Effect of Exhaust Gas Recirculation on Performance and Emissions of a Modern Small Diesel Engine Fueled with Biodiesel-Kerosene Blends

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ABSTRACT
The objective of this paper is to evaluate the effects of biodiesel blends with kerosene, with exhaust gas recirculation (EGR) on a diesel engine, and to compare performance and emission results with that of conventional diesel fuel. In this experimental work, six fuels: biodiesel (B100); diesel (D100); kerosene (K100); biodiesel 20% and kerosene 80% by vol. (B20 K80); biodiesel 50% and kerosene 50% (B50 K50); and biodiesel 80% and kerosene 20% (B80 K20) were investigated with and without EGR system. Biodiesel, produced from canola oil through a transesterification process, was used to examine the performance and emissions of a HATZ 2G40 2-cylinder, air-cooled, direct-injection (DI) diesel engine. All blends were tested at three different engine speeds (1000 rpm, 2100 rpm and 3000 rpm) and at each speed three loads, such as low load (≈20%), medium load (≈50%) and high load (≈80%) were applied. The effects of the blends on carbon monoxide (CO), nitrogen oxides (NOx), hydrocarbon (HC), and smoke emissions, as well as on the performance parameter of the engine, such as brake thermal efficiency (BTE), and brake-specific energy consumption (BSEC) were examined. It was observed that the EGR technique is very effective to reduce exhaust gas temperature; hence it's potential to decrease NOx formation without affecting engine performance.

Keywords– Biodiesel, engine performance and emissions, exhaust gas recirculation, kerosene, small modern diesel engine.

I. INTRODUCTION

Economic growth of a country is very dependent on the long-term availability of energy, whereby the source of energy should be safe and environmentally-friendly. Regulations for particulate matter (PM) and oxides of nitrogen (NO_x) emissions from diesel engines have been become more stringent, resulting in a need to find alternative fuels for the engines, as well as alternative ways of reducing toxic and harmful exhaust emissions while maintaining high thermal efficiency. Extensive research is continuously being conducted to achieve optimum engine operating conditions and fuel properties in order to reduce emission levels from diesel engines. However, NO_x emissions from diesel fuel remain the same as those emitted from gasoline, and therefore it is highly desirable to control NO_x emissions in order to meet environmental regulations. Diesel engines are generally characterized by low fuel consumption and very low CO emissions because a diesel engine can operate with a broader range of air-to-fuel (A/F) ratio, ranging from 15:1 to 60:1. Diesel engines are used mainly in heavy-duty equipment such as trucks and agriculture machinery. In order to reduce emission levels, an external mechanism is applied, such as exhaust gas recirculation, which is a type of aftertreatment system. The main objective of EGR is to reduce NO_x from diesel engines. Depending on the engine operating condition, EGR systems divert 5% to 30% of an engine's exhaust stream back into the combustion chamber [1].in a diesel engine, the formation of NO_x is directly related to the temperature in the combustion chamber, and takes place when that temperature exceeds 2000 K [2]. Therefore, in order to reduce NO_x emissions in the exhaust, it is important to maintain peak temperatures within a controlled range. One plausible way of reducing a diesel engine's NO_x emission is by late injection of fuel into the combustion chamber. Although this technique is effective, fuel consumption becomes significantly higher. EGR is an alternative option by which recirculating a portion of the exhaust gas helps reduce NO_x emissions [2]. Along with NO_x emission reduction, some engine performance characteristics are also affected by the EGR system, such as brake thermal efficiency and brake-specific fuel consumption.

The alternative option of diesel fuel has been gaining popularity worldwide, however in the past decades; the price hike of petroleum has compelled the search for alternative fuels [3]. Biodiesel is the best alternative of petroleum fuel, having several advantages, such as being biodegradable and eco-friendly, with less PM, CO and HC emissions, which is the paramount factor to consider. Moreover, biodiesel ensures the requirements of health effects testing [4] and is easily produced from varied sources such as plant oils, waste cooking oils, and animal fats [5]. Furthermore, canola oil contains the lowest saturated fat level compared to all major vegetable oils, resulting in high engine performance in cold weather. In addition, biodiesel prepared from canola oil contains about 10% oxygen by weight, which helps reduce emissions of hydrocarbons, toxic compounds, carbon monoxides, and particulate matter. The major advantage of biodiesel is that it can be easily blended with diesel fuel in different proportions, or used directly in a diesel engine without any major engine modifications. Several rules and regulations have been issued for canolabased biodiesel use in Canada, which states that 2% biodiesel is mandatory, and that the biodiesel used for blending should meet ASTM D6751 standards. Low-level biodiesel blends such as B2 (biodiesel 2% and diesel98%) and B5 (biodiesel 5% and 95% diesel) can safely be used in any compressionignition engine designed to be fuelled by diesel. This may include light-duty and heavy-duty diesel cars and trucks, tractors, boats, and electrical generators [6]. Leading manufacturers in North America have stated that the use of a biodiesel blend of up to 5% will not deteriorate their engines' warranties, while other manufacturers will warranty up to 20% biodiesel blend. Despite the advantages, there are also several disadvantages to using biodiesel, e.g., lower volumetric energy content, higher kinematic viscosity, higher NOx emissions, and lower atomization. Experimental results show that brake power deteriorated when a diesel engine is fueled with biodiesel, which directly increases brakespecific fuel consumption (BSFC). This hypothesis is supported by experiments undertaken by Lin et al. [7], who found that at high load, the maximum difference in engine power and torque between diesel and eight types of vegetable oil methyl ester (VOME) were 1.49% and 1.39%, respectively. This trend is also supported by qi et al. [8], who explained that because the engine delivered fuel on a volumetric basis, and because biodiesel's density is higher than that of pure diesel, the engine supplies more biodiesel fuel to compensate for the lower heating value. Biodiesel's oxygen content is found as the main factor for the increase in NO_x emissions, as well as higher gas temperature in the combustion chamber [9]. Ozsezen et al. [10] used waste palm oil methyl ester (WPOME) and canola oil methyl ester (come) in diesel engines and found that the NO_x emissions of the WPOME and come increased by 22.13% and 6.48%, respectively.

Kerosene was used as an additive to more closely match the properties of biodiesel to those of diesel, which is composed of a hydrocarbon molecule chain with a predominant fraction of branched and straight-chain alkanes, C_nH_{2n+2}, typically $7 < n < 17$ [11]. Very few have been carried out where by biodiesel was blended with kerosene to test a diesel engine and an aircraft engine. Emission control can be achieved in an aero engine by adding oxygenated fuels, such as alcohols and biodiesel, into hydrocarbon fuels [12-15]. The reason for that trend is due to long chain alcohol, which decreases CO and soot emissions [16]. Aydin et al. [17] examined a 20% kerosene and 80% biodiesel blend (produced from cottonseed oil) in a single cylinder diesel compression ignition engine and compared the emission results to those of a 20%diesel and cottonseed biodiesel blend. The effects of the blends on CO, NO_x, smoke emissions, and various engine performance parameters were investigated.

Biodiesel contains 10% oxygen molecule, which is ideal for improved and complete combustion. However, at a high combustion temperature, it generates NO_x, which may impact the emission regulations. Hence, in our experiments, we used the EGR system to control NO_x emissions. Some researchers, such as Ladommatos et al. [18], investigated the effects of the EGR system on NO_x emission, and tested the effect of EGR on diesel engine emissions. They noticed a large reduction in NO_x emissions at the expense of higher particulate and unburnt hydrocarbon emissions. Yokomura et al. [19] suggested that EGR is one of the most effective processes for NO_x reduction. Zheng et al. [20] studied the effects of EGR on NO_x emission at different engine loads, and reported that as the load increased, diesel engines tended to generate more smoke due to reduced oxygen. Therefore, EGR, although effective to reduce NOx, further increased smoke and pm emissions. There is much literature that explains the reason for the increase in pm, and indicates that with the use of biodiesel with an EGR system, increased smoke occurs with an increased percentage of EGR because of the reduced availability of oxygen for fuel combustion, resulting in relatively incomplete combustion and an increase in the formation of pm [21, 22].

Saravanan et al. performed a series of tests on a single cylinder water-cooled diesel engine with hydrogen used as dual fuel mode with the EGR technique. They reported an increase in brake thermal efficiency, as well as lower smoke levels, particulate, and NO_x emissions due to the absence of carbon in the hydrogen fuel [23]. Hountalas et al. presented a 3dmulti-dimensional model to examine the effects of EGR temperature on a turbo-charged di diesel engine at three different engine speeds. They reported that high EGR temperature affected the engine's brake thermal efficiency, peak combustion pressure, air/fuel ratio, and soot emissions, and that the combined effects of increased temperature and decreased o_2 concentration resulted in low NO_x emissions. In addition, they suggested that EGR cooling is necessary to retain low NO_x emissions and to prevent increased soot emissions without affecting the engine's efficiency at high EGR rates [24].

The main objective of the present work is to experimentally determine performance characteristics and emissions of a diesel engine operating on a blend of biodiesel with kerosene on various proportions, and with varying low EGR percentages in the inlet, and to compare it with the diesel fuel's emissions. To the authors' knowledge, no initiative has been carried out to compare the performance and emissions of biodiesel and kerosene blends, employed with an EGR system with that of pure diesel. Here, we have utilized the EGR technique at low rates up to 15%.

II. METHODOLOGY AND EXPERIMENTAL SETUP

2.1 Materials Requirement

To obtain biodiesel and kerosene-blended fuel, the following materials were required:

1. Ultra-low sulfur diesel fuel (ULSD), which contains approximately less than 15 mg/kg of sulfur [25], obtained from a local gas station.
2. Pure canola oil, purchased from a local supermarket.
3. Methanol and sodium hydroxide (NaOH), provided by Lakehead university's chemistry lab.
4. 1-k kerosene of standard specification ASTM 3699-90 [26], obtained from a local supermarket.

2.2 Biodiesel Preparation

There are several methods to prepare biodiesel from oils and fats. However, only two methods are widely utilized to obtain biodiesel with high yield: acid-catalyzed transesterification, and base-catalyzed transesterification. Out of these, the base-catalyzed transesterification method was applied to prepare biodiesel in our experiment, which follows the ASTM 6751 standard, and through which we achieved a conversion yield of approximately 85%. In the biodiesel production, we used sodium hydroxide as the catalyst and methanol as the base, because this technique has a shorter time of separation of the glycerine from crude biodiesel.

2.3 Experimental Setup

An experimental investigation was carried out to examine the influence of exhaust gas recirculation on the performance and exhaust emissions of a diesel engine. The engine used for the investigation was a HATZ 2G40 2-cylinder, 4stroke, air-cooled diesel engine. The specifications of the engine are provided in table 1. The engine's torque and power output was measured using a hydraulic dynamometer. A gas analyzer was used to measure exhaust emissions. Manometers were used to measure the volume flow rates of the inlet charge, as well as the exhaust gas to be re-circulated. The instrument specifications are shown in table 2. All readings were taken only after the engine attained stable operation. The gas analyzers were switched on before starting the experiments in order to stabilize them before starting the measurements. Fuel consumption was measured by using a graduated cylinder and a stop watch.

2.4 EGR Technique to Reduce NO_x

EGR is a useful technique for NO_x reduction of IC engines. Exhaust from the engine consists mainly of CO_2, N_2 and water vapour. When this exhaust recirculated into the cylinder, it acted as a diluent in the combustion mixture. In addition, it reduced the oxygen (O_2) concentration in the combustion chamber. Because the specific heat of the EGR was higher than the fresh air, EGR increased the heat capacity (specific heat) of the intake charge, thus reduced the increased temperature for the same amount of heat released in the combustion chamber [2].

There are three hypotheses that rationalize the reduction of NO_x: increased ignition delay, increased heat capacity, and dilution of the intake charge with inlet gases. According to the ignition delay theory, EGR causes an increase in ignition delay, and has the same effect as delaying the injection timing. On the other hand, the heat capacity hypothesis illustrates that the addition of the inert exhaust gas into the intake may increase the heat capacity of the non-reacting matter present during the combustion. The increased heat capacity has the effect of lowering the peak combustion temperature. Finally, the dilution of exhaust gas into fresh intake air mixture may reduce the adiabatic flame temperature [27].

In our experiment, the EGR circuit consists of a rubber hose and stainless steel butterfly valves fitted to control the quantity of exhaust gas being recirculated. During exhaust gas recirculation, the EGR control valves were used to regulate the amount of exhaust allowed back into the combustion chamber. The EGR ratio was determined by the following formula.

$$\%\ EGR = \frac{Mass of EGR * 100}{Mass of total intake mixture into the cylinder}$$

Table 1: Engine specifications

Engine make & model	HATZ 2G40
Engine type	4-stroke, air-cooled
Number of cylinders	2
Bore/stroke	92mm/75mm
Displacement	997cc
Compression ratio	20.5:1
Fuel injection timing	8°btdc (≤2250 rpm); 10°btdc (≥2300 rpm)
Fuel injection pressure	26 MPa
Continuous maximum-rated power	13.7 kW @ 3000 rpm
Maximum-rated power	17 kW @ 3600 rpm

2.5 Diesel Engine and Measurement Devices A light-duty HATZ 2G40 (2-cylinder) engine (fig. 1) was used in this study for load tests at three engine speeds (1000, 2100 and 3000 rpm), each at three different loads, low load (LL), medium load (ML) and high load (HL), respectively. Two types of software (dyno 2010 and mb1-smart1500 opacity) were used to measure important parameters such as torque, brake power, speed and opacity. Specialized equipment was used to detect the emissions (CO, NO_x, CO_2 and HC) which includes a nova gas 7466k analyzer, a Dwyer 1205a (for precise co emission), and a smart 1500 opacity meter to measure the quantity of smoke produced. The specifications of emission measurement devices are shown in table 2.

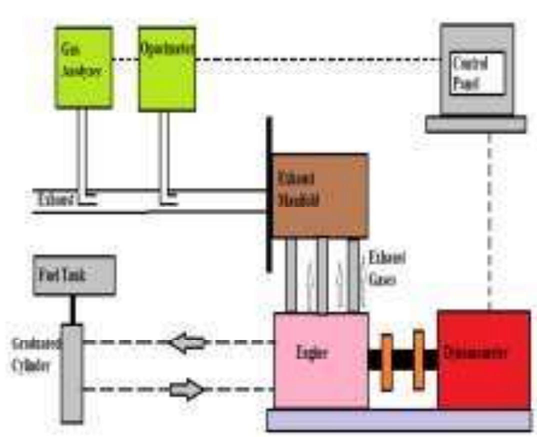

Fig. 1: Schematic diagram of experimental setup

Table 2: Emission analyzers' specifications

Method of Detection	Species	Measured Unit	Range	Resolution	Accuracy
NovaGas 7466 PK					
Electrochemical (Infrared detector	CO	%	0-10%	0.10%	±1%
Infrared detector	CO_2	%	0-20%	0.10%	±1%
Electrochemical	NO	ppm	0-2000 ppm	1 ppm	±2%
Electrochemical	NO_2	ppm	0-500 ppm	1 ppm	±2%
Electrochemical	O_2	%	0-25%	0.10%	±1%
Infrared detector	HC	ppm x 10	0-20000 ppm	10 ppm	±1%
Dwyer 1205A Electrochemical	CO	ppm	0-2000	1 ppm	±5%
ExTech EA10	Temp.	0.1°C	(-)200°C-1360 °C	0.1°C	±0.3%
Smart 1500	Opacity	%	0-100%	0.1%	±2%

III. RESULTS AND DISCUSSION

These experiments studied the effects of EGR on the engine's performance parameters, such as brake thermal efficiency and specific fuel consumption, as well as HC and co emission characteristics, smoke density, and NO_x concentration in the tail pipe emissions. In our experiments, biodiesel was blended with kerosene to improve the cold flow characteristics of fuel in the severe atmosphere of the northern region of Canada. We also determined the fuel characteristics such as kinematic viscosity, density, and calorific value, as shown in table 3.

3.1 Fuel Characteristics

3.1.1 Calorific Value

The calorific value represents the amount of heat released into the combustion chamber when burning a certain unit amount of fuel, and shows the available energy in a fuel. The calorific value was obtained by using a plain jacket bomb calorimeter. Experimental data shows that pure kerosene has the highest calorific value among all blends, whereas pure biodiesel has the lowest calorific value due to its highest viscosity. As shown in table 3, biodiesel has a calorific value of 40.225 MJ/kg, which is about 10% and 12% lower than diesel and kerosene, respectively.

3.1.2 Density and Viscosity

The density of biodiesel is an important physical property, and a slight change in density can affect engine power. Biodiesel is denser than diesel and kerosene (table 3). The fuel density affected the engine performance because fuel injection pumps metered fuel by volume, not by mass. Density and viscosity are among the physical properties of biodiesel fuel, or as a blended fuel, which are mainly responsible for the engine's performance results. These parameters are related to the combustion process, which is highly dependent on the quality of atomization. Generally, increasing the fuel density increased the power output of a diesel engine per unit volume of fuel consumed [28]. In our experiments, biodiesel had a kinematic viscosity of 4.76 cSt, whereas diesel and kerosene had viscosity of 2.40 cSt and 1.36 cSt, respectively.

3.2 Engine Performance

3.2.1 Brake-Specific Fuel Consumption (BSFC) and Brake-Specific Energy Consumption (BSEC)

Brake-specific fuel consumption is a measurement of fuel efficiency of an internal combustion engine that burns fuel and produces output power. It was found that brake-specific fuel consumption decreased with an increase in EGR, and reached a minimum value at approximately 15% EGR. The decrease in BSFC with EGR was due to the increase in intake charge temperature, which increased the rate of combustion of the fuel, hence causing a decrease in BSFC. The BSFC decreased as the load increased, because at low engine loads, the fuel injection pressure and turbulence intensity in the combustion chamber are lower than at high engine loads. In particular, the BSFC of biodiesel increased because of the higher density. As the engine delivered fuel on a volumetric basis and the biodiesel's density was higher than that of diesel, which supplied more biodiesel to compensate for the lower heating value.

The BSEC is another important engine parameter to evaluate its capability when using fuels with different calorific values. The following formula was used to calculate BSEC:

$$BSEC = BSFC * CalorificValueoffuel$$

As shown in figure 2, under different combustion conditions, the average BSEC for diesel, kerosene, biodiesel, B20K80, B50K50, and B80K20 fuels at high load and at 3000 rpm were 9.543, 9.642, 11.019, 9.906, 10.730, and 10.573 MJ/kWh, respectively. The lower calorific value and higher viscosity of canola oil biodiesel led to increases in the BSEC. However, with increasing load, the BSEC had a decreasing trend due to higher power output.

This hypothesis is supported by Gumus and Kasifogul, who reported that brake-specific energy consumption is higher in the case of pure biodiesel than pure diesel due to the lower heating value and higher viscosity [29].

3.2.2 Brake Thermal Efficiency (BTE) Brake thermal efficiency demonstrates how well an engine converts a fuel's chemical energy into mechanical energy. The brake thermal efficiency of the HATZ 2G40 engine with diesel was 32.67% at 3000 rpm at high load condition. In biodiesel at the same operating conditions, brake thermal efficiency was 33.11%, and BTE slightly increase

with the increase in biodiesel blends compared to diesel due to higher oxygen (10% higher oxygen contain than diesel) content in biodiesel which enable proper and
complete combustion. From the figure, which shows

Table 3: Fuel characteristics

Fuel	Properties		
	Kinematic viscosity at 40˚C, (cSt)	Calorific value (MJ/kg)	Density (kg/m³)
D100	2.40	44.681	838
B100	4.76	40.225	873
K100	1.36	45.624	774
B20 k80	2.04	44.521	794
B50 k50	3.06	42.910	824
B80 k20	4.08	41.312	853

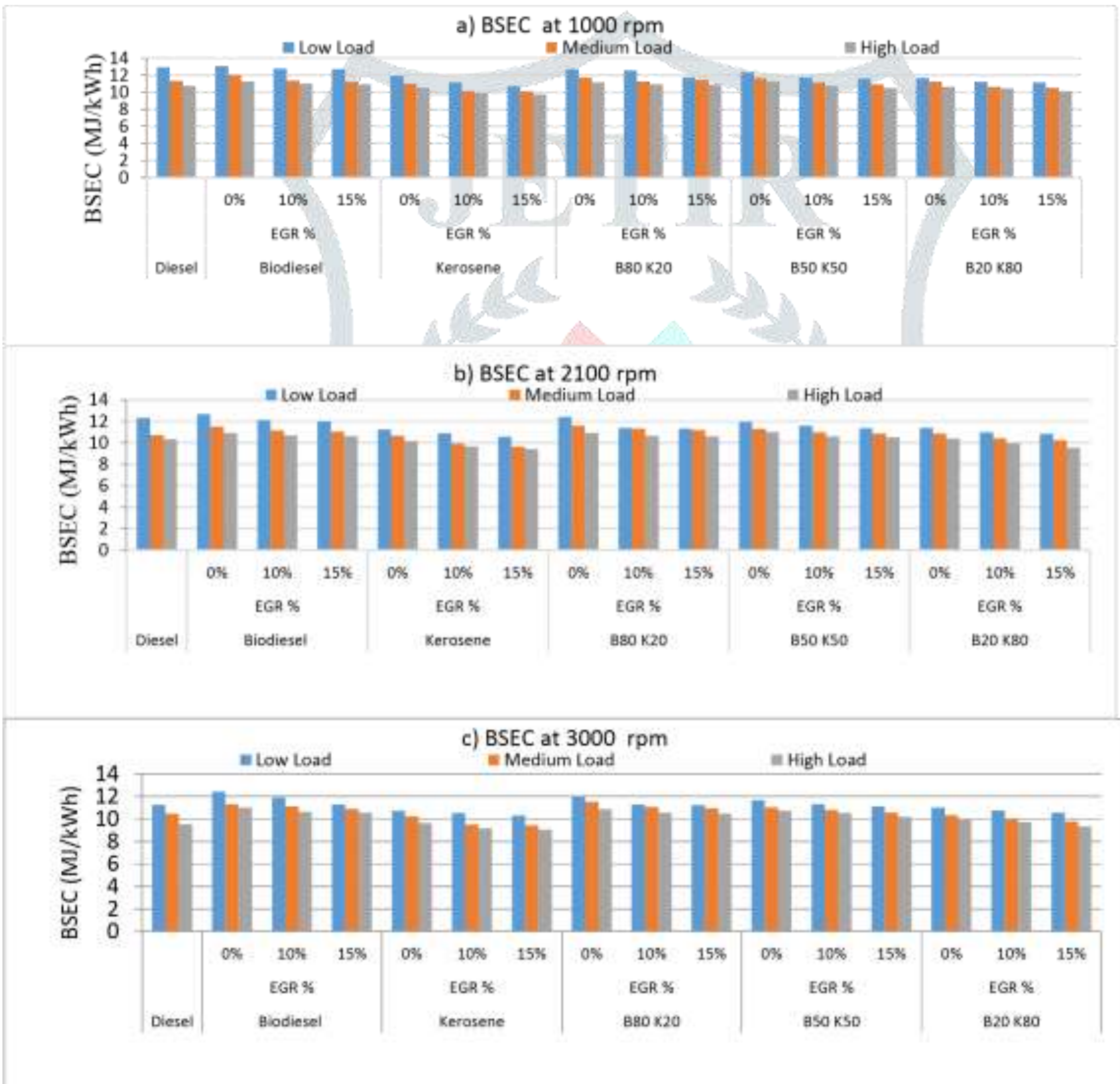

Fig. 2: BSEC of different fuel blends with and without EGR at a) 1000 rpm; b) 2100 rpm; and c) 3000 rpm

the variation of BTE with engine load, the brake thermal efficiency increased with the increase in engine load for all operating modes. BTE increased with the increase in EGR percentage, mainly due to re-burning of HC that entered the combustion chamber with the recirculation of exhaust gases. In addition, the EGR increased the intake charge temperature, which in turn increased the rate of combustion [30]. When the kerosene percentage was increased in the blend, brake thermal efficiency also improved because of the decreased BSFC with the increase in the amount of kerosene. From the graph, it can be evaluated that with the increased speed, the BTE improved due to the improved burning of the fuel.

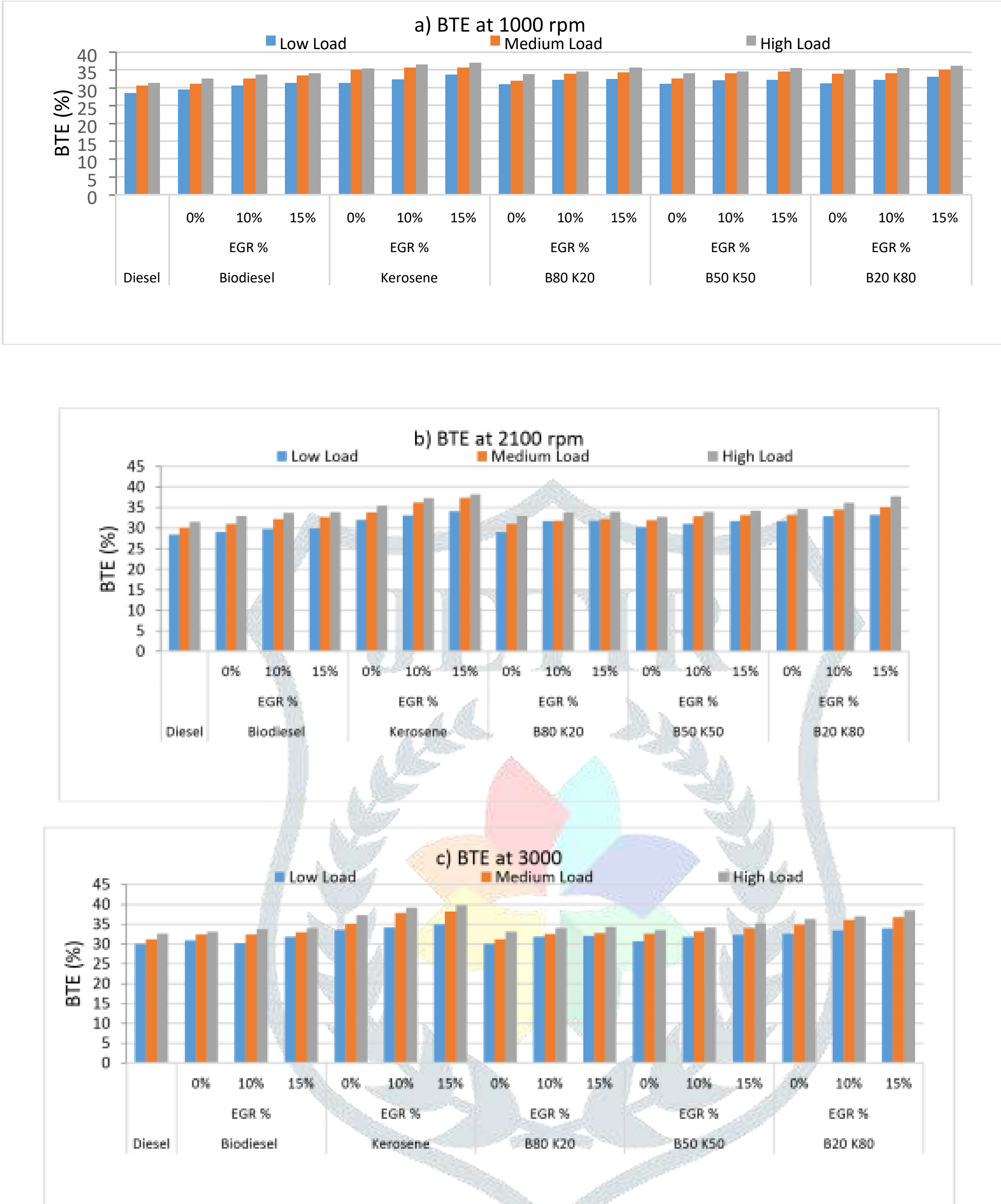

Fig. 3: BTE of different fuel blends with and without EGR at a)1000 rpm, b)2100 rpm, and c) 3000 rpm

3.3 Engine Emissions

3.3.1 Oxides of nitrogen emission (NO_x)

Figure 4 shows the variations of NO_x emissions with and without EGR at 1000, 2100 and 3000 rpm. A maximum of 15% increase in NO_x emissions for B100 was observed at high load condition as the results of 10% oxygen content of the B100, and a higher gas temperature in combustion chamber. In addition, biodiesel's higher cetane number shortens ignition delay, and thus Combustion advances [31], which was also a reason of higher NO_x emissions with biodiesel. The emission of NO_x tended to decrease significantly with the increased EGR rate for all loading conditions in all fuels due to the reduction of oxygen concentration for the presence of inert gases such as CO_2 and H_2O in the cylinder. This decreased the flame temperature in the combustion chamber [32].

A main objective of our research work was to control NO_x emission, and we noticed, as shown in figure 4, that NO_x decreased as the EGR percentage increased. At high torque of the engine (2100 rpm), at high load condition, NO_x emission for diesel and biodiesel was 274 ppm and 307 ppm, respectively. This means biodiesel produced 12% Higher NO_x than diesel, whereas at 15% EGR, NO_x emission was reduced by 4.23%. B20K80 emitted very similar NO_x to that of diesel at various engine speed and load conditions.

Fig. 4:NO_x emission of different fuel blends with and without EGR at a)1000 rpm, b)2100 rpm, and c) 3000 rpm

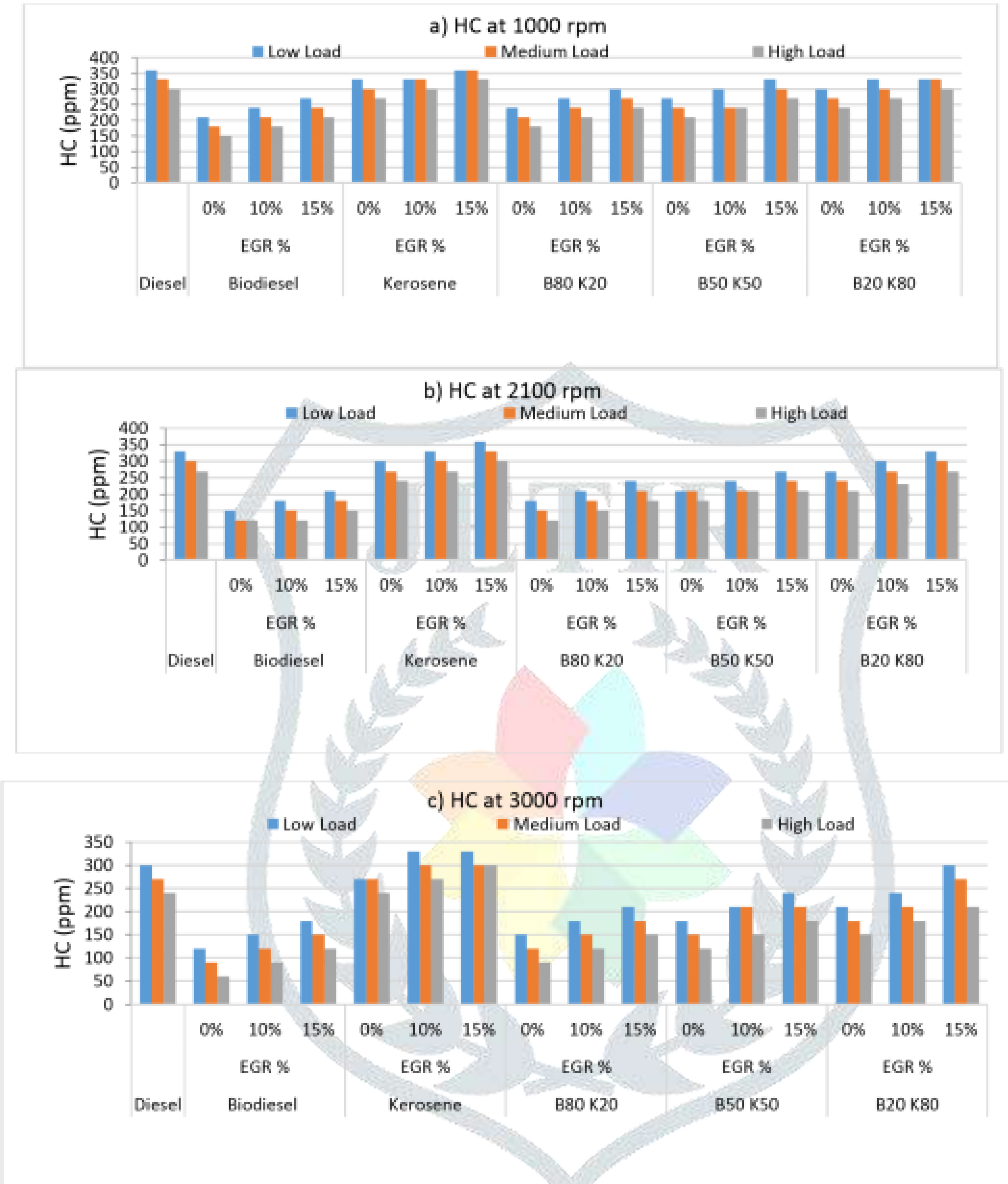

Fig. 5:
HC emission of different fuel blends with and without EGR at a)1000 rpm, b)2100 rpm, and c) 3000 rpm

Fig. 6: CO emission of different fuel blends with and without EGR at a)1000 rpm, b)2100 rpm, and c) 3000 rpm

3.3.2 Hydrocarbon (HC) emission

Kerosene and diesel produced more hydrocarbon emission than biodiesel. However, when the biodiesel content increased, the reduction in HC emission was noticed. Figure 5 shows the variations of hydrocarbon (HC) emissions with various fuels with varying percentage of EGR. From the figure 5, it can be observed that hydrocarbon emission increased with the EGR percentage due to an insufficient amount of oxygen in the combustion chamber and an increase in CO_2 content of the inducted mixture instead of fresh-air, resulting in incomplete combustion. An increase of approximately 25% was noticed with EGR in the case of biodiesel at 2100 rpm at high load condition than without EGR. However, the increased biodiesel percentage in biodiesel-kerosene blends showed a reduction compared to HC emissions of diesel. This is because biodiesel contains higher oxygen, leading to more complete combustion and higher cetane number, which could reduce the ignition delay, and could therefore result in HC emissions reduction [33-34]. At an increased load, the hydrocarbon emissions decreased, similar to one reported in [35]. To summarize, when biodiesel was added to kerosene, HC emissions decreased, and the level was even below the level of diesel.

3.3.3 Carbon Monoxide (CO) Emission According to figure 6, it is a common trend that CO emissions are reduced when diesel is replaced by pure biodiesel due to an increase in oxygen content, as well as a lower carbon-tohydrogen ratio in biodiesel compared to diesel [36]. At non-EGR with biodiesel, there was more than 50% reduction in CO emissions compared to diesel and kerosene. The extra oxygen content of biodiesel promoted complete combustion, thus leading to the reduction in CO emissions. Because biodiesel has a higher cetane number, there is a lower possibility of the formation of a rich fuel zone, which in turn reduces CO emissions [37-38]. From the figure 6, it

3.3.4 Smoke Emission

Smoke is produced as a result of incomplete fuel combustion. Therefore, improvements in combustion can reduce smoke emission [39]. In figure 7, the variation of emission that depends on engine speed for different fuel types is shown, and it is clear that the amount of smoke in the exhaust gas increased with the high biodiesel content in the blends. This is due to higher viscosity of biodiesel and an increase in pressure, which caused over-penetration of biodiesel in a small diesel engine and possible wall-quenching and increased smoke emission. However, some literature depicts a reduction of smoke emission in the case of biodiesel [40] in a bigger engine and argues that the main reason for a reduction in smoke emissions is the 10% oxygen content in biodiesel fuel, as well as its lower aromaticity and sulphur content. This suggests that, better engine design is necessary for small diesel engine running on biodiesel to avoid over penetration and consequent higher smoke emissions. On the other hand, with the use of an EGR system, smoke emission decreased due to proper mixing of viscous biodiesel with burnt gas in this small engine, and in the case of biodiesel, a working at 2100 rpm at high load condition. 4.6% reduction was noticed with the EGR system .

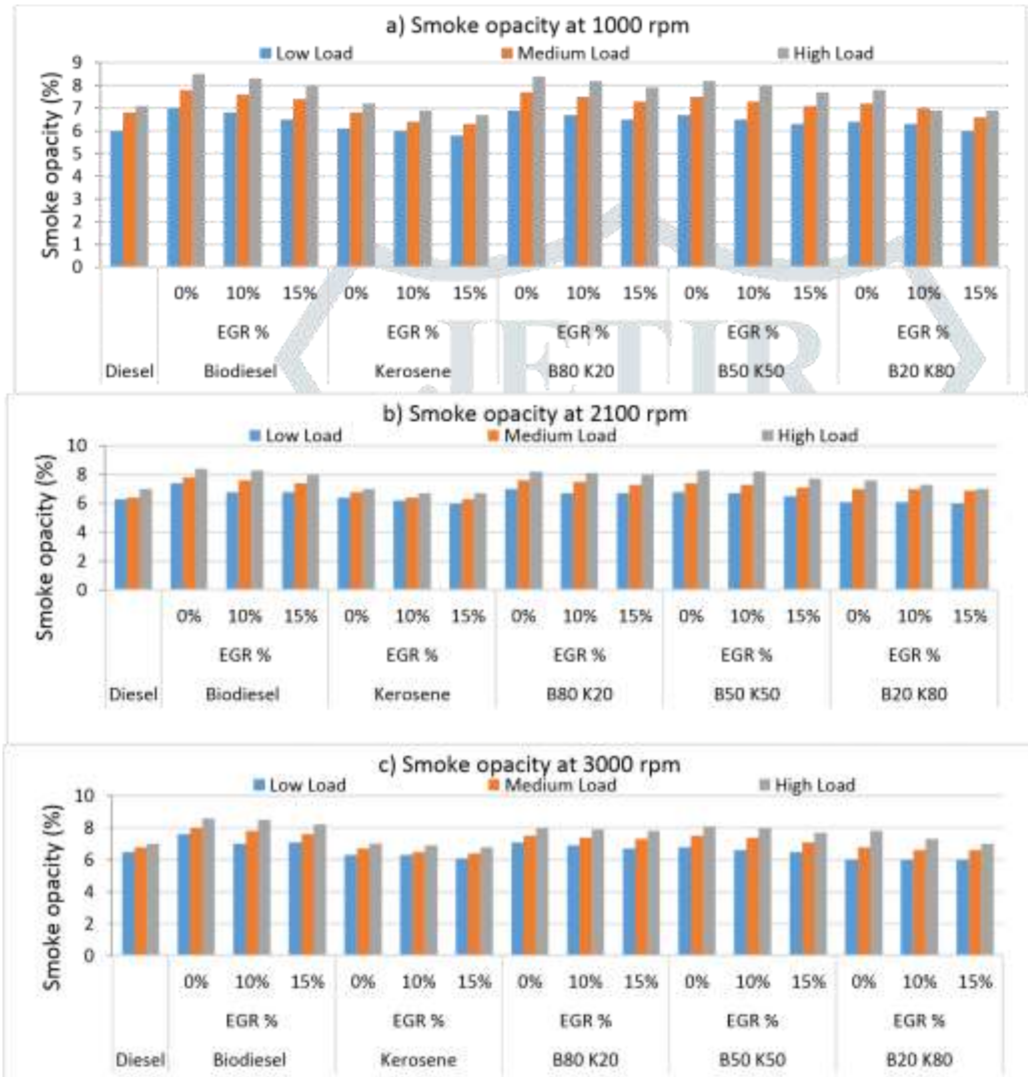

Fig. 7: Smoke opacity of different fuel blends with and without EGR at a)1000 rpm, b)2100 rpm, and c) 3000 rpm

IV. CONCLUSIONS

In our experimental work, we used biodiesel made from canola oil blended with 1-kgrade kerosene to improve cold flow characteristics, and to mitigate harmful NO_x emission produced from biodiesel. An EGR system was installed on a HATZ 2G40 air-cooled engine. It is generally believed that kerosene should not be interchanged with diesel in a diesel engine, however kerosene has the same properties as diesel, except that kerosene burns dry, which may increase wear and tear of the fuel metering pump. However, in our experiments, we used kerosene blended with biodiesel, which may enhance the lubricating quality and prevent the combustion chamber from wear.

The following are the conclusions drawn from the experimental results:

1. Biodiesel has higher viscosity and lower calorific value. This is the main reason for the increase in BSFC, which increased the BSEC of biodiesel by 4.1% and approximately the same for B50K50. While with the use of the EGR system, BSEC decreased by 7.2%, and approximately the same as pure diesel.

With the EGR system and load, BTE increased. For B50K50 blend, a 2.14% improvement was noticed at 3000 rpm at high load, with 15% EGR compared to pure diesel.

2. Biodiesel showed a rise of approximately 26% in NO_x emission compared to pure diesel; however, when kerosene was added to the biodiesel, and with EGR, NO_x decreased a little, and with 15% EGR in the B50K50 fuel blend, the NO_x level is similar to that of pure diesel.

3. Hydrocarbon emission declined with an increase in biodiesel in the blends. By contrast, the HC emission increased with EGR conditions. In the case of B50K50 with 15% EGR, the HC emission was 10% less than pure diesel.

4. Oxygen content in biodiesel served in reducing CO emission without EGR, but HC increased with EGR. At high torque (2100 rpm), there was approximately 62% reduction in CO with biodiesel compared to pure diesel, and at the same engine operating condition with B50K50 fuel blend and with 15% EGR, co emission decreased by 49% over pure biodiesel.

5. Smoke opacity increased with biodiesel but decreased with EGR. Kerosene showed the lowest smoke emissions, and different biodiesel-kerosene blends had a little higher smoke that pure diesel.

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