An analysis of the characteristics of CRDI engine utilising sustainable orange-peel oil injected at varying pressures

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Abstract: Environmental degradation and the depletion of oil reserves are serious worries around the world, particularly in developing countries such as India, which primarily imports oil. Because petrol and diesel are the most commonly used fuels in India, finding a suitable replacement is an urgent need. Essential oils are currently gaining popularity in this area. Orange peel oil is appropriate for CI machines, and it is gaining popularity in India due to its probable for large-scale hire and comparatively little environmental impact. In this work, orange peel oil is extracted via steam distillation and incorporated with diesel at a 20 percent ratio, denoted by the symbol OPO20. Experiments are conducted on a single-cylinder, water-cooled, four-stroke Kirloskar AV-1 CRDI diesel engine that is coupled with an eddy current dynamometer as a loading device and other necessary apparatus.. On a test engine, the effects of fuel injection pressure on the performance, emission, and combustion characteristics of a common-rail direct injection (CRDI) engine using OPO20 were investigated at 300, 450, 600, 750, and 900bar fuel injection pressures. Compared to diesel@300bar, the OPO20's brake thermal efficacy at 900bar (OPO20@900bar) injection pressure is increased by 1.84 percent. The BSFC, CO, HC and smoke emission decreases for the OPO20@900bar compared with neat diesel@300bar. Compared to ordinary diesel@300bar, the smoke, HC, and CO emissions for the OPO20@900bar were reduced by 50%, 22.3%, and 18.8%, respectively. NOx emissions for OPO20 at 900 bar are 13% higher than diesel at 300 bar. Maximum peak cylinder pressure and heat release rate are somewhat greater for OPO20@900bar than for diesel@300bar.

Key words: OPO20, Injection Pressure, Performance, Combustion, Emission.

1. Introduction

Energy is the major component of commercial growth. In accumulation to promoting economic growth, it is crucial for improving people's quality of living and social development. Building a solid foundation of drive resources is crucial for the economic and social expansion of any nation. Fossil fuels have been an essential source of conventional energy for decades. As a consequence of ongoing industrialization and modernization trends, the worldwide demand for energy is increasing at a quicker rate. The majority of developing nations import fossil fuels to meet their energy needs. Consequently, these nations must use their export earnings to purchase petroleum products. In 1971, in response to the complaints of a global oil imbalance, every nation attempted to find a substitute for petroleum diesel using the resources available to them.

The global economy relies heavily on the combustion of fossil fuels. Every day, fossil fuels equivalent to approximately 180 million barrels of oil are burned. The fuel consumption rate corresponds to the annual combustion of fuel mass that took landscape approximately one million years to gather as fossil sums. For the biosphere's developing nations, such as India, biofuels can provide a viable solution to their crises. Climate changes caused by rising carbon dioxide (CO_2) emissions, global warming, rising air pollution, and the depletion of fossil fuels are the most pressing issues of this century. In light of limited fossil fuel capitals and ecological worries, efforts are finished to identify a viable substitute. Current researchers have focused on biofuels as an environmentally favorable energy source in order to decrease air contamination and reliance on fossil fuels. Moreover, petroleum combustion exhaust is the leading cause of environmental pollution. Consequently, it becomes necessary to seek out alternative fuels that are self-sustaining, biodegradable, and environmentally favorable.

Biofuels may play a substantial role in the evolution to a low-carbon family by combining the benefits of reducing greenhouse gas emissions and decreasing the need to import oil. Biofuels have the potential to surmount fossil fuels' limitations. Several nations have enacted policies encouraging the use of biofuels to lessen their support on fossil energies and to protect the environment. Due to the higher cost of lipid feedstock, however, the production costs of biofuel are not economically competitive when compared to fossil fuel. When these economies are relatively developed and the agricultural sector is considered, the potential role of biofuels becomes more evident. Recent research indicates that bio-ethanol, biodiesel, and, to a slighter extent, purified vegetable oils are the most auspicious biofuels. This has rekindled notice in the use of bio-oils as a energy substitute, prompting a review of their performance in basic diesel appliances and their similarity to fossil fuel in terms of its properties.

2. Resources and Approaches

2.1 Orange peel oil as alternate fuel

Orange peel oil is one of these non-edible oils that addresses both the problematic of not moving food intake and the problem of separating agricultural land. As a result, orange peels are considered discarded, and the oil extracted from them is not in high claim, excluding in the cosmetics industry, where they are renowned for their unique spirit, fragrance, and flavor. Consequently, orange peel oil stands alone as a addition to the exponential request for oil. In 2020 & 2021, the global orange crop was approximately 47.24 million metric tons, and in 2021 & 2022, it is anticipated to increase to just over 49 million metric tons. In 2020, the production of oranges in India amounted to over 9.85 million tons which is highest in the APAC countries. Orange peel oil is a biofuel resulting from orange skin that contains 90% D-limonene and has numerous applications.

2.2 Orange peel oil extraction by steam decontamination process

Distillation is the classic method for isolating volatile chemicals from plant material to obtain essential oils. Aromatic plants exposed to boiling water or steam evaporate to free their essential oils during distillation. Distillation of two immiscible liquids, say water and essential oil, enhances essential oil recovery based on the principle that the combined vapour pressures equal the ambient pressure at boiling temperature. Thus, the components of essential oils, whose normal steaming points range from 200 to 300 degrees Celsius, are vaporized at temperatures near to that of liquid. The vapor infused with essential oils rises and enters a thin tube cooled by an external source. As steam and essential oil vapors condense, they are collected and separated in a 'Florentine flask'. Because essential oils are lighter than water, they float on top, while water sinks to the bottom and may be easily separated. The amount of essential oil produced is influenced by four key factors: distillation time, temperature, operating pressure, and, most crucially, plant material kind and quality. The production of essential oils from plants typically ranges from 0.005 to 10%.

Historically, three types of distillation existed: water distillation, water-steam distillation, and steam distillation. The most common method for obtaining essential oils is "direct" steam distillation. There is no water added to the distillation tank during this procedure. Instead, steam comes from an external basis into the tank. The essential oils are liberated from the plant material when the steam ruptures the sacs housing the oil molecules. The standard shortening and separation procedure commences at this point. In addition to the aforementioned methods, there are a number of other enhanced techniques for turbodistillation, hydro-diffusion, vacuum-distillation, continuous-distillation, cold-expression, dry-distillation, and molecular-distillation are all methods for creating natural fragrance compounds and essential oils. Fig. 1 depicts the steam distillation procedure that is utilized to extract used lemon and orange peel. The bottom section of the primary chamber contains water and is recognized as the steam distillation compartment. The water in the distillation chamber is transformed to vapor by absorbing heat through the bottom walls of the chamber. The peels are arranged on a grid within the steam compartment, which is then sealed and heated by the steam vapour. Vapors containing lemon/orange essence and steam vapour are channeled from the distillation chamber to a condensing chamber for cooling. Due to their different densities, the liquid water and oil mixture is then collected in a tank, where the peel oil rises to the top and the water sinks to the bottom. The lemon/orange peel oil is drained from the collecting vessel, along with any contaminants, and mixed with a little amount of ether. This mixture is then placed over a water bath, and the heat from the water bath causes the ether to evaporate, leaving only the pure lemon/orange peel oil remained. This eliminates the volatile component of the oil. Finally, solid particles are extracted using a filtration procedure involving 40 mm filter paper, allowing for the withdrawal of hydrous lemon/orange peel oil.

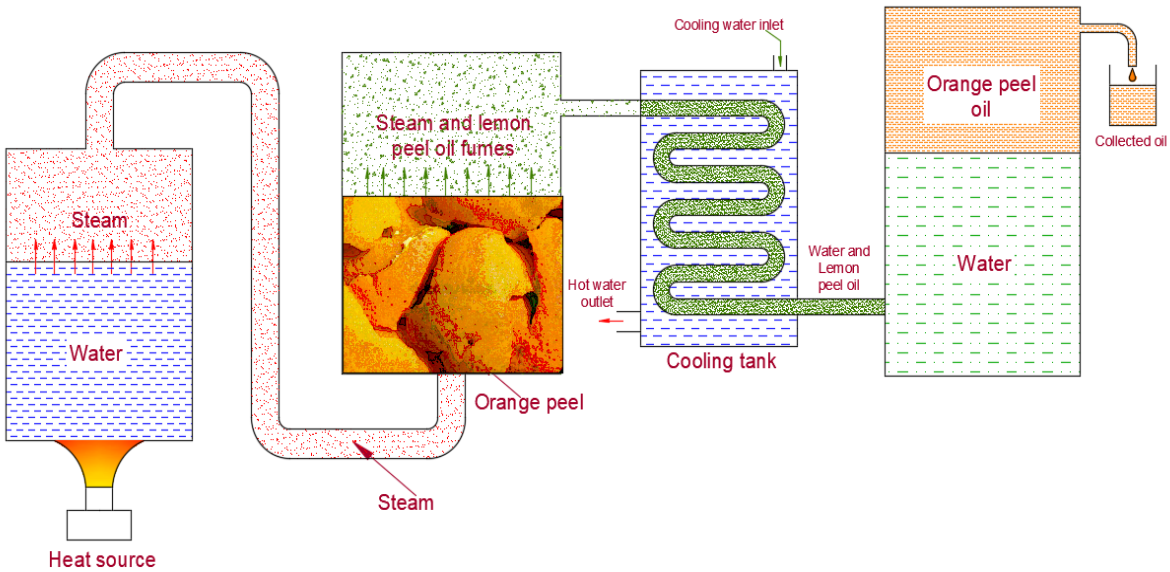

Fig. 1 is a schematic depiction of the orange rind oil extraction process.

ASTM standard is used to obtain and assess the chemical and physical properties of the orange peel oil blend in comparison with diesel fuel. The sign OPO20 represents a mixture of orange peel essential oil and diesel. In the following table 1, the chemical and physical properties of OPO20 and diesel are compared.

Table 1 — Possessions of Diesel and Orange peel oil blend

Property	Measurement standards	Diesel	OPO20
Specific gravity	ASTM D1298	0.834	0.8351
Kinematic viscosity @40ºC in cSt	ASTM D445	2.8	2.83
Flash point (°C)	ASTM D92	53	52
Fire point (°C)	ASTM D93	59	64
Pour point (°C)	ASTM D97	-16	-5
Gross calorific value (kJ/kg)	ASTM D240	44374	44018
Density@ in gm/cc	ASTM D1298	0.833	0.8328
Cetane index no	ASTM D 976	51.3	51.2

2.3 Experimental Arrangement

The tests are carried out on a water-cooled, four-stroke, single-cylinder Kirloskar AV-I diesel engine linked with an eddy current dynamometer outfitted with the required equipment to assess performance, combustion, and emission parameters. The practical qualifications of the test appliance are shown in table2. The injection pressure was varied between 300 bar to 900 bar through CRDI system and operated with orange peel oil blend. Running the engine with OPO20 blend with continuous speed of 1500 rpm and studied the performance, emission and combustion appearances for various load conditions.

Table 2 - Specifications of the test vehicle

Category	Only cylinder, perpendicular, aquatic cooled, 4-stroke diesel appliance
Bore	80 mm
Stroke	110 mm
Compression Ratio	17.5:1
Orifice Width	20 mm
Dynamometer armrest span	195 mm
Extreme Power	3.7 kW
Speed	1500 rpm
Filling Device	Eddy current dynamometer

A common rail direct injection system was used to test the Kirloskar AV1 four-stroke, single-chamber, water-cooled diesel engine. The engine's rated output was 3.7 kW. The machine was worked with varying injection pressures of 300 bar to 900 bar at a continuous speed of 1,500 rpm. The weight of the appliance is diverse from 20%, 40%, 60%, 80% and 100% through eddy current dynamometer. The diagram sight of the investigational setup for the CRDI machine is shown in Fig. 2

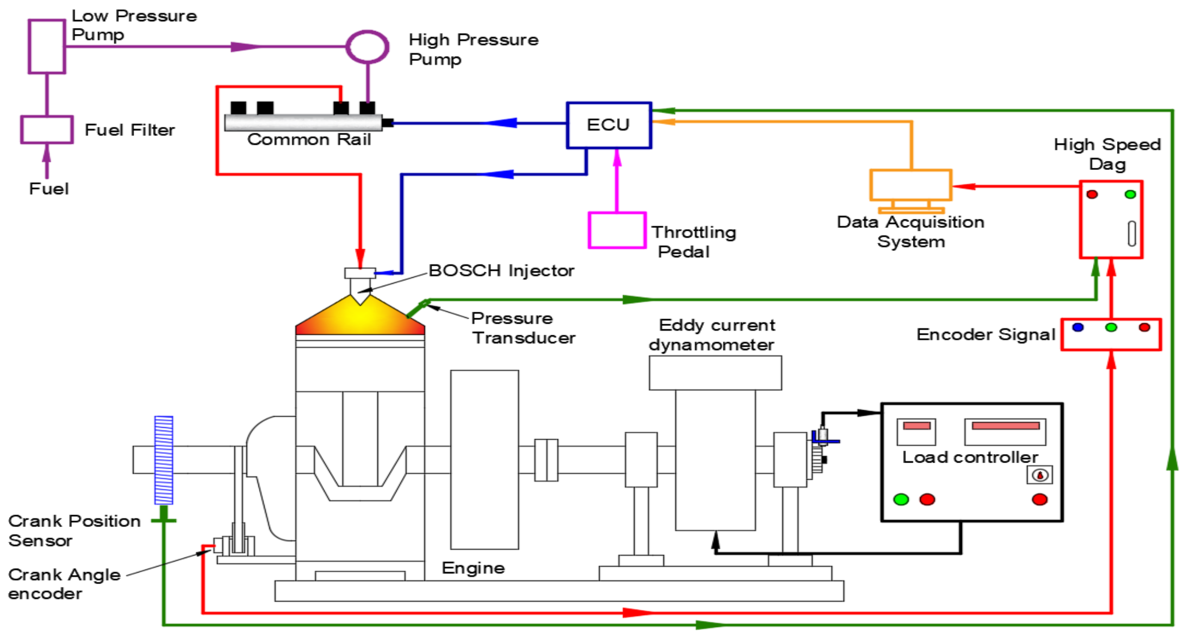

Fig. 2 is a illustration of the investigational apparatus.

A gasoline filter, a low-pressure pump, a high-pressure pump, a common rail, a pressure regulating valve, a pressure sensor, an electronic fuel injector with three nozzle holes (brand Delphi TVS), and a Bosch electronic control unit (ECU) compose the CRDI (Common Rail Direct Injection) system. The ECU is an open loop control; parameters such as the main injection angle, fuel injection pressure, pilot injection quantity, pilot injection angle, and injection duration can be fed into the ECU from a computer while the engine is running using the "Tuner Pro" software interface. Only the fuel injection pressure is increased from 300 bar to 900 bar during this operation. The required injection pressure is sent to the ECU, which regulates the rail pressure using a pressure sensor signal. A fuel line is connected between the rail and the electronic fuel injector, which injects fuel into the cylinder at the user-specified pressure. Tables 3 and 4 detail the specifications of the AVL Di gas analyser and smoke meter, respectively.

Table 3: Explanation of the AVL gas analyzer

Brand	AVL
Kind	AVL Di Gas 444
Power Supply	11...22 volage ≈ 25 W

Warm up time	≈ 7 μιν
Connector gas in	≈ 180 I/h, max. overpressure 450 hope
Reply time	$T_{95} \leq 15s$
Working temperature	5...45 °C
Storage temperature	0...50 °C
Relative humidity	≤ 95%, non-condensing
Disposition	0...90°
Measurement (w x d x h)	270 x 320 x 85 mm^3
Mass	4.5 kg net weight without fittings
Boundaries	RS 232 C, Pick up, oil temperature postmortem

Table 2 — Specification of AVL smoke meter

Brand	AVL 437 Smoke meter
Kind	IP 52
Correctness and reproducibility	± 1 % full scale evaluation
Gauging range	0 to 100 opaqueness in %
	0 to 99.99 absorption m^{-1}
Dimension chamber	Active span 0.430 m ± 0.005m
Heating time	220V about 20 min.
Light source	Halogen bulb 12 V/5W
Supreme smoke temperature	250 °C
Power source	190 – 240 V AC, 50 Hz, 2.5 A
Sizes	570mm × 500mm ×´ 1250mm

3. Outcomes and Discussion

3.1 Brake thermal efficiency

Variations of brake thermal efficiency versus brake power for diverse injection pressures of a CRDI appliance operating with orange peel oil blend OPO20 are depicted in Figure 3. According to the graph, high injection pressure increases the thermal efficacy of the brakes for the OPO20 at 900bar. The brake thermal efficiency (BTE) for the orange peel oil mixture OPO20 with 900bar injection pressure is 1.84% increase when compared to diesel at 300bar. This might be because of consequence of legitimate atomization and more complete burning happened because of expansion in the injection pressure, which suggests that a greater injection pressure is optimal for enhancing the discharge characteristics of OPO20 mix. Due to the improved oxygen contented in the blended fuel at all injection pressures, BTE was enhanced. The mixed energy comprises more oxygen, which surges the combustion efficiency and consequently the BTE..

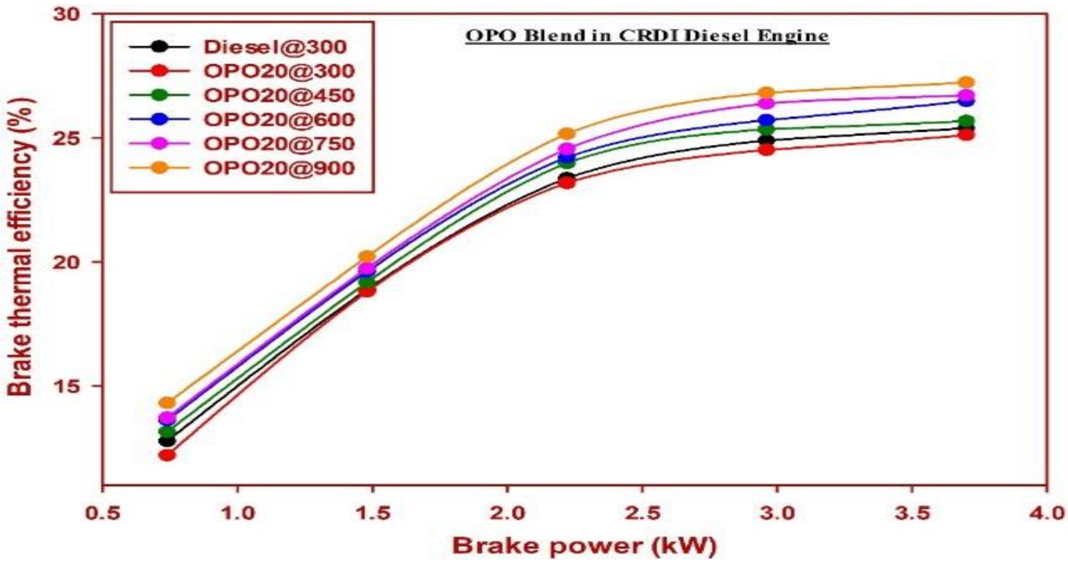

Figure 3: Variations of BTE with brake force

3.2 Brake specific fuel consumption

Differences of BSFC versus brake power for various injection pressures of a CRDI engine operating with OPO20 are depicted in Figure 4. Equated to diesel, the BSFC for the orange peel oil blend OPO20 with high injection pressure of 900 bar is lower. The BSFC values for diesel@300 and OPO20 at 900bar are 0.330 and 0.296 kg/kW-hour, respectively. This is subsequently of surge of injection pressure diminishes the fuel molecule distance across and along these lines, atomization happens appropriately and causes better ignition. Therefore, a greater quantity of biodiesel is essential to harvest the same quantity of power as diesel, and this fact justifies the aforementioned trend in the BSFC. However, it was discovered that the BSFC decreases as injection pressure increases. Inferior injection pressure attributed to least combustion, as a result of oxygen starvation due to less penetration, least dispersion of the fuel.

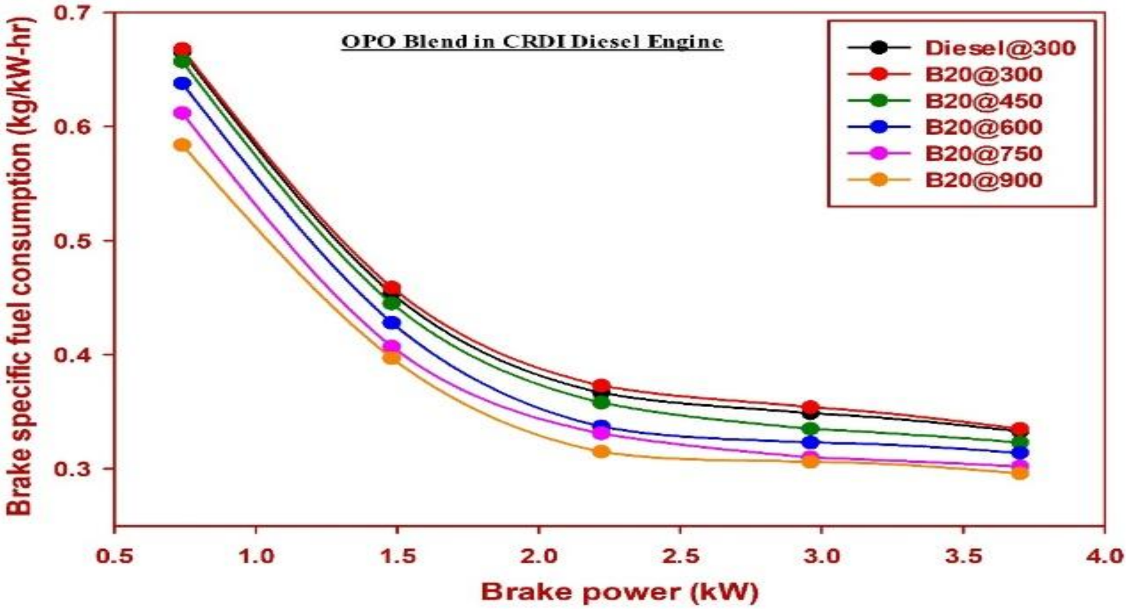

Fig. 4— Differences of BSFC with brake power

3.3 NOx emission

The graph in Figure 5 depicts variations in NOx versus brake power for varying injection pressures of a CRDI machine operating with OPO20. The orange peel oil blend OPO20 exhibits a 13% increase in NOx emissions at 900 bar injection pressure associated to diesel at 300bar. The reported NOx emissions for diesel@300 and OPO20 with injection pressure of 900 bar are 784ppm and 901ppm, respectively. Fuel is burned more effectively because fuel injection pressure increases fast atomization and shortens the ignition delay period. At elevated temperatures, N_2 will respond with oxygen and harvest a greater quantity of NOx due to enhanced combustion.

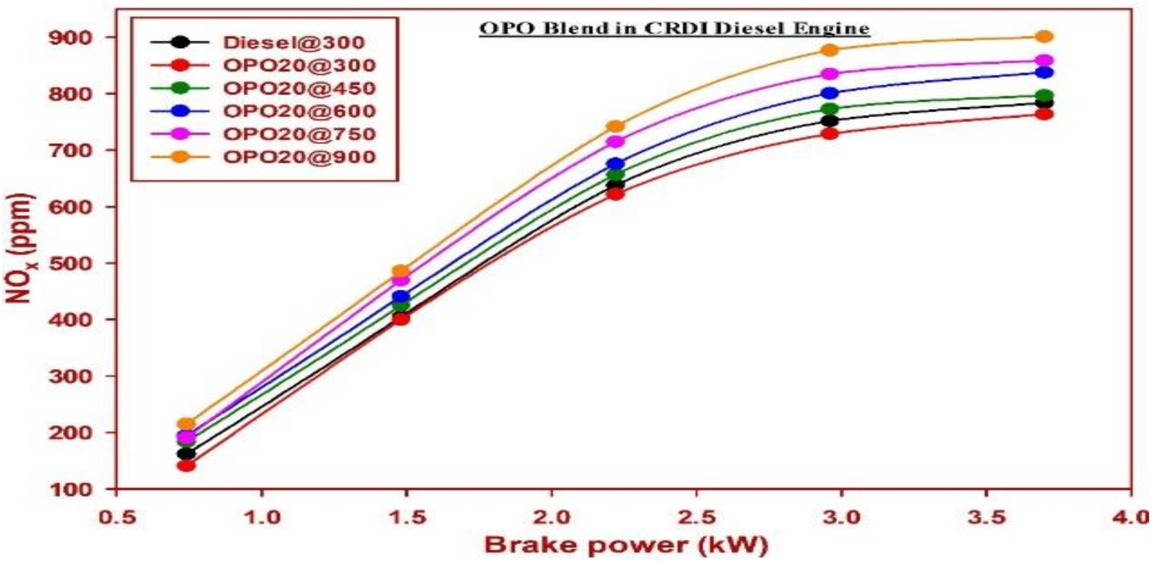

Fig.5— Difference of NOx release with brake power

3.4 Smoke Density

Fig. 6 depicts differences in smoke emission versus brake power for varying injection pressures in a CRDI diesel engine using orange peel oil blend OPO20. The smoke emission for the OPO20 with high injection pressure of 900bar is decreased when compared with diesel@300bar. It has decreased 18.2% compared to diesel@300bar. 56HSU and 45.8HSU are the reported smoke emissions for diesel@300 and OPO20 with 900bar injection pressure, respectively. An surge in fuel injection pressure further lessens the quantity of smoke, which results in a decrease in emissions. At higher injection pressures, the attendance of oxygen in the OPO20 and the fine atomization of the fuel decrease the haze density.

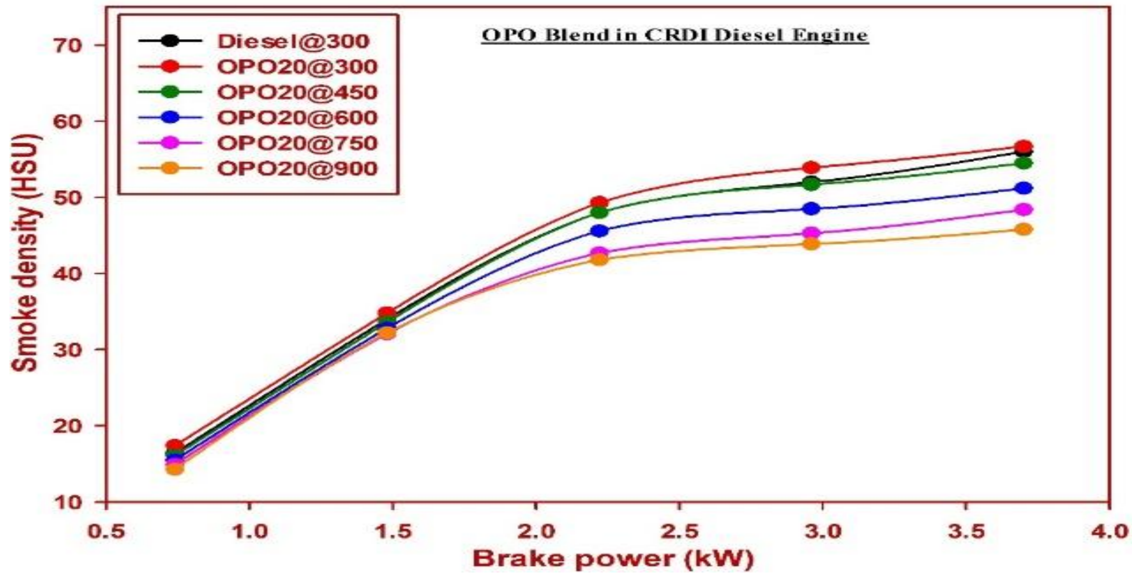

Fig.6— Difference of Smoke density with brake power

3.5 CO release

Figure 7 depicts variations in carbon monoxide emission versus brake power for various injection pressures of a CRDI engine powered by OPO20. The CO emission for the OPO20 with injection pressure of 900 bar shows lower value which is 50% decreased when likened with neat diesel@300bar. The CO release for diesel@300bar, OPO20 with 900 bar injection pressure is 0.40, 0.20 % of vol. respectively. Carbon monoxide is a byproduct of imperfect burning and the incomplete oxidation of carbon-containing mixes; it forms when there is insufficient oxygen to produce carbon dioxide. Rich fuel condition describes this disorder. Because CO emissions are created by a rich mixture, increasing the injection pressure results in a less rich mixture.

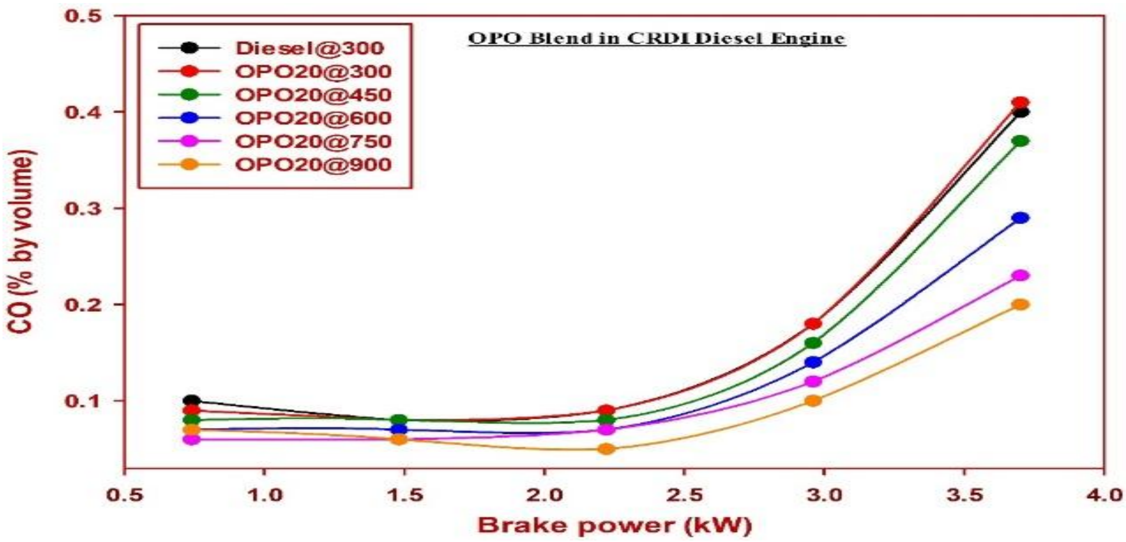

Figure 7: Variation in CO emissions with brake force

3.6 HC release

Figure 8 depicts the relationship between hydrocarbon (HC) emissions and braking power for varying injection pressures in a CRDI machine using orange peel oil blend OPO20. Associated to diesel@300bar, the orange peel oil blend OPO20 with 900 bar injection pressure reduces HC emissions. Likened to diesel@300bar, the OPO20 blend with 900 bar injection pressure reduces HC emissions by 22.3%. The reported HC emissions for diesel@300bar and OPO20@900bar are 85 and 66 ppm, respectively. The graph suggests that when the gasoline injection pressure is better, hydrocarbon emissions are reduced further. The reason for due to high penetration of petroleum jet because of higher injection pressure produces better combustion of fuel.

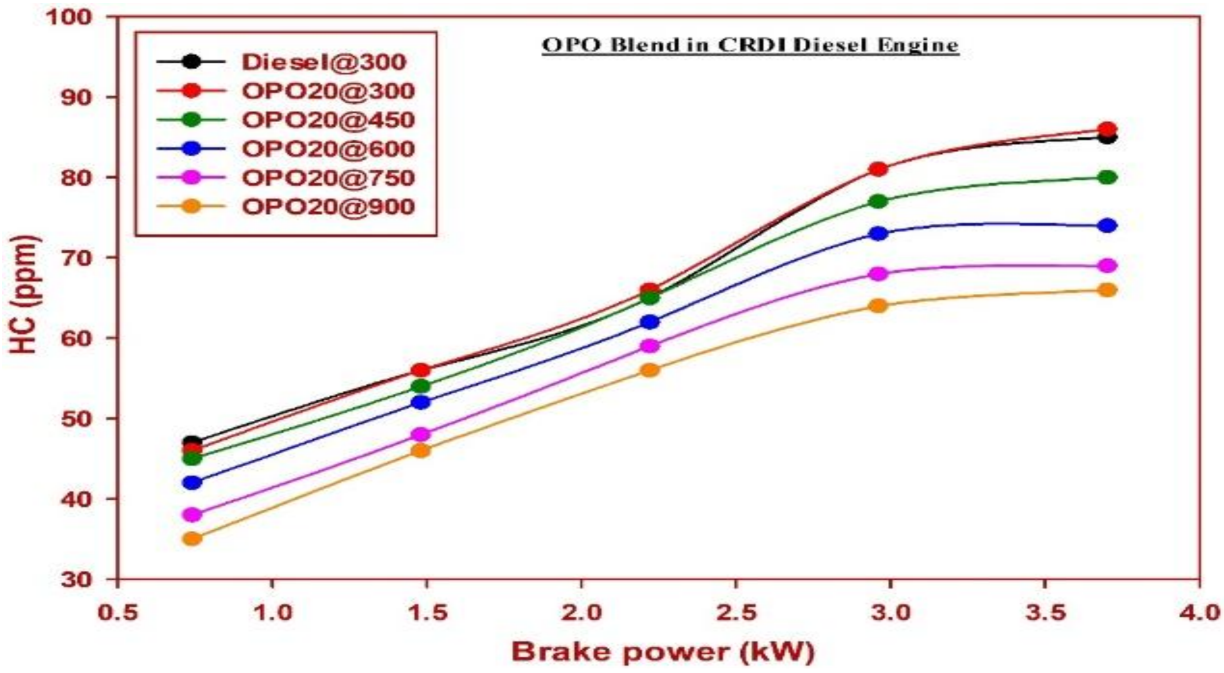

Fig. 8— Difference of HC release with brake power

3.7 In cylinder pressure

Figure 9 depicts the relationship between In cylinder pressure and crank angle for varying injection pressures in a CRDI machine operating with orange peel oil blend OPO20. Supreme cylinder pressure follows earlier for orange peel oil blend OPO20 compared to diesel@300bar due to the shortened delay. This is because the higher oxygen gratified in orange peel oil allows for During the pre-combustion phase, the fuel is completely burned and continued combustion during the primary combustion phase. The graph demonstrates that OPO20@900bar had a 1.73 percent developed top pressure than diesel@300bar. Throughout the entire spectrum of machine procedure, the same trend is observed for the trial fuel. The increase in injection pressure has resulted in an increase in in-cylinder pressure, possibly due to the fine spray formed during injection and enhanced atomization, which lowers the delay time and promotes improved combustion. Maximum maximal cylinder pressure is reported to be 61.24bar for diesel@300bar and 62.32bar for OPO20@900bar.

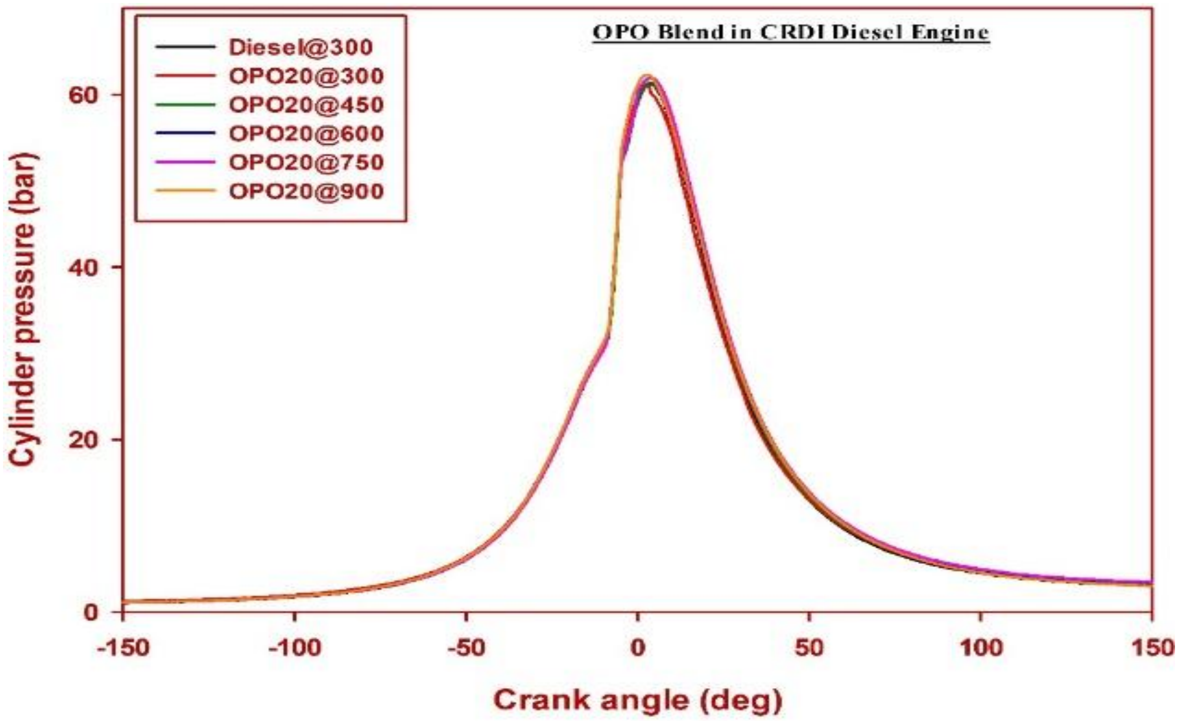

Fig. 9— Difference of In cylinder pressure with crank angle

3.8 Heat Release Rate

Figure 10 demonstrates the link between heat release rate and temperature and pinion angle for varying injection pressures in a CRDI machine operating with orange peel oil blend OPO20. Numerous researchers anticipate that the combustion process will be facilitated by the density, compressibility, and viscosity of biofuel. The calorific value of OPO20 blend is lower than that of diesel due to its oxygen content. The presence of oxygen in orange peel oil facilitates complete fuel combustion. The HRR of OPO20 at 900 bar is greater than diesel at 300 bar. The apex of the heat release rate and the combustion phasing of the OPO20 blend advance as the fuel injection pressure increases from 300bar to 900bar due to a reduction in the ignition delay caused by improved fuel-air mixing. When the injection pressure is increased, the ignition delay period decreases as a result of a smaller mean diameter of the fuel drop, a shorter disintegrate length, more dispersion, and improved atomization of the injected fuel. The peak HRR for OPO20 at 900bar of fuel injection pressure is 129.85 kJ/m3deg, whereas it is 123.54 kJ/m3deg for diesel at 300bar.

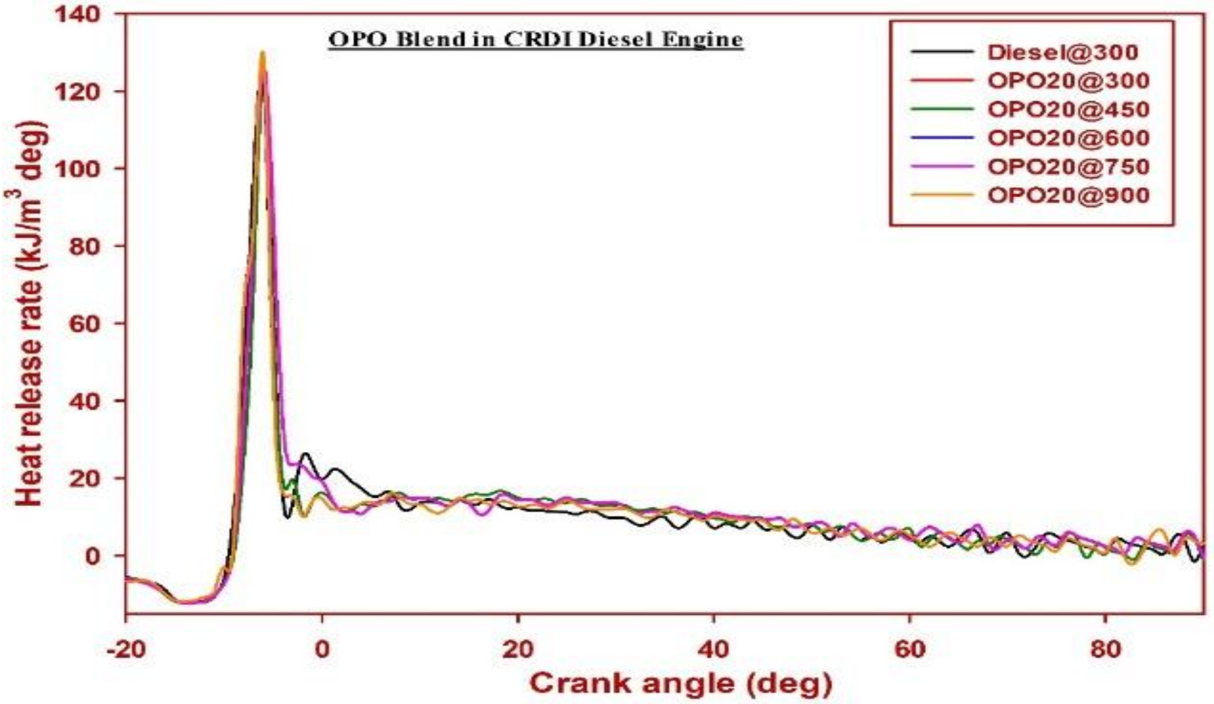

Figure 10 depicts the link between heat emission rate and crank angle.

4. Conclusion

This work discusses the effect injection pressure on the performance, burning characteristics , emission and of CRDI machine powered with orange peel oil blend (OPO20) and the following conclusions have been made in this study,

- The essential oil of orange peel is extracted by steam distillation then 20% injected with diesel.
- The properties of orange peel oil blend are measured through ASTM standards and associated with diesel.
- The braking thermal efficacy of the orange peel oil blend OPO20 at 900bar injection pressure is 1.84 percent higher than that of diesel@300bar.
- The BSFC, CO, smoke and HC emission are decreases for the OPO20 when increasing the injection pressure to 900bar compared with neat diesel@300bar.
- CO, haze, and HC emissions of the orange peel oil mix OPO20 at 900bar injection pressure are reduced by 50%, 22.3%, and 18.2%, respectively, when compared to diesel@300bar.
- In comparison to diesel@300bar, OPO20 at 900bar injection pressure emits 13% more NOx. In comparison to diesel@300bar, the maximum peak in-cylinder pressure and heat release rate for OPO20@900bar are somewhat higher.

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