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# Emission and Performance Analysis of a Modern Small DI Diesel Engine Fuelled with Low Volume Canola Oil-Diesel Blends Using EGR

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**ABSTRACT:-** An increasing concern on the depletion of fossil fuel and its rising demand for global energy has encouraged many researches on alternative renewable biofuel. Vegetable oil is noticeable to be a potential source of energy that can substitute fossil fuels because of its similar properties to diesel fuel and it is readily available. However, the high viscosity of vegetable oil limits its application in diesel engines. This study investigated the effect of low volume canola-vegetable oil blends with petroleum diesel on performance and emission of a 2 cylinder light-duty direct injection (DI) diesel engine at various engine speeds: low idling speed (1000 rpm), speed for maximum torque (2100 rpm) and speed for maximum power (3000 rpm) for different load conditions at each speed: low (≈20%), medium (≈50%) and high (≈80%). Canola oil was directly mixed with diesel at 2% and 5% by volume. Canola oil up to 5% in diesel showed less carbon-monoxide (CO) than diesel with negligible change in unburned hydrocarbon (HC), oxides of nitrogen ($NO_x$) and smoke emissions, as well as in performance. However, the use of exhaust gas recirculation (EGR) shows a significant decrease in fuel consumption, smoke and $NO_x$ emission.
**KEYWORDS:-** Modern small diesel engine, canola oil, exhausts gas recirculation, performance and emissions.

**Nomenclature**

| | |
|---|---|
| ASTM | American society for testing and materials |
| B0 | 100% diesel |
| B5 | 5% biodiesel in diesel |
| BP | Brake power |
| BSEC | Brake specific energy consumption |
| BTE | Brake thermal efficiency |
| C2 | 2% canola oil in diesel |
| C5 | 5% canola oil in diesel |
| CN | Cetane number |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide |
| DI | Direct injection |
| HC | Hydrocarbon |
| NO | Nitric oxide |
| $NO_2$ | Nitrogen dioxide |
| NOx | Oxides of nitrogen |
| $O_2$ | Oxygen |
| ppm | Parts per million |
| rpm | Revolution per minute |

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## I. INTRODUCTION

The increasing demand of fossil fuels has led to a rapid depletion in the world reserves of fossil fuels. Also, this tremendous usage of fossil fuels in engines leads to environmental pollution, with emission of harmful gases from the exhaust producing carbon monoxide (CO), oxides of nitrogen ($NO_x$) and unburned hydrocarbons (HC) and particulate matter (PM). Many proposals have been made regarding the availability of an environmentally friendly fuel that could be domestically sourced. The properties of vegetable oil are somewhat close to diesel, and because it is biodegradable and renewable, it is a great candidate to replace the current fossil fuel. High viscosity of vegetable oil causes various engine related problems such as piston ring sticking, and engine deposits if it is used in its raw form. High viscosity also results in flame burnout and difficulty in starting in cold weathers. Blending, emulsification [1], cracking and pyrolysis [2], or transesterification [3–6] are the few methods which were used by the researchers in order to overcome these problems. Lots of researches on biodiesel have publicized that the fuel made from vegetable oil and animal fats can be properly used on diesel engine [7–9].

For the past two decades, many researchers have investigated the effects of using vegetable oil in engines as a direct fuel, or as a blend with diesel fuel in CI engines[10–12]. It was testified that vegetable oil has the advantage of miscibility with diesel or kerosene and does not change the quality of solution for a long time at any mixed ratio. Thus, vegetable oils can be blended with either diesel or kerosene to reduce the viscosity thereby making the oils useful for engine operation [13]. Esteban et al. [14] investigated different vegetable oils and diesel, and their dependence on surface tension. They discovered that the vegetable oils must be heated to 120$^o$C in order to match the surface tension value of petroleum diesel fuel at 40$^o$C. In addition, the viscosity of vegetable oils exponentially decreases at higher temperatures and, if mixed with diesel, its viscosity increases with an increase in percentage of canola oil in the diesel [15]. As per these characteristics, preheating is considered to be the most effective method for neat vegetable oil operation practically [16, 17]. In spite of poor spray behaviour of vegetable oil, exhaust emissions such as HC, PM and CO emissions can be reduced, whereas at full load condition, an increase in NOx emission was observed since vegetable oil belongs to the oxygenated fuel group [18]. Bernado et al. [19] used camelina oil as a fuel for diesel transport engines, and found that although fuel consumption was higher than diesel, it produced 50% less CO than diesel at 2000 rpm. Also, $CO_2$ and smoke were low under low load condition, while $NO_X$ emissions were slightly higher than diesel. Shehata et al. [20] investigated performance and emission characteristics of neat sunflower oil at different engine speeds and load conditions. They found that brake specific fuel consumption (BSFC) was higher compared to diesel fuel, while brake power and torque were lower. There were increased CO and $CO_2$ emissions, but NOx emissions were significantly reduced. Atmanli et al. [21] studies the effects of n-butanol in a diesel engine fuelled with vegetable oil-diesel blends. They found that addition of n-butanol increases brake torque, power, brake thermal efficiency (BTE) and $NO_x$ emissions whereas it decreases HC and CO emissions. Corsini et al. [22] studied the behaviour of both straight and used vegetable oil in a diesel engine. The result shows power loss at low load using straight rapeseed oil and biodiesel. At higher loads all the fuels showed same behaviour except biodiesel with high power at 2800 rpm. Roy et al. [15] studies comparison of emissions of a diesel engine fuelled with canola oil-diesel and biodiesel-diesel blends at high idling operations. They found that up to 5% canola oil in diesel gives better performance and emission than biodiesel in diesel up to 5%. Canola oil is used in this study, which is classified as edible and is widely grown in Canada. The main purpose of this research was to study the effectiveness of this old trend of using vegetable oil at low percentage with diesel in modern small diesel engine. A detailed study at different engine speeds and at various load conditions with and without exhaust gas recirculation (EGR) was attempted, and performance and emissions of 2% canola oil in diesel (C2) and 5% canola oil in diesel (C5) were compared to that of petroleum diesel.

## II. METHODS AND MATERIALS

### A. Materials

Materials used for experimentation include the following: petroleum diesel purchased from a local fuel station throughout the experiment, pure canola oil purchased from a local supermarket.

### B. Tested Fuels and Their Properties

In this study, total three fuels were studied at 0% and 20% EGR: B0 (diesel), C2 (2% canola oil in diesel) and C5 (5% canola oil in diesel). The density of all the fuels were tested at room temperature whereas the kinematic viscosity was tested at 40$^o$C using a capillary U-tube viscometer. Viscosity is an important factor which influences the fuel atomization and should be within the ASTM limit (6 cSt.) The calorific value of each fuel was tested using a bomb calorimeter. The fuel properties for all the tested fuels blends are given in the table 1.

**Table 1: Properties of Canola Oil-diesel blends**

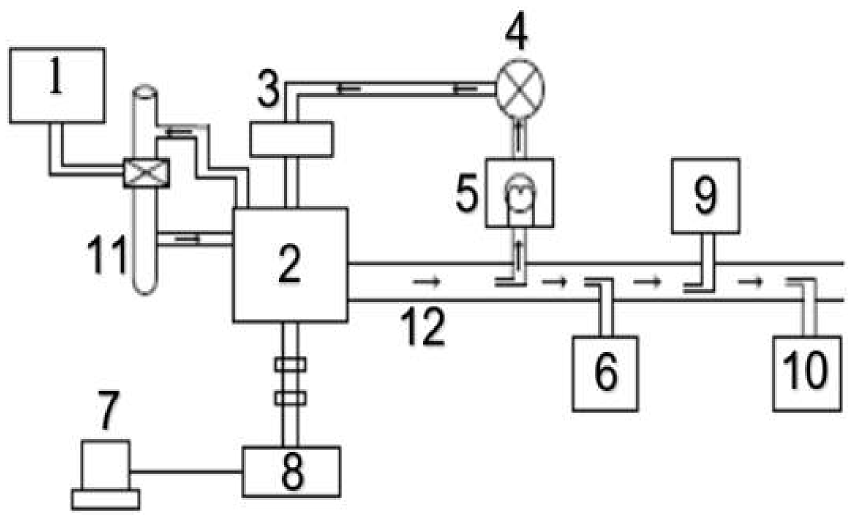
| Fuel | Density (Kg/m3) | Calorific Value (MJ/Kg) | Kinematic viscosity @ 40$^o$C (cSt) |
|---|---|---|---|
| D100 | 835 | 44.825 | 3.15 |
| C100 | 975 | 39.38 | 32.6 |
| C2 | 837.8 | 44.716 | 3.27 |
| C5 | 842 | 44.553 | 3.39 |

**C. Engine Specification**

The engine used in this study is a modern light duty HATZ 2G40, which is an air-cooled, twin cylinder, 4-stroke naturally aspirated direct injection (DI) diesel engine. The schematic diagram of engine setup is given in Fig. 1. It comprises of a direct fuel injection system with maximum torque at 2100 rpm. The engine specifications are shown in Table 2.

**Table 2: Engine Specification**

| | |
|---|---|
| **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 |




**1. Fuel tank, 2. Engine, 3. Air tank, 4. Control valve, 5. Intercooler, 6. CO analyser, 7. Data acquisition system, 8. Dynamometer, 9. Multi-gas analyser, 10. Smoke opacimeter, 11. Graduated cylinder, 12. Exhaust**

**Fig. 1: Schematic layout of engine setup**

**D. Engine Test Procedure**

All the experiments were carried out on the engine, which was coupled with a water-brake dynamometer for different load conditions. These tests were performed at three engine speeds: 1000 rpm (low), 2100 rpm (medium) for maximum torque, and 3000 rpm (high) for maximum power, and at three different loads of 20% (low load), 50% (medium load), and 80% (high load); they were tested at each rpm, and at 0% and 20% EGR rate. These loads were measured by the dynamometer. To begin the experiments, the engine was run with diesel for about 30 minutes to warm it up before testing any other blends. Engine load, brake power and fuel consumption were measured to calculate brake-specific fuel consumption (BSFC), brake-specific energy consumption (BSEC) and brake thermal efficiency (BTE) of the engine. After every experiment, the engine was run for a short time with diesel before switching back to the next test fuel to ensure complete combustion of the residual fuel. NOVA Model 7466 PK was used as multi-gas analyser to measure $O_2$, CO and $CO_2$ in percentage and to measure NO, $NO_2$ and HC in ppm; a Dwyer 1205A was used as a CO analyser to measure CO in ppm. The Smart 1500 smoke opacity analyzer was used to measure smoke. The exhaust gas analysers' specifications are shown in Table 3.

**Table 3: Emission Analyser 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 | 0-800 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% |

### E. Exhaust Gas Recirculation (EGR)

EGR is a useful method for reducing $NO_x$ formation inside the engine [23]. In this study, 20% EGR was applied, i.e. 20% of the exhaust gases were recirculated back into the inlet manifold where it mixes with the fresh air. This helps in reducing the amount of $O_2$ available for combustion. This dilutes the intake charge by reducing the concentration of $O_2$ and reduces the peak combustion temperature inside the combustion chamber which will restrict the formation of $NO_x$ [22]. The EGR rate is calculated by,

$$\%\,EGR = \frac{Mass\ of\ EGR}{Mass\ of\ total\ charge\ intake} X\ 100$$

## III. RESULT AND DISCUSSION

### A. Engine Performance

#### 1) Brake Specific Energy Consumption (BSEC)

Fig. 2 shows the variation in BSEC for canola oil-diesel blends at different rpm and load at 0% and 20% EGR. It was observed that the BSEC decreases with increasing speed and load conditions for all the fuels. At low speed and low load, less fuel is injected into the combustion chamber resulting in lowered cylinder temperature and pressure and hence it produces less power, which makes higher BSEC at low speed for all the fuels at low load. There was slight increase (insignificant) in BSEC at 0% EGR on both C2 and C5 when compared with diesel. With 20% EGR, a 5-7% decrease was observed for all the fuels when compared with 0% EGR. The decrease in BSEC with EGR is due to increase in intake charge temperature which increases the rate of combustion of the fuel.

#### 2) Brake Thermal Efficiency (BTE)

The variation in BTE with varying engine load and speed for different combinations with diesel and canola oil-diesel blends at 0% and 20% EGR is shown in Fig. 3. There is no significant change in BTE was observed with C2 and C5 up to 2100 rpm, however, a slight increase (1% or less) was observed at 3000 rpm when compared with diesel at 0% EGR. An increase in BTE 5-7% or more was observed for all the fuels at 20% EGR due to increase in intake charge temperature which increases the rate of combustion of the fuel.

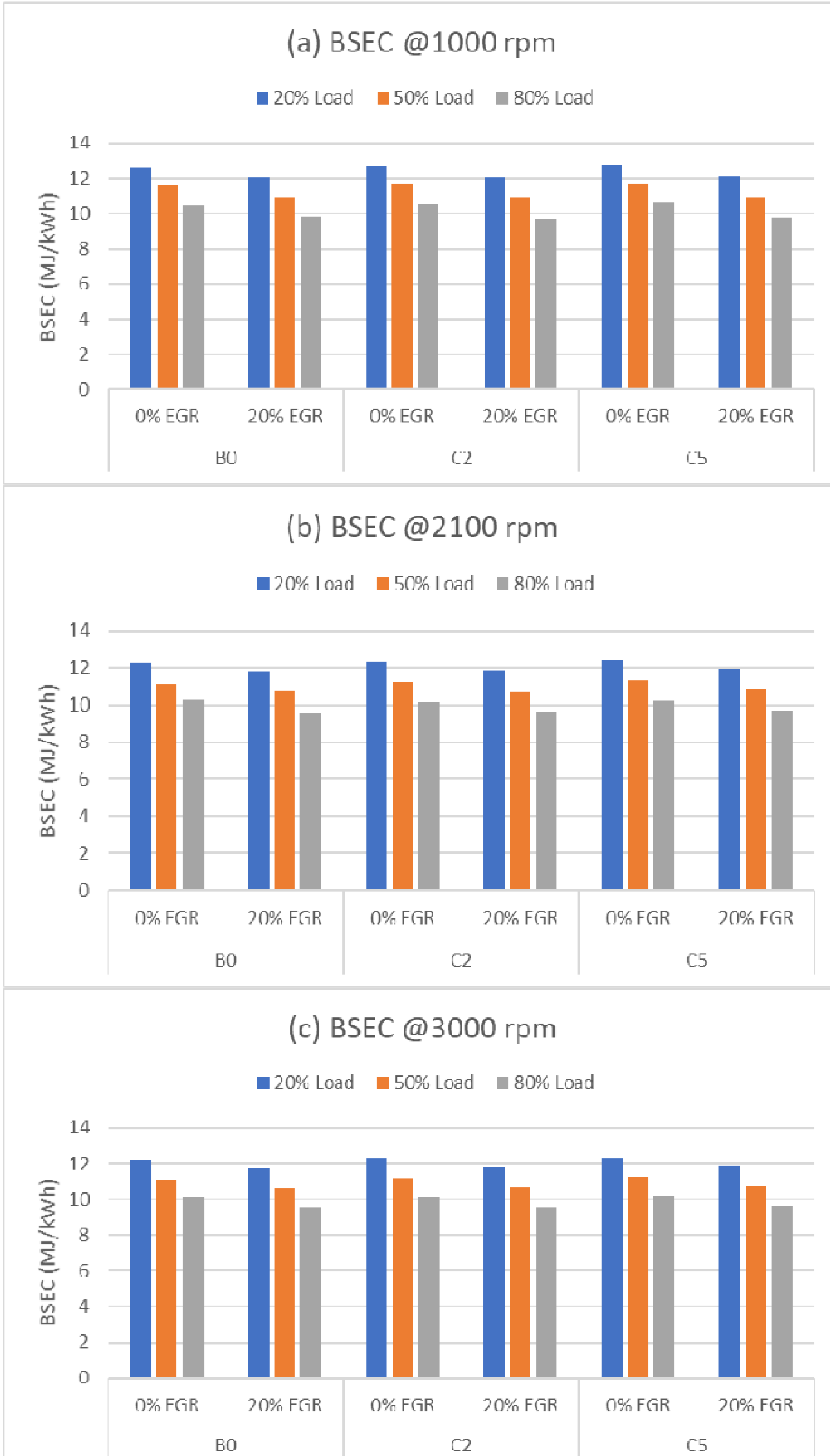



**Fig. 2: BSEC of the engine for different canola oil-diesel blends with and without EGR at a) 1000 rpm, (b) 2100 rpm, and (c) 3000 rpm**

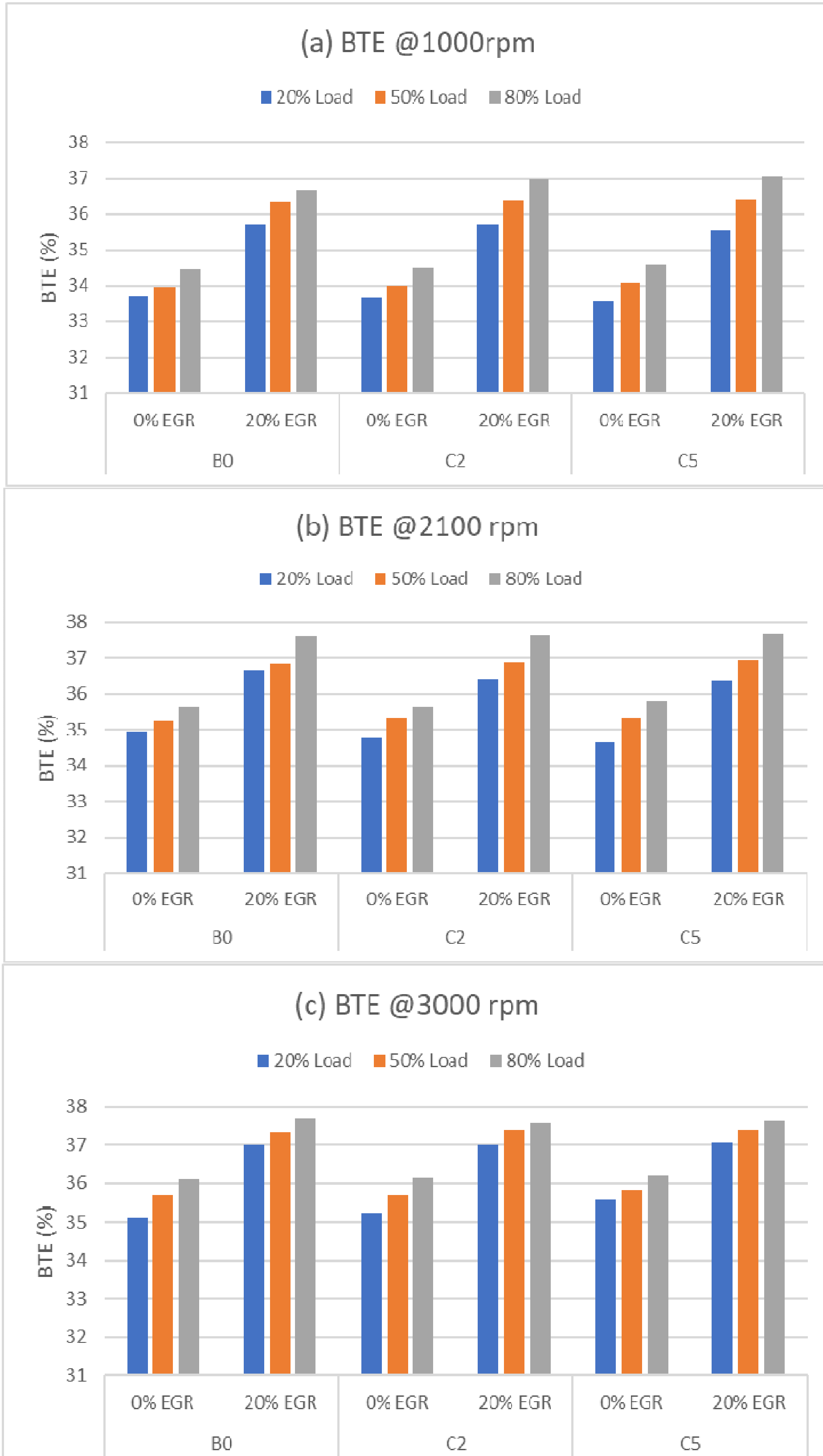



**Fig. 3: BTE of the engine for different canola oil-diesel blends with and without EGR at a) 1000 rpm, (b) 2100 rpm, and (c) 3000 rpm**

**B. Emissions Analysis**

**1) Carbon monoxide (CO) emission**

Fig. 4 compares the variation in carbon monoxide at 1000 rpm, 2100rpm and 3000 rpm at low, medium and high loads at 0% and 20% EGR rates. It is found that at low engine speed the CO emissions are maximum, and it decreases with increase in load. At low speed, the in-cylinder temperature is low, which lead to improper vaporisation and mixing of air and fuel resulting in increased CO. Both C2 and C5 show 6-8% less CO emission than diesel. This lower percentage of canola oil in diesel shows similar properties of diesel but a small amount of oxygen can help in better combustion. An increase in CO (more than 30%) was observed for all the fuels at 20% EGR compared to 0% EGR due to deficiency of oxygen.

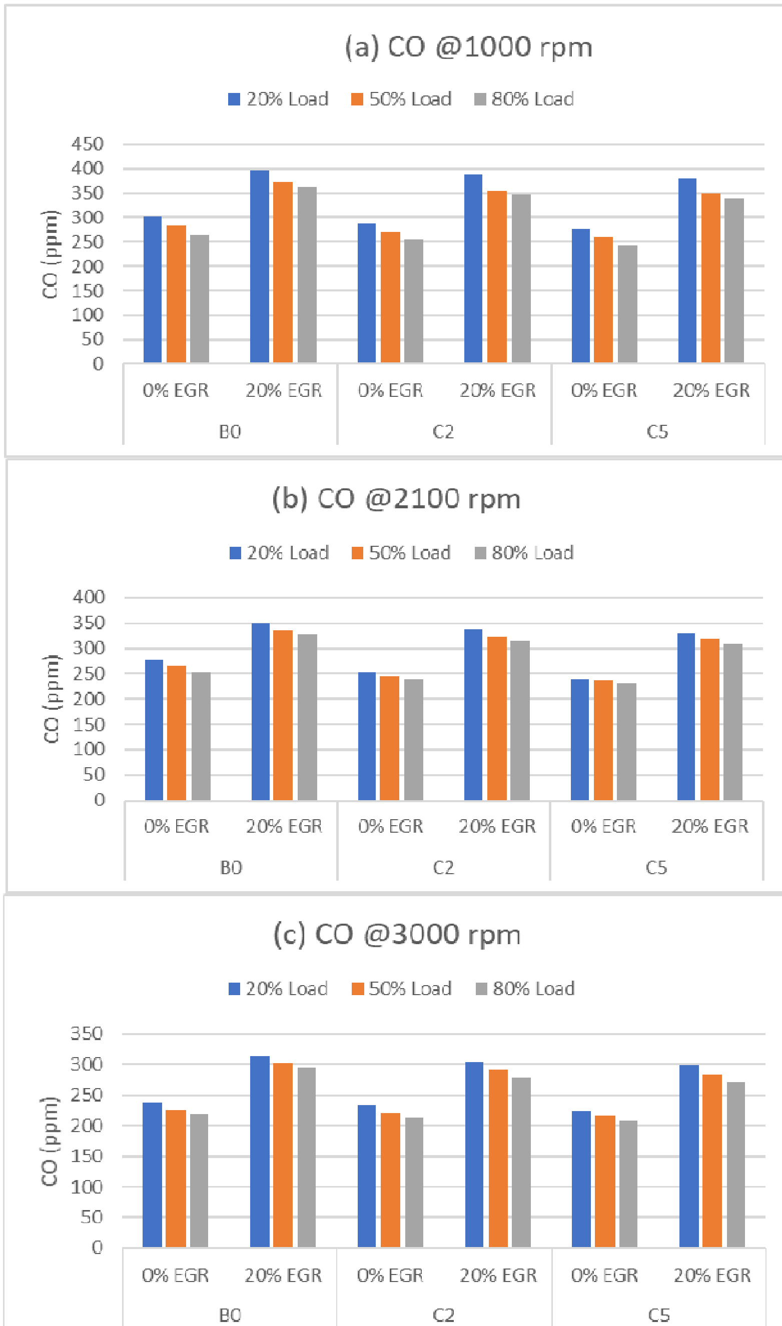



**Fig. 4: CO emissions of the engine for different canola oil-diesel blends with and without EGR at a) 1000 rpm, (b) 2100 rpm, and (c) 3000 rpm**

**2) Unburned hydrocarbon (HC) emission**

Fig. 5 illustrates the variation in total unburned hydrocarbon at 1000 rpm, 2100 rpm and 3000 rpm for three different load conditions: low, medium and high, at 0% and 20% EGR. There are negligible changes in HC for C2 and C5 than diesel at 1000 rpm, however, about 5% and more than 15% decrease in HC at 2100 and 3000 rpm was observed for C2 and C5. This seems that a little amount of oxygen in canola oil-diesel blends helped in better combustion at higher speeds. There was an average increase in HC 5-15% observed for all the fuels at 20% EGR than 0% EGR because of the deficiency of oxygen in the air-fuel mixture.

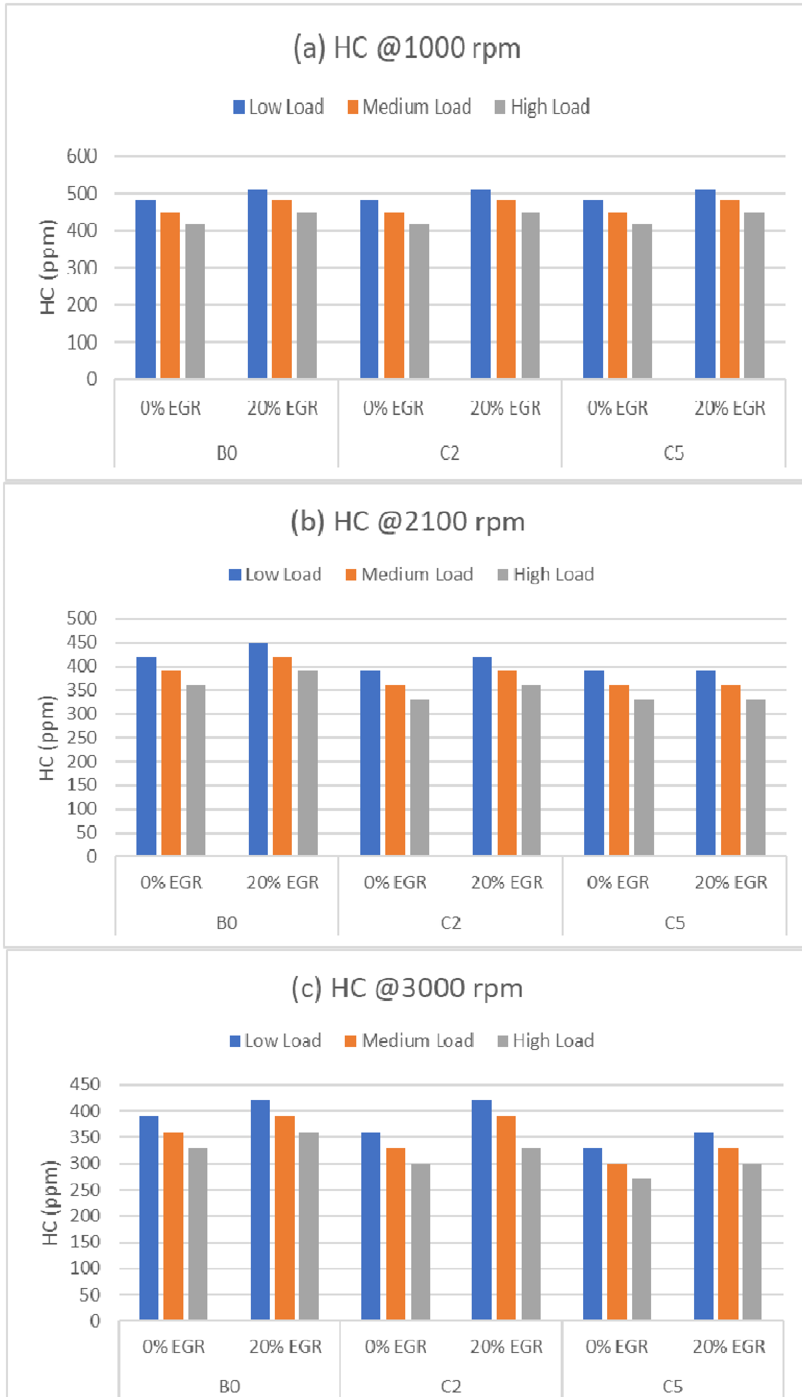



**Fig. 5: HC emissions of the engine for different canola oil-diesel blends with and without EGR at a) 1000 rpm, (b) 2100 rpm, and (c) 3000 rpm**

**3) Oxides of nitrogen ($NO_x$) emission**

NOx is the sum of NO and $NO_2$. In Fig. 6, the variation in $NO_x$ for various fuels at 1000 rpm, 2100 rpm and 3000 rpm for three different load conditions: low, medium and high, for 0% and 20% EGR is shown. There is negligible change in NOx emission for C2 and C5 than diesel at all engine speeds and load conditions at 0% EGR. With 20% EGR, a significant decrease (10-15%) in $NO_x$ was observed for all the fuels as the EGR mechanism decreases the combustion temperature and decreases the air-fuel ratio because of the reduction of oxygen.

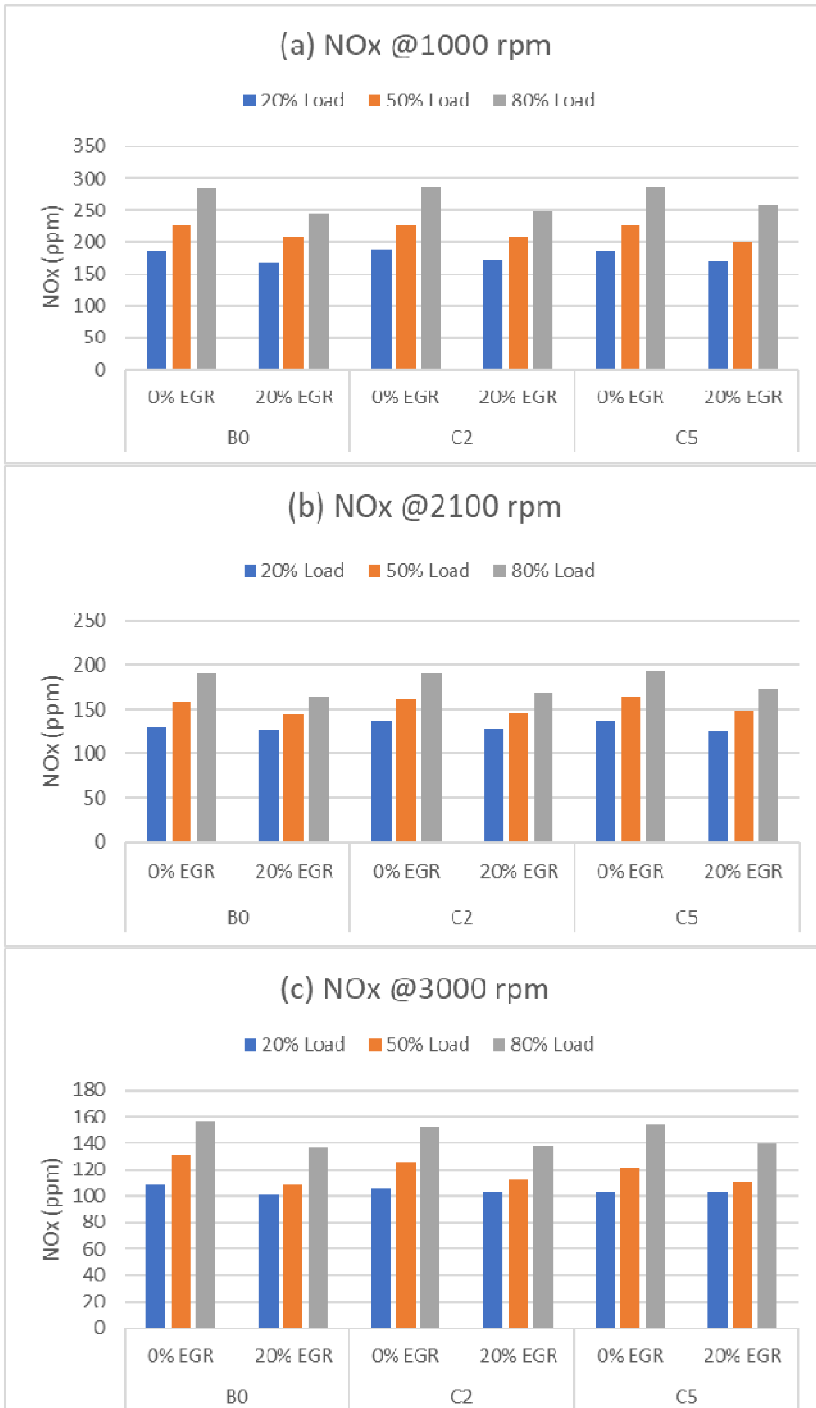



**Fig. 6: NOx emissions of the engine for different canola oil-diesel blends with and without EGR at a) 1000 rpm, (b) 2100 rpm, and (c) 3000 rpm**

**4) Smoke emission**

The variation of smoke intensity for different fuels was measured at 0% and 20% EGR is shown in Fig. 7. This smoke intensity was measured at the speed for the maximum torque of the engine (2100 rpm) for three different load conditions: low, medium and high. A very slight increase in average smoke emission for both C2 and C5 than diesel was observed at 0% EGR. This small change in smoke may be due to its slight decrease in heating value and increase in viscosity that could have affected the fuel atomization [24]. However, smoke opacity reduced about 10% with 20% EGR for all fuels than 0% EGR. This is due higher intake temperature with EGR that helps better fuel atomization and mixing. Furthermore, increased load showed higher smoke emission for all the fuels with or without EGR conditions. Higher amount of fuel supplied at higher loads may have caused increased wall-adherence for this small engine and consequently less complete combustion producing higher smoke.

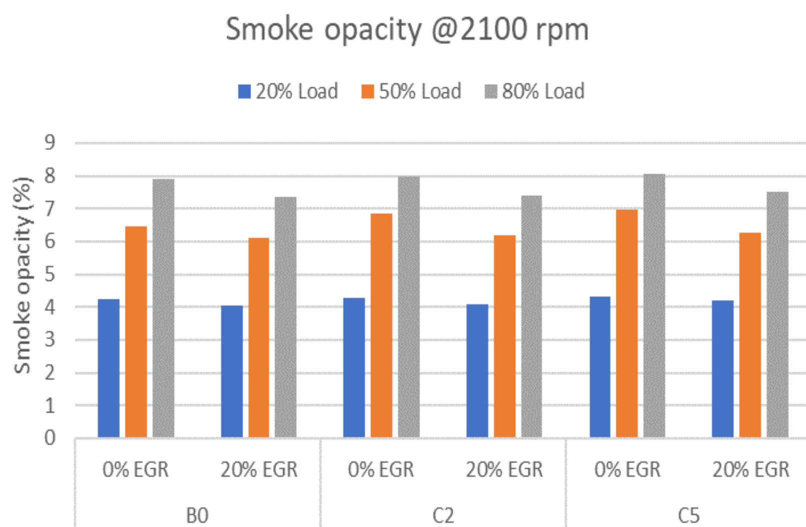



**Fig. 7: Smoke emissions of the engine for different canola oil-diesel blends with and without EGR**

## IV. CONCLUSION

An experimental investigation has been conducted to study the performance and emissions of pure canola oil in diesel using EGR. Based on the experimental results, following conclusions can be drawn.

a) Up to 5% canola oil in the blends, there is 6-8% decrease in CO was observed at 0% EGR condition, and higher load and speed helped in reducing CO emissions. However, CO emissions deteriorated significantly with 20% EGR rate.
b) More than 15% HC reduction were obtained with 5% canola oil in diesel at 3000 rpm at non-EGR condition, but, 20% EGR rate showed about 15% increase in HC emission at this condition.
c) At non-EGR condition, almost no change in NOx emission was observed for C2 and C5 fuels compared to diesel, however, 10-15% NOx reduction was achieved with 20% EGR rate.
d) In this small engine, 20% EGR rate helped reducing smoke emission about 10% for all fuels, and almost no change is noticed in smoke emissions with C2 and C5 than diesel at non-EGR condition.
e) In terms of performance, a slight increase in BSEC at 0% EGR on both C2 and C5 when compared with diesel was observed. However, with 20% EGR, a 5-7% decrease was observed for all the fuels when compared with 0% EGR. A slight increase in BTE with C2 and C5 was observed at 3000 rpm when compared with diesel at 0% EGR, and BTE increase 5-7% or more was observed for all the fuels at 20% EGR.
f) From the performance and emission point of view, the experimental results suggest that canola oil up to 5% with pure diesel can be used with lower CO and HC emission keeping the engine performance almost unchanged, and a lower EGR rate (20%) can improve the NOx and smoke emissions too.

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