Effect of NO_x and Mechanical Efficiency in Single Cylinder Diesel Engine using Multiple Injection of Biodiesel- An Experimental Investigation

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Abstract

This research paper investigates the impact of multiple injections of biodiesel, derived from sources such as Karanja seed oil, Cotton seed oil, and Waste cooking oil, on a single-cylinder diesel engine. Through experimentation, it has been observed that the sequential injection of these biodiesel blends results in a significant reduction in nitrogen oxide (NO_x) emissions. Simultaneously, mechanical efficiency is found to increase, highlighting the potential for optimizing combustion processes in diesel engines for improved environmental and operational performance. The findings suggest a promising avenue for enhancing the sustainability of diesel engines by leveraging alternative biodiesel sources and injection strategies.

Keywords: *Multiple injection, Biodiesel, Partially premixed charge, Emission, Efficiency, EGR*

1. Introduction:

A significant problem in daily living has been the increased need for conventional fuels. Natural resources for conventional fuels are being used at an alarming rate. Biodiesel is a beneficial source of fuel and a potential replacement for conventional gasoline in the future [1]. It is regarded as a natural fuel. The vegetable oils used to make the biodiesel like Karanja Seed Oil, Waste Cooking Oil, Cotton Seed Oil, and others can be used[3][4][5]. Biodiesel has become more popular across the world as people become more concerned about energy consumption and pollution. However, from a key standpoint as a supplemental or alternative fuel, it has sparked many more disputes, and sectors have yet to favorably adopt the derived fuel. Energy consumption is rising everywhere, due to the world's modernization and industrialization. Simultaneously, conventional fuel is depleting, and CO_2 emissions are becoming a serious environmental issue. Conventional fuels provide 95 percent of transportation energy,and demand is growing, especially in fast-developing countries like India. The energy crisis is caused by two factors: the first is the world's rapidly growing population, and the second is a shift in human lifestyle.

It is also commonly understood that emissions from the burning of fossil fuels are the major cause of global warming, and many countries have passed legislation to counteract the negative environmental consequences of high population expansion. At the current pace of use, the known crude oil reserves would be depleted in less than 30 years due to an astronomical increase in energy demand attributable to the rapid expansion of industrialization in many developing countries such as India.

The current energy situation has active research into non-conventional, renewable, and lower-polluting fuels. The industrial nation's massive population increase, technological improvement, and standard of life have resulted in this complex situation in the realm of energy supply and demand. Alternative fuels for vehicles, such as biodiesel that are renewable, are needed today

Fuels such as Karanja Seed Oil, Waste Cooking Oil, and Cotton Seed Oil are preferred for internal combustion engines because they are easy to handle and have good calorific value and density[3][4][5]. Vegetable oils have been tested on diesel engines around the world to see how they work and what emissions are released. In the short term, this fuel can be used directly on diesel engines. Karanja trees have been utilized for soil reclamation and revegetation near coal mines. In India, peasants have long used Karanja Seed to bind the soil on sloping uplands [5]. Cooking oil used at high heat, edible fat mixed in the kitchen garbage, and oily wastewater immediately dumped into the sewer are all examples of waste cooking oil [3][7][8]. Cottonseed oil is a waste product from the cotton industry that used to be far more significant than vegetable oil [4][9]. The effectiveness of repeated injections was studied in a steel engine with modern structures, and the reason behind it was investigated by a light engine [10] [11]. The discovery of a metal engine reveals that a well-designed multi-injection system is more effective than a single injection. The heat transfers between the heat generated by a mixture of fuel gas and the linear cylinder can be limited by separation. This shows how injections affect fuel distribution, heat transfer, and, as a result, engine efficiency. The study of Extensive injection into diesel engines shows that the soot-NO_x commercial curves may be closer to the source than conventional single-pulse injections, resulting in a significant reduction in both soot and NO_x emissions [11]. Injectable fuel burns quickly and does not contribute much to the production of ashes with disinfectant injections. Many injections are shown to have NO_x reduction mechanisms similar to a single injection with a different injection schedule. In an experimental context, investigate alternative injection tactics for Ethanol Partially Premixed Combustion [6][12]. The goal of this study was to find a good injection method for ethanol-fueled PPC combustion. The test is performed on a single heavy-cylinder engine at medium and low loads, the number of injections for each cycle, the duration of the injection, and the ratio between the different injection pulses were all changed simultaneously, and the inflammatory behavior was analyzed. The results showed that for PPCs fueled with ethanol, the double injection technique should be selected since it provides better combustion performance. Low emissions and great efficiency are achieved while combustion noise is kept to a minimum.[11] Test the performance and output of DICI engine features powered by Karanja Seed biodiesel in test studies. Karanja Seed is used with a 10% biodiesel content and a 90% diesel content. The attributes are found to be within the allowed limits based on the characterization research. Operating metrics including air/fuel ratio, thermal brake, mechanical, and volume efficiency are reduced compared to neat diesel, there is a significant drop in CO (46.91%) and a significant increase in CO_2 emissions. [14] CI engine performance and emissions utilizing waste cooking oil biodiesel under various loads and engine conditions were studied. In the test, one four-stroke cylinder engine was used. Flexors include engine speed, fuel time, gasoline flow rate, and test fuel flow rate. Results show that NO_x emissions are increased but CO emissions are decreased.

The impact of biodiesel-based cotton seed oil on engine performance and production is being considered. Cotton seed oil was produced by the transesterification process and used as a biodiesel. The catalyst, methanol or ethanol, had a substantial influence on the transesterification results, according to the data. Findings from engine tests revealed that biodiesel compounds reduced exhaust emissions such as carbon monoxide (CO), smoke emissions, and particulate matter (PM). The biodiesel compound has caused a slight increase in the release of nitrogen oxides (NO_x).[13][14][15].

1. **Transesterification reaction**:

The transesterification process is also known as the alcoholic process. In this process, alcohol is displaced from one ester to another ester, which is likely to hydrolysis but instead of water, it uses the alcohol. This method is used to decrease the high viscosity of triglycerides. Triglycerides are the main substance in vegetable oil and animal fats. The chemical procedure which converts vegetable oil or animal fats into biodiesel is known as the transesterification process.

$H_2C – OCOR$			ROCOR	H_2C - OH
|	Catalyst			|
$H_2C – OCOR$ +	3ROH	$\rightleftharpoons$	ROCOR +	H C - OH
|				|
$H_2C – OCOR$			ROCOR	H_2C – OH
Triglyceride	Alcohol		Alkyl Ester	Glycerol

Fig. 4.3 Transesterification Reaction

Transesterification of triglycerides produces fatty acid alkyl esters and glycerol. The glycerol layer settles down at the bottom of the reaction vessel. Diglycerides and monoglycerides are the intermediates in this process. The step-wise reactions are reversible and a little excess of alcohol is used to shift the equilibrium towards the formation of esters. After the reaction time, the mixture was placed in a separate funnel and allowed to stand overnight to ensure that the separation of alkyl esters and glycerol phase occurred completely. The glycerol phase (bottom phase) was removed and left in a separate container. Alkyl esters (biodiesel) were heated to remove methanol and co-solvent. The remaining catalyst was extracted by successive rinses with hot and soured distilled water. Finally, the water present was eliminated by heating at 110^0C.

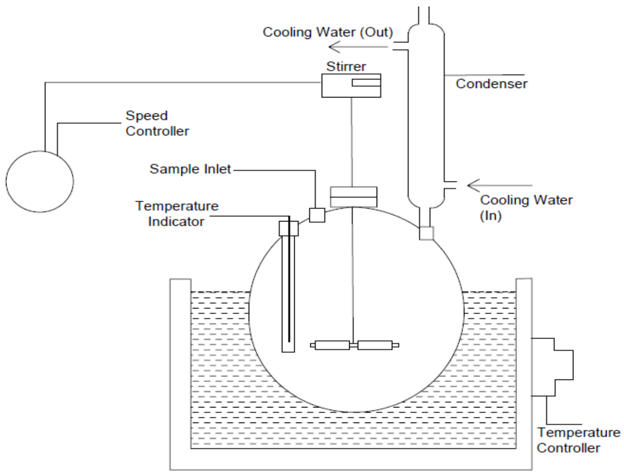

Fig: Experimental Set Up for Transesterification

2. **Experimental setup:**

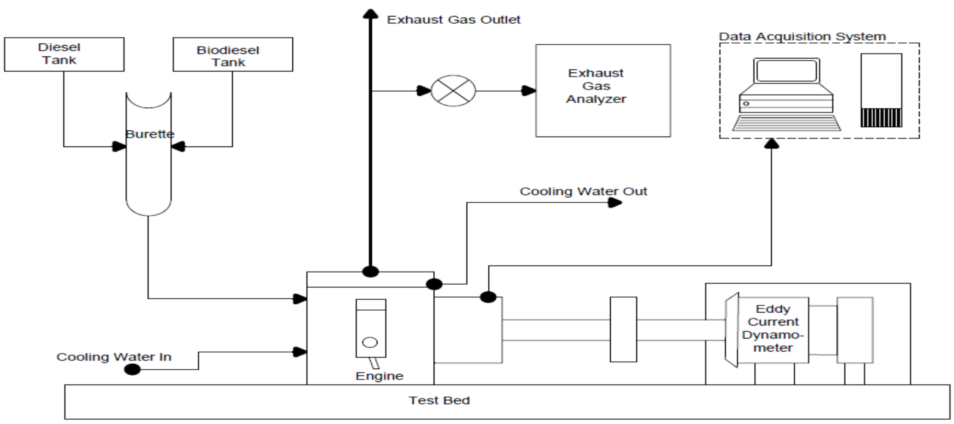

Fig: CRDI Single Cylinder CI Engine

A single-cylinder four-stroke Diesel engine is connected to an eddy current dynamometer for applying the load on the engine as shown in Fig. The fuel tank, air box, fuel gauge device, manometer, digital temperature indicator, and digital rpm indicator are all housed in a stand-alone control panel box. The temperature indicator shows the value of the temperature of the cooling water inlet, outlet, and calorimeter. Rotameters are used to measure cooling water flow to the engine and calorimeter. Apex innovation made lab view-based software IC EngineSoft configured to the engine to study brake power, brake mean effective pressure, brake thermal efficiency, volume efficiency, brake specific fuel consumption, air-fuel ratio, and heat balance sheet. It incorporates Microsoft Excel engine analysis software, and the ECU is connected to the engine to change parameters such as injection pressure and injection times.

Specifications of Engine

- Dynamometer arm length (R) = 185 mm = 0.185m
- Bore (D) = 87.5 mm = 0.0875m
- Stroke (L) = 110 mm = 0.11m
- No. of Cylinders (x) = 1
- Sp. Gravity of fuel (Diesel) = 0.83
- Coefficient of discharge for an orifice (C_d) = 0.62
- Diameter of an orifice (d_o) = 20 mm
- Atmospheric pressure (P_a) = 100 kPa
- Ideal gas constant for air (R_i) = 0.287 kJ/kg K
- Specific heat of water (C_p) = 4.187 kJ/kg K
- Specific heat of gas (C_{pg}) = 1.1 kJ/kg K
- Engine speed (N) = 1500 rpm
- CV of Diesel = 42000 kJ/kg
- Water Density (W_{den}) = 1000 kg/m^3
- Air Density (A_{den}) = 1.17 kg/m^3

Karanja seed oil, waste cooking oil, and cotton seed oil were produced by the transesterification process, and made the blends B5, B10, and B15 were with pure diesel. These blends of biodiesel were tested to find their properties and later were added to the fuel tank. The observations according to the test matrix by varying the parameters such as load (3,6,9, and 12 kg), pressure (600,500, and 400 bar), angle of injection with single and multiple injections, and with the addition of EGR. AVL-made exhaust gas analyzer was used for measuring the smoke parameters such as HC, NO_x, CO_2, O_2, CO, etc. A smoke meter was used to measure opacity which measures the amount of light blocked in smoke. The fuel properties for B5, B10, and B15 are summarized in the following table.

Table: Properties of Fuels at various blends

Fuel	**Calorific Value (KJ/Kg)**	**Density (kg/m^3)**	**Viscosity (NS/m^2)**	**Fire Point (^oC)**	**Flash Point (^oC)**
Diesel	42143	830	2.09	56	53
Karanja Seed Oil	38056	880	6.6	145	120
K5%	41939	832	2.3	60	56

K10%	41734	835	2.5	65	60
K15%	41530	837	2.8	69	63
Waste Cooking oil	37947	870	5	75	60
W5%	41933	832	2.2	57	53
W10%	41723	834	2.4	58	54
W15%	41514	836	2.5	59	54
Cotton Seed Oil	40996	860	5.9	160	140
C5%	42085	831	2.3	61	57
C10%	42028	833	2.5	66	62
C15%	41971	834	2.7	72	66

3. **Nitrogen Oxide Emissions (NO_x)**

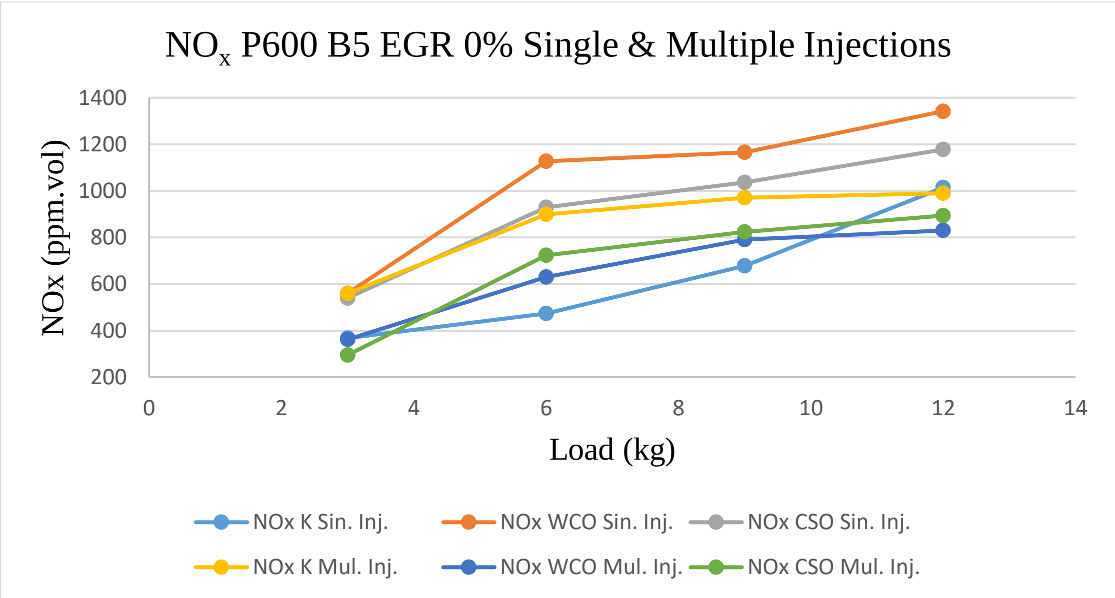

Fig. 4.1 Graph of NOx Vs Load at Single and Multiple Injection

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The blend B5 of Karanja seed oil, waste cooking oil, and cottonseed oil was tested for single injection and multiple injections at various loads (3kg, 6kg, 9kg, and 12kg) and pressure 600 bar with zero EGR. Multiple injections were carried out using split angles of 14^0 (main injection), 21^0 (Pilot injection), and 7^0 (relative angle) before the top dead center, and a single injection was carried out at 23^0 before the top dead center. [20]. It is observed that the value of NO_x was increased with the increase in load in both the cases of single and multiple injections, also NO_x value was lesser in multiple injections as compared to single injections due to a higher delay period. At 12 kg load value of NO_x was reduced from 1014 ppm to 990 ppm using Karanja seed oil, NO_x was reduced from 1342 ppm to 830ppm using waste cooking oil and NO_X was reduced from 1178 ppm to 894 ppm using cottonseed oil.

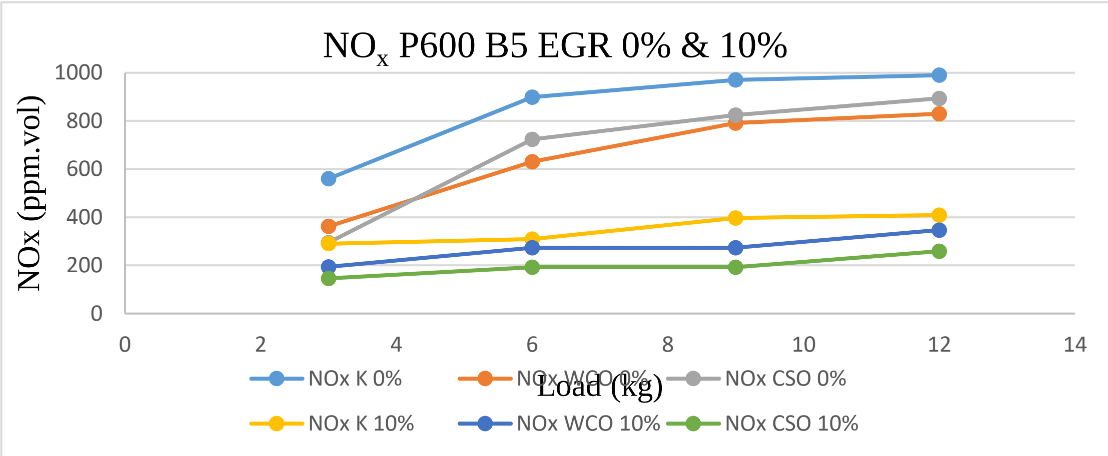

Fig. 4.2 Graph of NOx vs Load with or without the addition of EGR

The plot of load Vs NO_x for all three B5 blends with 0% and 5% EGR at various loads and 600 bar pressure using multiple injections, shows that the value of NO_x increases with the load in both cases with 5% EGR and zero EGR. Also, it was observed that when EGR was added up to 10% the value of NO_x decreased as compared with zero EGR because NO_x emissions are generated mostly from the nitrogen present in the incoming atmospheric air to the engine due to high combustion temperature during the combustion process. The viscosity of the Karanja seed oil is more than the waste cooking oil and cotton seed oil so the poor atomization of fuel took place and hence increase in NO_x was seen. At 12 kg load value of NO_x was reduced from 990 ppm to 409 ppm, 830 ppm to 347 ppm, and 894 ppm to 259 ppm for Karanja oil, waste cooking oil, and cotton seed oil respectively.

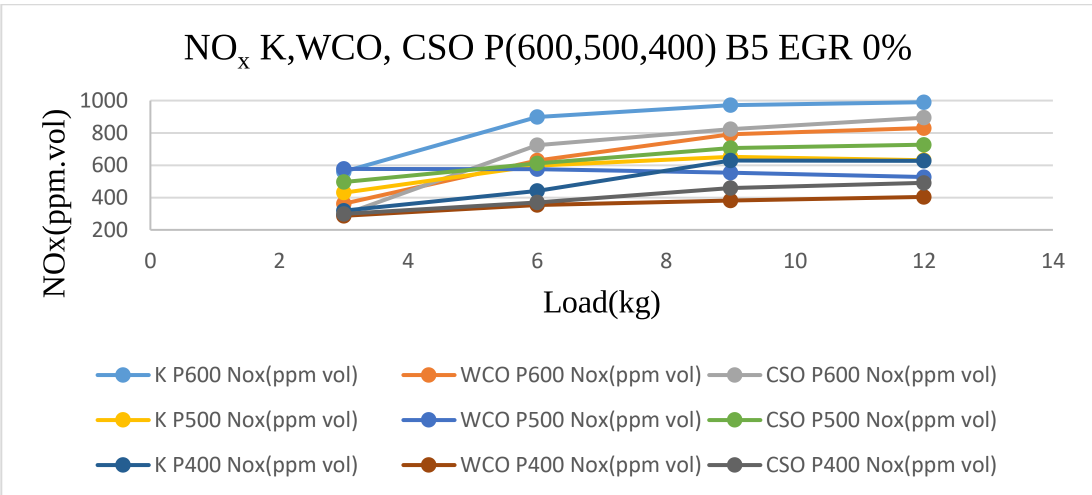

Fig. 4.3 Graph of NO_x vs Load at different pressure

The engine was tested at different pressures like 400 bar, 500 bar, and 600 bar for all three B5 fuels with varying loads and zero EGR. It was observed that the NO_x value increases with an increase in pressure due to a lesser delay period. To keep the NO_x value minimum pressure needs to be reduced so good atomization and proper combustion can be carried out. At 12 kg load, the NO_x value shows a lower range for 400 bar pressure and it is reduced from 990 ppm to 627 ppm, 830 ppm to 404 ppm, and 894 ppm to 491 ppm for Karanja oil, waste cooking oil, and cotton seed oil respectively.

4. Mechanical Efficiency (%)

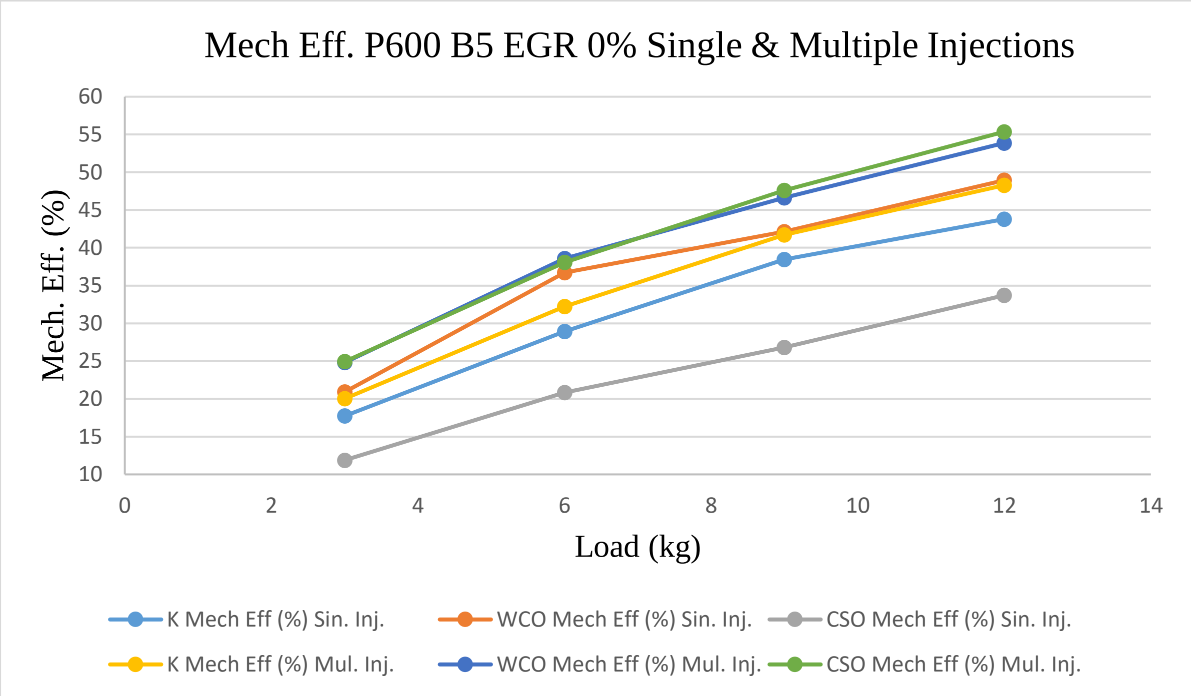

Fig. 5.1 Graph of Mech. Eff. vs Load at Single and Multiple Injection

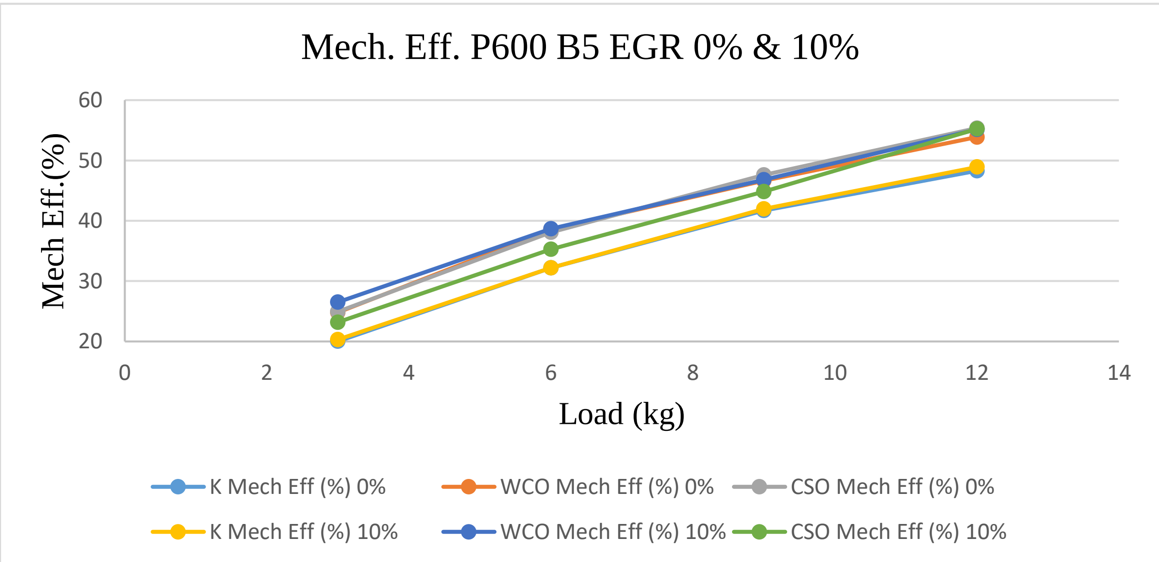

Fig. 5.2 Graph of Mech. Eff. vs Load with or without the addition of EGR

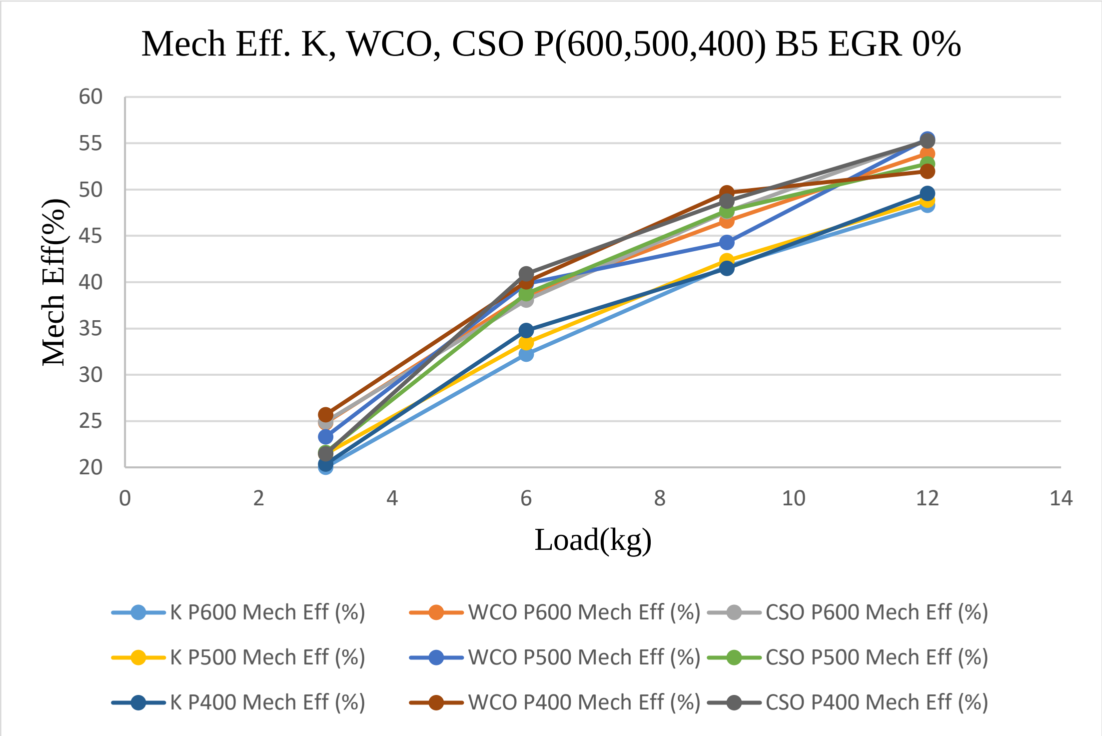

Fig. 5.3 Graph of Mech. Eff. vs Load at different pressure

The above graph shows the performance of the engine was observed by varying injection patterns, EGR %, and pressure respectively. It was observed that using multiple injections and increasing the value of EGR8 mechanical efficiency was improved and this is due to the fuel droplets getting sufficient time to spread with the fresh air. Most of the fuel admitted would have evaporated and formed a combustible mixture with air, which results in complete combustion. No major difference was seen in mechanical efficiency with variation in pressure because the peak cylinder pressure in the diesel engine also depends on the viscosity of the fuel. At 12 kg load efficiency of the engine using multiple injections is increased from 43% to 48%, 48% to 53%, and 33% to 43% for Karanja oil, waste cooking oil, and cotton seed oil respectively.

5. **Conclusion:**

Increased use of biodiesel requires simpler production techniques that are more efficient and do not have specific chemical requirements. Making biodiesel with the transesterification process is a simple and effective way to produce biodiesel. The production of biodiesel from these fuels has significant local, regional, and national impacts. In India, making biodiesel is a cost-effective option. Furthermore, the usage of biodiesel may reduce the consumption of conventional fuels, resulting in future savings in fossil fuels. Fuel properties like calorific values, density, flash point, fire point, and cetane number are identified by the standard test procedure.

The experimental investigations conducted on a compression ignition engine using biodiesel blends of Karanja seed oil, waste cooking oil, and cottonseed oil (B5, B10, and B15) in conjunction with diesel have provided valuable insights into the performance and emission characteristics of the engine. The comprehensive analysis, involving modifications in injection pressure and the incorporation of exhaust gas recirculation (EGR) from 0% to 10%, has revealed the effectiveness of these strategies in controlling nitrogen oxide (NOx) emissions without compromising the overall performance of the diesel engine. The results underscore the potential of exhaust gas recirculation and multiple injections as viable and sustainable methods for achieving a balance between environmental concerns and optimal engine operation. This research contributes to the ongoing efforts to develop cleaner and more efficient combustion technologies for compression ignition engines using biodiesel blends, paving the way for environmentally friendly and high-performance diesel engine applications.

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7. **Conflicts of interest**: The authors have no conflicts of interest to declare.

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Nomenclatures

CR- Compression Ratio
VCR- Variable Compression Ratio
CV-Heating Value of Fuel (kJ./kg)
P - Density of a Fuel (kg.m-3)
D -Diesel Fuel
K- Karanja Fuel
P- Cylinder Pressure
MGT- Mean Gas Temperature
HC- Hydrocarbon Emission
PM- Particulate Matter
CO- Carbon Monoxide Emission
CO_2 -Carbon dioxide Emission
NO_x -Oxides of Nitrogen Emission
BT -Brake Thermal
SFC -Specific Fuel Consumption
BSFC -Brake Specific Fuel Consumption
TDC -Top Dead Centre
BDC -Bottom Dead Centre
PPC- partially premixed charge
A/F- air-fuel ratio
PM- particulate matter
EGR- exhaust gas recirculation
ECU- electronic control unit
R- Dynamometer arm length
D- bore diameter
L- stroke length
d_0- orifice diameter
P_a- atmospheric pressure
CV- calorific value
B5- Blend 5%
B10- Blend 10%
B15- Blend 15%