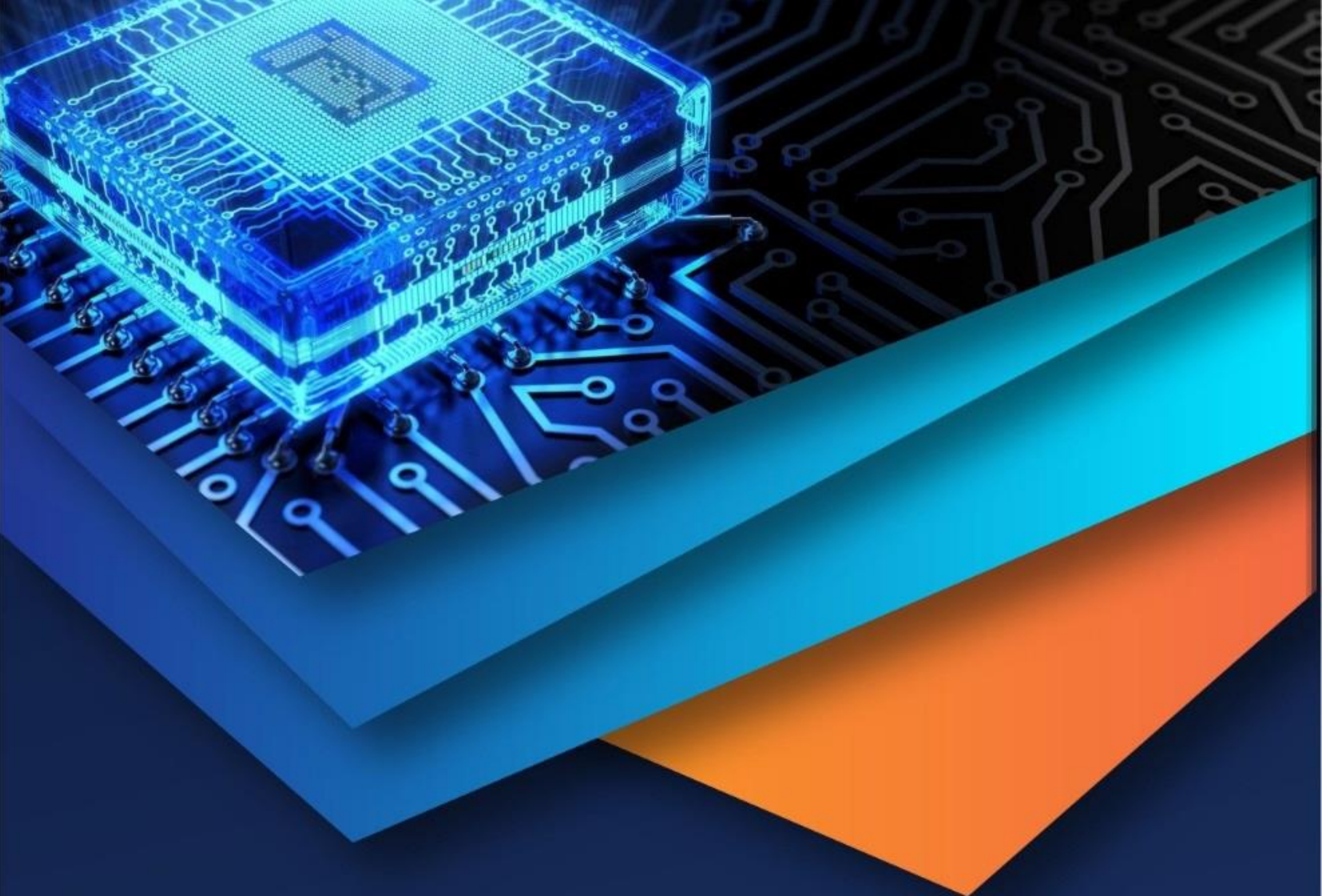
[20] D. C. Rakopoulos, C. D. Rakopoulos, and D. C. Kyritsis, "Butanol or DEE blends with either straight vegetable oil or biodiesel excluding fossil fuel: Comparative effects on diesel engine combustion attributes, cyclic variability and regulated emissions trade-off," Energy, vol. 115, pp. 314-325, 2016/11// 2016.

[21] S. Saravanan, G. Nagarajan, and S. Sampath, "Combined effect of injection timing, EGR and injection pressure in reducing the NO _{<i>x</i>} emission of a biodiesel blend," International Journal of Sustainable Energy, vol. 33, pp. 386-399, 2014/03/04/ 2014.

[22] C. Sayin, M. Gumus, and M. Canakci, "Effect of Fuel Injection Timing on the Emissions of a Direct-Injection (DI) Diesel Engine Fueled with Canola Oil Methyl Ester−Diesel Fuel Blends," Energy & Fuels, vol. 24, pp. 2675-2682, 2010/04/15/ 2010.

[23] P. Senthilkumar and G. Sankaranarayanan, "Effect of Jatropha methyl ester on waste plastic oil fueled DI diesel engine," Journal of the Energy Institute, vol. 89, pp. 504-512, 2016/11// 2016.

[24] A. Imran, M. Varman, H. H. Masjuki, and M. A. Kalam, "Review on alcohol fumigation on diesel engine: A viable alternative dual fuel technology for satisfactory engine performance and reduction of environment concerning emission," Renewable and Sustainable Energy Reviews, vol. 26, pp. 739-751, 2013/10// 2013.



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