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EXPERIMENTAL COMPARATIVE STUDY BETWEEN PERFORMANCE AND EMISSIONS OF JATROPHA BIODIESEL AND DIESEL UNDER VARYING INJECTION PRESSURES

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ABSTRACT

Most modern searches are directed to alternative fuels because the buffer stock from the petroleum oils reduces with time and the fossil fuels are worst impact on environmental pollution. Now days, there are many sources of renewable energy. Bio diesel is just one source, but a very important one. Currently Jatropha biodiesel (JBD) is receiving attentions as an alternative fuel for diesel engine. Environmental impact assessment is one of the key essential factors to prevent global warming by reducing carbon monoxide and NOx emissions from various sources. This thesis presents the work done within the Ph. D research project focussing on the utilization of JBD with different fuel injection pressure angles in indirect injection (IDI) diesel engine. The work scope included fundamental experimental studies on brake thermal efficiency and emission studies of Jatropha in comparison to diesel fuel and the feasibility analysis of diesel substitution with JBD and future work recommendation of possible changes to the injection system. An IDI diesel engine was tested by diesel,100% biodiesel (B100), with respect to varying fuel injection pressures of 160, 170 and 180 kgf/cm^2. The engine characteristics with Jatropha biodiesel were compared against those obtained using diesel fuel. From the results, it is observed that at 100% load the brake thermal efficiency of the biodiesel improves as the fuel injection pressure is increased while keeping advance angle of fuel injection unchanged and for diesel the brake thermal efficiency decreases at the same conditions. In the subsequent section, the engine emissions from Jatropha biodiesel and diesel fuels are compared, paying special attention to the varying fuel injection pressures at different crank angles. Reasons behind prominent emissions such as NO_X, HC, CO_2, CO and smoke are comprehensively discussed.

KEYWORDS: *Bio-diesel, Fuel injection pressures, Brake thermal efficiency and exhaust emissions.*

I. INTRODUCTION

Diesel engines are the most efficient prime movers, Bio diesel is an alternative to petroleum based fuels derived from vegetable oils, animal fats and used waste cooking oil including triglycerides. It is very common for all articles base on biodiesel to start claiming that Rudolf diesel fuelled one of his early engines with penut oil at the Paris exhibition in 1900 [1]. Vegetable oils are widely available from various sources and the glycerides present in the oils can be considered as viable alternative for diesel fuel [2]. Usage of bio diesel will allow a balance to be sought between agriculture, economic development and the environment [3]. Biofuels provided 1.8% of the worlds transport fuel in 2008 [4]. According to the International Energy Agency, bio fuels have potential to meet more than a quarter of world demand for transportation fuels by 2050[5]. This necessitates the search for alternative of oil as energy source. Several countries including India have already begun substituting the conventional diesel by certain amount of biodiesel [6]. The production of biodiesel would be cheap as it could be extracted from non edible oil sources. Jatropha curcas (Linaeus), a non edible oil-bearing and drought- hardy shrub with ecological advantages, belonging to the Euphorsicae family was found to be the most appropriate renewable alternative source of biodiesel [7]

The production of Jatropha seeds is about 0.78 kg per square meter per year. The oil content of Jatropha seed ranges from 19% to 41% by weight. Fresh Jatropha oil is slow drying, odourless and colourless oil but turns yellow after aging [8].

Forson used Jatropha oil and diesel blends in compression ignition [CI] engines and found its performance and emission characteristics similar to that of mineral diesel at low concentration of Jatropha oil in blends [9]. Applications of Jatropha biodiesel in diesel engine having advantages like decrease net carbon dioxide, carbon monoxide, hydrocarbon and particulate matter emissions and its fuel properties akin to conventional diesel for ease of use in diesel engines. However some drawbacks include lower heating values, poorer cold flow characteristics and mainly reported higher emissions of oxides of nitrogen. Jatropha biodiesel can be used in its pure form or can be blended with diesel to form different blends. Because the properties of Jatropha biodiesels are similar to convert diesel fuel so it can be used in CI engines with very little or no engine modifications.

Biodiesel is most common biofuel for diesel engine. It is produced from oils or fats using transesterification and is a liquid similar in composition to fossil/mineral diesel. It is a domestic, renewable fuel for diesel engine derived from natural oil like Jatropha oil. Biodiesel has an energy content of about 12% less than petroleum-based diesel fuel on a mass basis. It has a higher molecular weight, viscosity, density, and flash point than diesel fuel.

The proposed studies are aimed to effective utilization of Jatropha straight vegetable oil with different fuel injection pressures in a single cylinder. An indirect injection diesel engine delivers fuel into a chamber off the combustion chamber, called a pre chamber, where combustion begins and then spreads into the main combustion chamber. The pre chamber is carefully designed to ensure adequate mixing of the atomized fuel with compression heated air. This has the effect of slowing the rate of combustion, which tends to reduce audible noise. It also softens the shock of combustion and produces lower stress on the engine components [10]. The addition of pre chamber, however, increase heat loss to the cooling system and there by lowers engine efficiency. A side from the above advantages, early diesels often employed in indirect injection in order to use simple, flat-top pistons and made the positioning of the early bulky diesel injectors easier. The present project aims to identify key characteristics of the fuel injection pressures that effect the performance and emissions of engine running on Jatropha straight vegetable oil.

This research aimed to investigate the effect of JSVO and diesel into a constant (slow) speed indirect injection diesel engine (Field marshal make) widely used for irrigation pump sets in the country. After identifying performance and emission parameters, the fuel obtained by JSVO and diesel in pre defined volumetric percentage were characterized and its performance characteristics were compared vis-à-vis fossile diesel as a base line. A detailed fuel injection pressure maintenance protocol was developed as per the data generated for the use of JSVO engines different crank angles.

It was reported in above references that engine parameters have significant effect on performance and emissions of diesel engine when run with biodiesel and diesel. Engine tests were carried out at different fuel injection pressure angles and loads. This research aimed to investigate the effect of biodiesel and diesel on emissions including exhaust smoke of a IDI diesel engine. Investigation of exhaust smoke with biodiesel as a fuel in IDI diesel engines is a new dimension of work.

II. METHODOLOGY

A. Physical and chemical properties of Jatropha straight vegetable oil.

The cetane indiex to biodiesel was determined by ASTM D. 976 method. The flash point was determined By ASTMD . 92 methods. The pour point was determined by ASTMD. 97 method. The kinematic viscosity way determined by ASTMD. 445 method. The specific gravity way determined by ASTMD.1298 method. The copper strip corrosion test way determined by ASTMD.130 method. The water and sediment test way determined by ASTMD. 1796 method. The specifications and manufacturers of the instruments were given in the following Table I.

Table1: Properties of JSVO and Diesel fuels

Properties	**Jatropha oil**	**Diesel**
Density[gm/sec]	-	0.84
Kinematic viscosity at 30^0 C	55	4.0
Calorific value [MJ/kg]	39.5	45
Cetane number	43	47
Solidifying point ºC	-10	-14
Boiling point ºC	286	248

B. Preparation of Biodiesel from Jatropha oil.

Jatropha oil has golden yellow color and is prepared from the seeds of Jatropha curcas. These seeds are black in colour and oval in shape [11]. Biodiesel was prepared with methane and ethanol each with different reaction conditions.

With methanol, the experiment was conducted with optimum molar ratio (6:1) keeping the catalyst concentration (1% NaoH), reaction temperature (65^0C) and reaction time (1hour). With ethanol, the experiment way conducted with optimum molar ratio (8:1) keeping the catalyst concentration (1% KoH), Reaction temperature (70^0C) and reaction time ($3^{1/2}$hour) .In this process oils and to make them fit for their use in the present diesel engines without any modification. In this process an ester reacts with an alcohol to form another ester and another alcohol. The catalyst for this reaction is KOH or NaOH. To accomplish the transesterification reaction described above, the oil, methanol, and catalyst are mixed together in a stirred reactor. 55 º-60 º C temperatures will cause the reaction to reach equilibrium more rapidly.

C. Refining of Jatropha oil.

After oil expelling, the crude vegetable oils contain some of the impurities such as uncrushed seed cake and other particulates. Therefore it way essential to refine the crude vegetable oils. The crude non-edible oils such as Jatropha oil were redefined in the laboratory through simple filtration methods. These filtered by using 4 micron filter paper sender vacuum condition. These filtered oils were dried in a vacuum drier at a const. temp at 60^0C for 4 hours to remove the traces of moisture. The dried oil was stored in the air tight dry PVC cans. The oils were filled up to the brim of the con to avoid any chances of oxidation. These cans were stored in a room at ambient temp. Properties to diesel and jatropha biodiesel of shown in table2. In this triglyceride is converted step wise to diglyceride , menoglycerides, and finally glycerol shown in fig.2, in the form of chemical reactions .

Triglycerides + P^1OH ⇔(Catalyst)
Diglycerides + P^1COOP_1
Diglycerides+ P^1OH ⇔(Catalyst) Menoglycerides + P^1COOP_1
Menoglycerides+ P^1OH ⇔(Catalyst) Glycerol + P^1COOP_1
Where
$P1=CH_3$
$P^1OH= CH_3OH$=Methanol
(PCOOH)= Catalyst (KoH or NaOH)
P $COOP^1$= P-$COOCH_3$= Methyl Ester
P-COOH= Fatty acid
P is a mixture of various fatty-acid chains.

Fig.1 Transestecification of triacylglycerol acid esters.

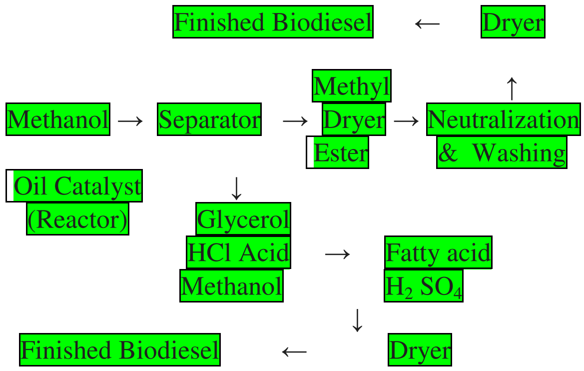


Fig.2: Schematic of Biodiesel Processing.

As shown in the reaction equation above, three moles of methanol react with one mole of triglyceride. In practice, most producers will use at least 100% excess methanol (6:1molar ratio) to force the reaction equilibrium towards a complete conversion of the oil to biodiesel. The reaction is slowed by mass transfer limitations since at the start of the reaction the methanol is only slightly soluble in the oil and later on, the glycerin is not soluble in the methyl esters. A two-stage process is used for the esterification of the Jatropha oil [12-13]. The first stage of the process is called esterification, and this is used to reduce the FFA (Free fatty acids) content in jatropha oil by esterification with methanol (99%pure) and acid catalyst (sulfuric acid-98% pure) in one hour reaction at 60°C. In the second stage, called transesterification, the triglyceride portion of the jatropha oil reacts with methanol and base catalyst (potassium hydroxide-99% pure), in one hour reaction at 65 °C, to form an ester and glycerol. In this process, the triglyceride is converted stepwise to diglyceride, monoglyceride, and finally glycerol A two-stage process is used for the esterificationof the jatropha oil [15-16]. After transesterification, two layers were observed on cooling. The top layer was rawbiodiesels and the bottom layer was glycerin. The glycerol layer was separated and the raw fatty acid methyl ester was water washed to remove unreacted methoxide by the process of water washing with air bubbling. It was then heated to remove the water traces to obtain clear biodiesel. Finally, after drying the found methyl ester is converted to the required biodiesel. Hence, it is seen that 900 ml of biodiesel is produced from 1 liter of Jatropha oil. Properties of diesel, biodiesel and blends as shown in Table 1.

III. EXPERIMENTAL TEST RIG AND TEST PROCESS

The engine used in this study was a diesel engine. The tested engine specification is shown in Table 2 and photo graph is shown in figure 3.

Fig.3: Photograph of Experimental Set-Up

Sl. No.	Particulars	Specifications
1	Make	Field marshal Diesel engines
	Model	FM-4
3	Rated Brake Power (BHP/kW)	10/7.35110
4	Rated speed (rpm)	1000
5	Number of cylinder	One
6	Bore x Stroke (mm)	120x139.7
7	Compression ratio	17:1
8	Coling System	Water Cooled
9	Lubrication System	Forced Feed
10	Cubic Capacity	1580 cc
11	Nozzle	DL30S1202MICO
12	Nozzle Holder	9430031264 MICO
13	Fuel Pump	9410032034
14	Fuel Pump Plunger	9x03/323 MICO
15	Injection Pressure	145 kg/cm^2
16	Specific Fuel Consumption	265 gm /kWhr OR 195 gm / bhp /hr
17	Sump Capacity	4.5 Ltr
18	Lubricating oil Consumption	15 g /hr
19	Net Weight	355 kg
20	Gross Weight	490 kg

Experiments were carried out on stationary water cooled , naturally aspirated, 4-stroke, single cylinder, indict injection compression ignition engine (IDI) engine with specification shown in table 3. The layout of testing shown in fig. 2.

The engine test process was carried out in two phases as described below.

A. The engine was sum with the diesel fuel initially the fuel injection advance angle was set at 19^0BTDC using the drop test and the fuel injector pressure was adjusted 160 kgf /cm^2 with the help of injector tester. The engine was started and allowed to run for 15-20 minutes to get stabilized. The applied load on the engine was made to zero and making the current flowing in load circuit to zero. Then the parameters' like voltage, current, temperatures all 6 points engine (Revolution per minute)RPM, monometer reading and time for 50 cc fuel consumption is recorded. After recording these parameters the exhaust gas emission parameters like HC, NOx, CO_2, CO were recorded by pelting the probe of AVL gas analyzer in the exhaust pipe. For noting down the smoke (opacity) the exhaust gas was directed to AVL smoke meter and the opacity was recorded. After this the load on the engine was increased 25%,50%,75% and 100% by adjusting the current flowing through the load circuit 6.25 amp,12.5amp, 18.75 amp and 25amp respectively while keeping the fuel injector triggering pressure and fuel injection advance angle uncharged 160 kgf/cm^2 and 19^0BTDC(before top dead centre). After attain the stable condition the observations were taken at all above mentioned operating points.

The engine was stopped, the fuel injection angle was altered to 19^0 BTDC and the engine was recorded once again on mentioned in previous case and the data was recorded on observation table. This process was reputed for fuel advance angle of 21^0, 23^0 and 25^0BTDC The entwine process as mentioned above was repeated for fuel injection pressure 160 kg/cm^2 , 170kg/cm^{2}and 180kgf/cm^2.

The fuel supply system was flushed with fresh Jatropha oil and then the fuel tank was felled with JSVO. The engine was run for sufficient time duration to ensure that the petro- diesel fuel phase is over and the engine has started running with Jatropha as fuel. The entire process followed in phase I was repeated while engine running with JSVO as fuel.

IV. COMBUSTION ANALYSIS

Emission Analysis.

Energy sources being considered diesel, biodiesel for the purpose of present work. After the engine reached the stabilized working condition fuel consumption, air consumption, engine load and exhaust emissions were measured. Maximum torque of the engine for diesel was varied from 11 N-m to 27 N-m when engine speed changed from 700 rpm to 1060 rpm.

Oxidation Mechanism:-.

NO_X production in CI engines is very complex, because it is influenced by many factors and many of these factors interact at different levels. NO_X is mainly a function of temperature in the combustion chamber. The combustion timing relates to the start of combustion relative to the piston position in the cylinder. The combustion timing relates to the start of combustion (SOC) relative to the piston position in the cylinder. Early combustion timing causes combustion to occur closer to TDC and perhaps during compression process, increasing pressure, temperature, and the NOx emission. A number of fuel properties have been shown to effect the emissions of NOx [17]. Usually at a temperatures of above 2100 K, the nitrogen and oxygen disassociate and participate in a series of reactions (Eqn.(a), Eqn.(b), Eqn.(c), Eqn.(d), and Eqn.(e)) [18] and this oxidation mechanism is known as Zeldovich mechanism as shown in equation 1.

(a) $O + N_2 \rightarrow NO + N$------------- (1 a)
(b) $N + O_2 \rightarrow NO + O$ ------------ (1 b)
(c) $N + OH \rightarrow NO + H$------------- (1 c)
(d) $NO + HO_2 \rightarrow NO_2 + OH$------ (1 d)
(e) $NO_2 + O \rightarrow NO + O_2$----------- (1 e)

1. Oxidation mechanisms (Zeldovich) for NOx formation

Biodiesel fuel has different physical properties such as higher density, speed of sound, and bulk modulus which can also lead to an earlier start of injection. Early injection timing and higher CN, advance the combustion timing which tends to increase the NOX. The combustion rate , as indicated by the heat release rate, also has an effect on NO_X production. More premixed combustion means a high initial rate of combustion, which increase NO_X. Premixed combustion corresponds to the fuel that is mixed with air and prepared to burn during the injection period. When the fuel auto ignites it usually burns very quickly. Cetane number and fuel volatility are the two most important properties that determine the combustion rate. High cetane number and low volatility lowers the combustion rate. A biodiesel with a high cetane number is expected to shorten the ignition delay period and thus the lower the amount of fuel that involved with the premixed portion of the biodiesel combustion, thus lowering NO_X emission.

V. RESULTS AND DISCUSSION

A. Brake thermal efficiency:- After the engine reached the stabilized working condition fuel consumption, brake specific energy consumption, and brake thermal efficiency which are discussed as follows.

Fig 4 &5. Shows the variation of brake thermal efficiency with fuel injection advance angles at 160, 170 and 180 kgf/cm^2. The results showed that, at 100% load the brake thermal efficiency of JSVO improves as the fuel injection pressure is increased while keeping advance angle of fuel injection is 19, 21, 23 and 25^0, and JSVO brake thermal efficiency starts decreasing when advance angle is increased beyond 25^0 BTDC. For diesel brake thermal efficiency decreases at same conditions.

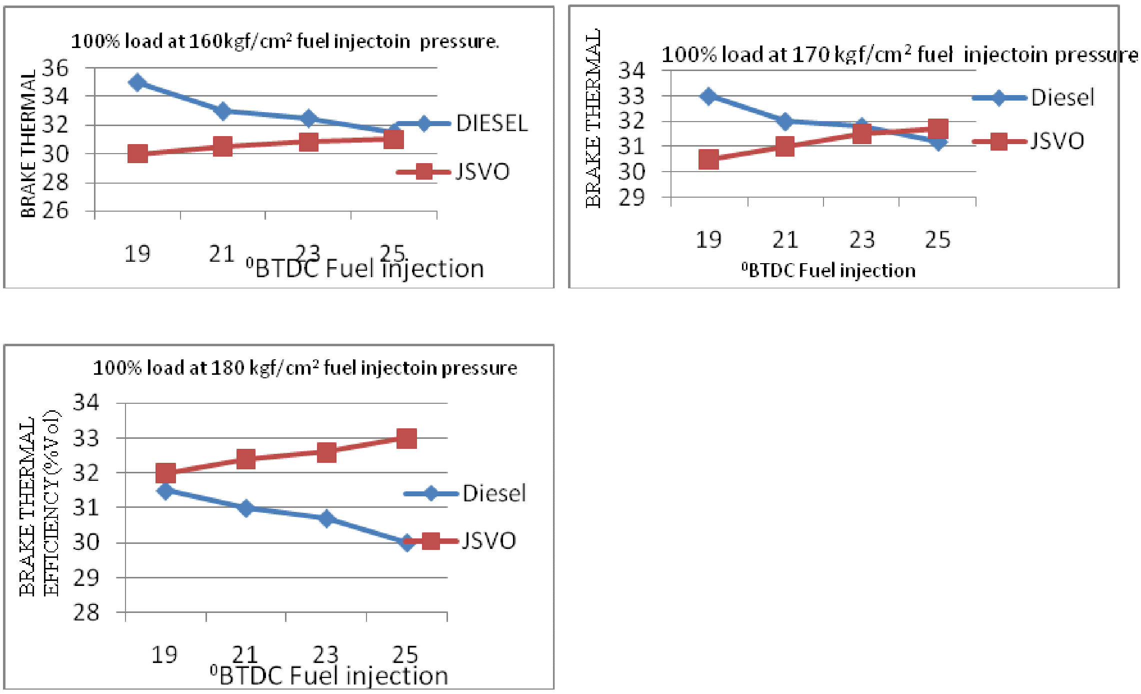


Fig 4: Brake thermal efficiency with various fuels at different fuel injection pressures and fuel advance angle (^{0}BTDC)

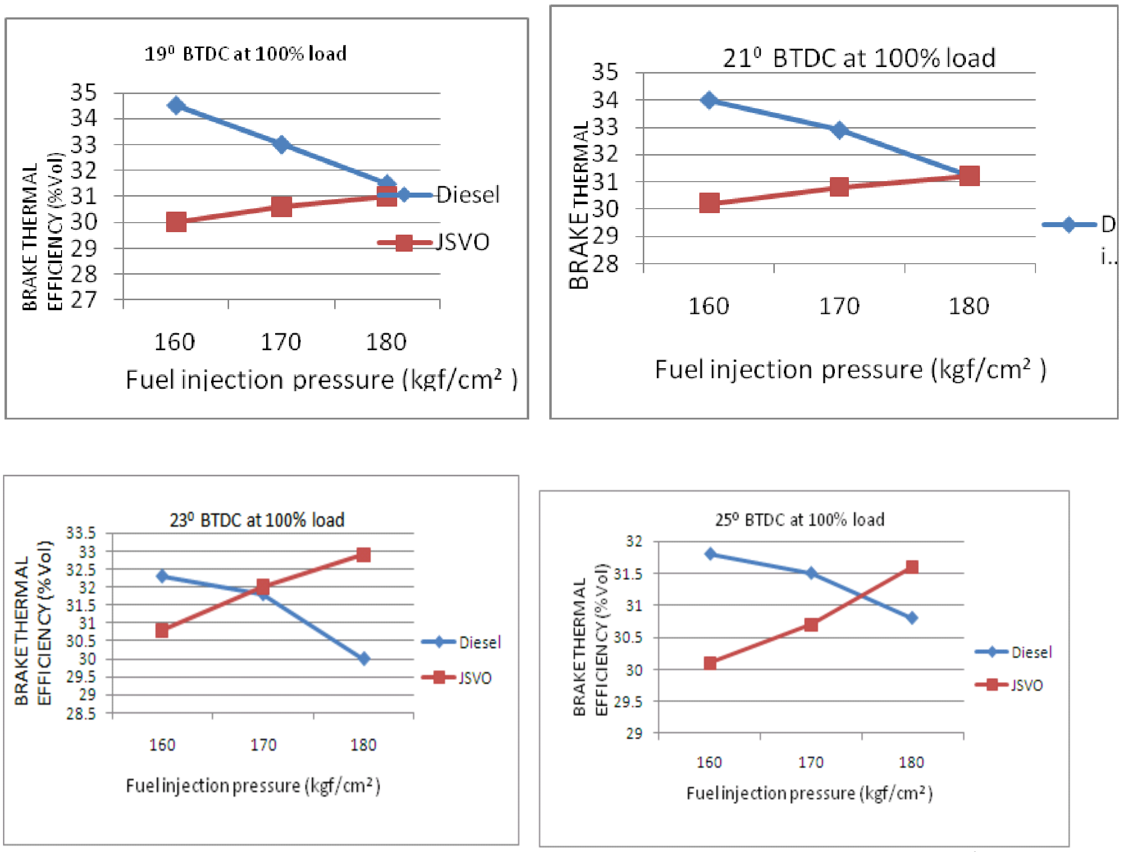


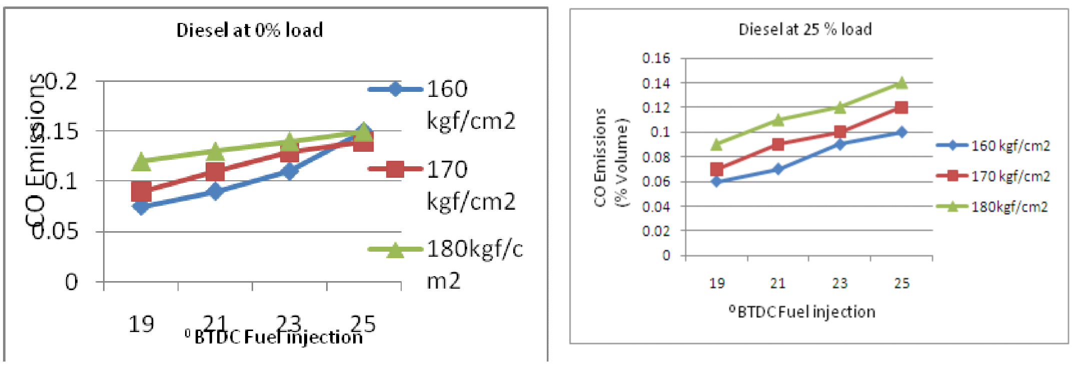
Fig 5: Brake specific fuel consumption with various fuels at different fuel advance angle (^{0}BTDC) and with different fuel injection pressures

B. Exhaust gaseous emissions:-

CO, CO_2, NO_X, HC and Smoke are measured as emissions in this study.

1. **CO emission:**

Fig 6 & 7. explains increasing and decreasing trend of carbon monoxide emission levels for diesel, and JSVO. The CO emission continuously increasing for diesel as the angle of fuel injection is increased from 19^0 BTDC to 25^0 BTDC in step of 2^0 for all load conditions. In case of JSVO, CO decreasing with increase of in advance angle of fuel injection up to the angle of 23^0 BTDC at all load conditions but the CO emissions starts increasing as the angle further increased to 25^0 BTDC. And CO emission continuously increasing for diesel as the fuel injection pressure is increased from 160,170 and180 kgf/cm^2 in step of 10 kgf/cm^2 for all load conditions. In case of JSVO, CO decreasing with increase fuel injection pressure is increased from 160,170 and180 kgf/cm^2 in step of 10 kgf/cm^2 for all load conditions, with these fuels were observed at this condition due to least excess of air. Higher oxygen content in the local mixture favours better combustion producing less CO in case of biodiesel and diesel fuels.



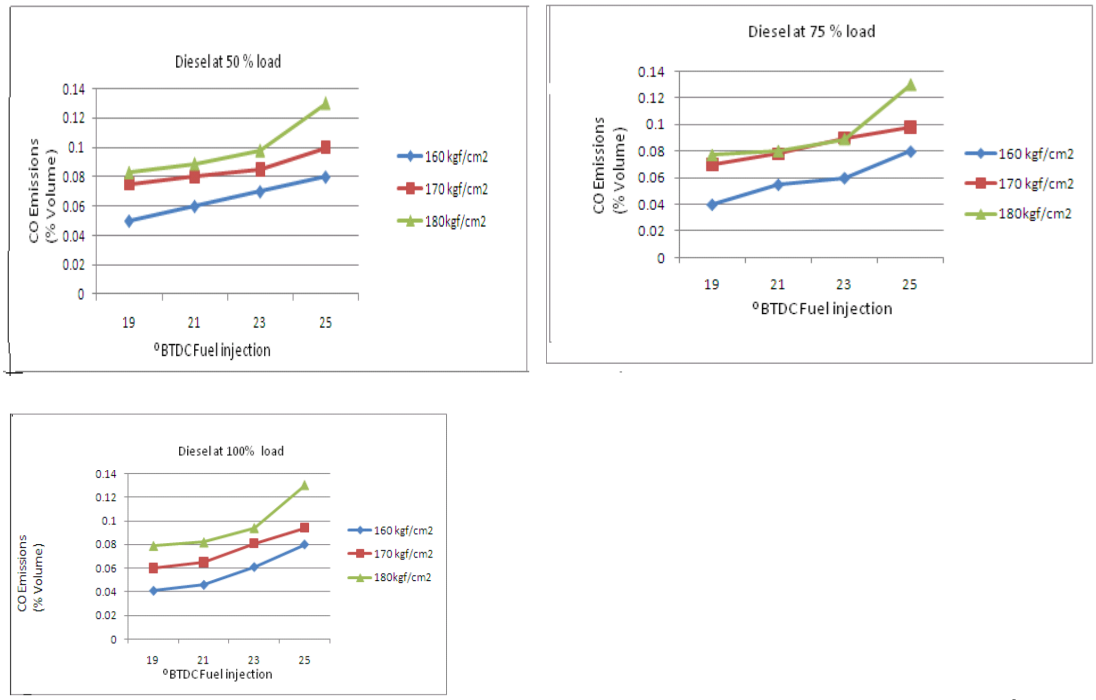
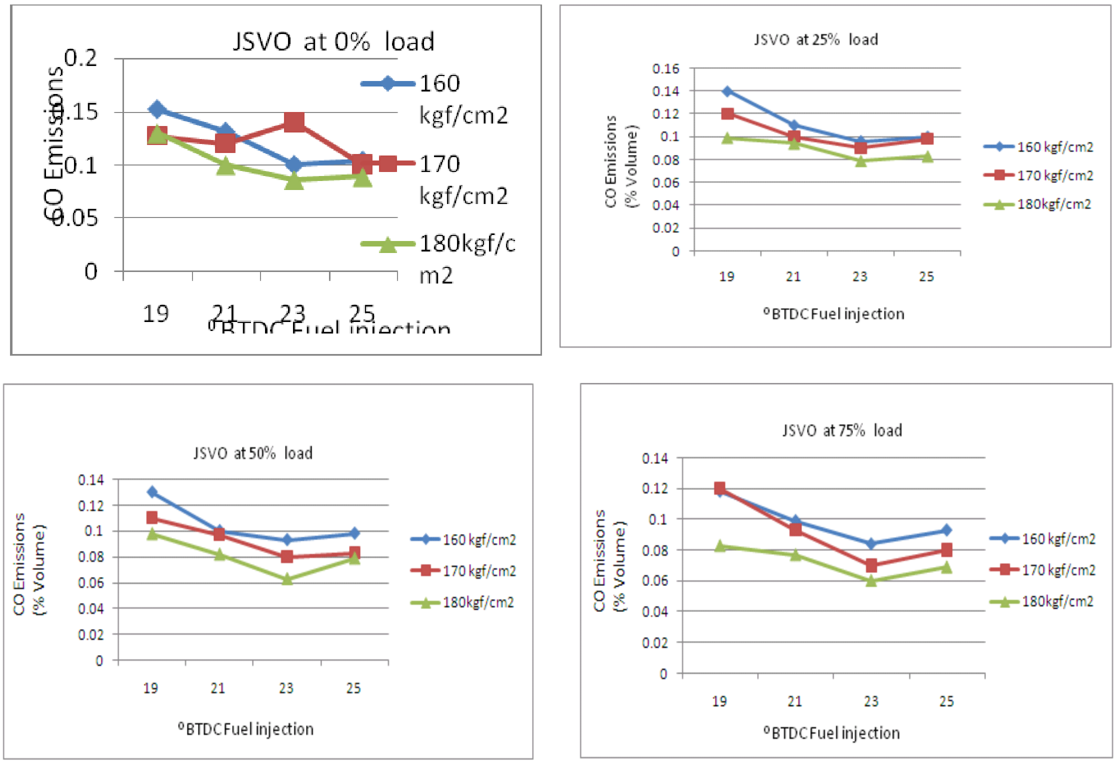


Figure6: CO emissions of Diesel fuel with various fuel injection pressures at different ^{0} BTDC Fuel injection advance angles.



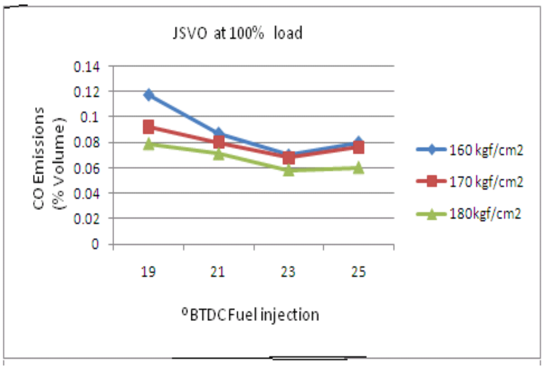
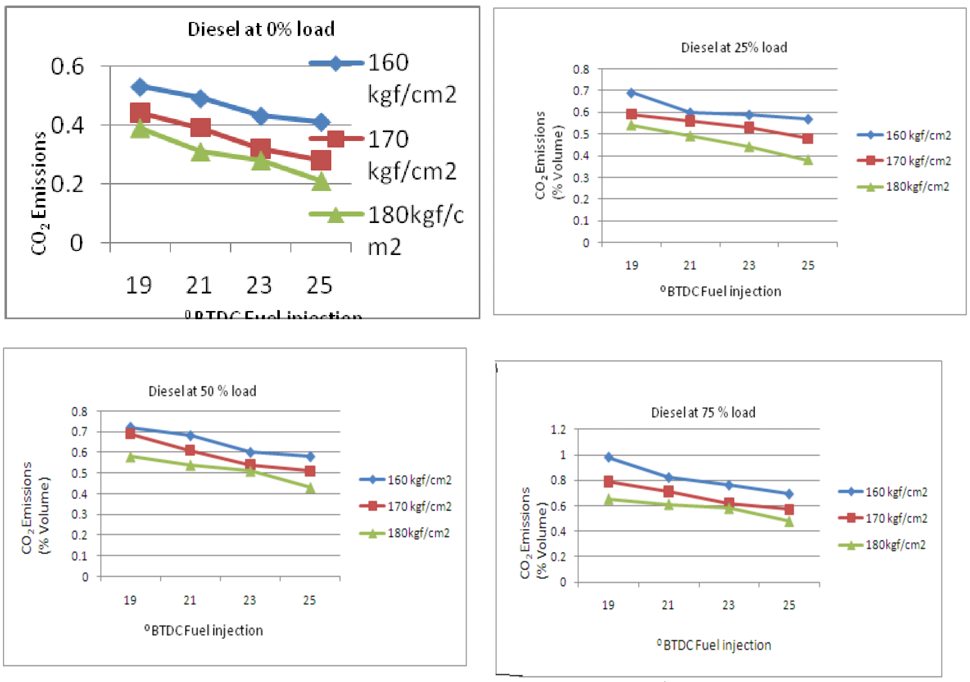


Figure7: CO emissions of JSVO fuel with various fuel injection pressures at different ^{0} BTDC Fuel injection advance angles.

2. CO_2 emission:

Fig 8& 9. Explains the decrease in CO_2 emission is observed at all but fixed injection pressure as the fuel injection advance angle is increased from 19^0 BTDC to 25^0 BTDC in steps of 2^0 at all engine load conditions. The CO2 emission of JSVO increases gradually as the advance angle of fuel injection is increased up to 23^0 BTDC but the CO_2 emission start decreasing beyond 23^0 BTDC of fuel injection which shows the fuel combustion efficiency starts deteriorating. . And CO_2 emission continuously decreasing for diesel as the fuel injection pressure is increased from 160,170 and180 kgf/cm^2 in step of 10 kgf/cm^2 for all load conditions. In case of JSVO, CO_2 increasing with increase fuel injection pressure is increased from 160,170 and180 kgf/cm^2 in step of 10 kgf/cm^2 for all load conditions, but the CO_2 emission start decreasing beyond 23^0 BTDC of fuel injection. As reported by this research that the advancing the fuel injection point too far can have negative consequence, resulting in erratic engine behaviour.



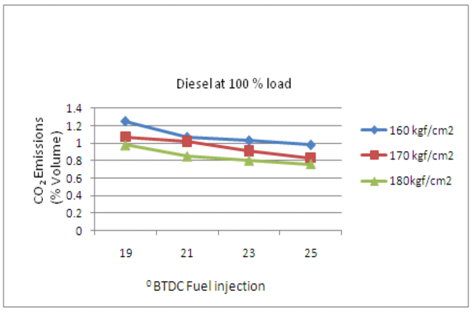


Figure 8: CO_2 emissions of Diesel fuel with various fuel injection pressures at different ^{0} BTDC Fuel injection advance angles.

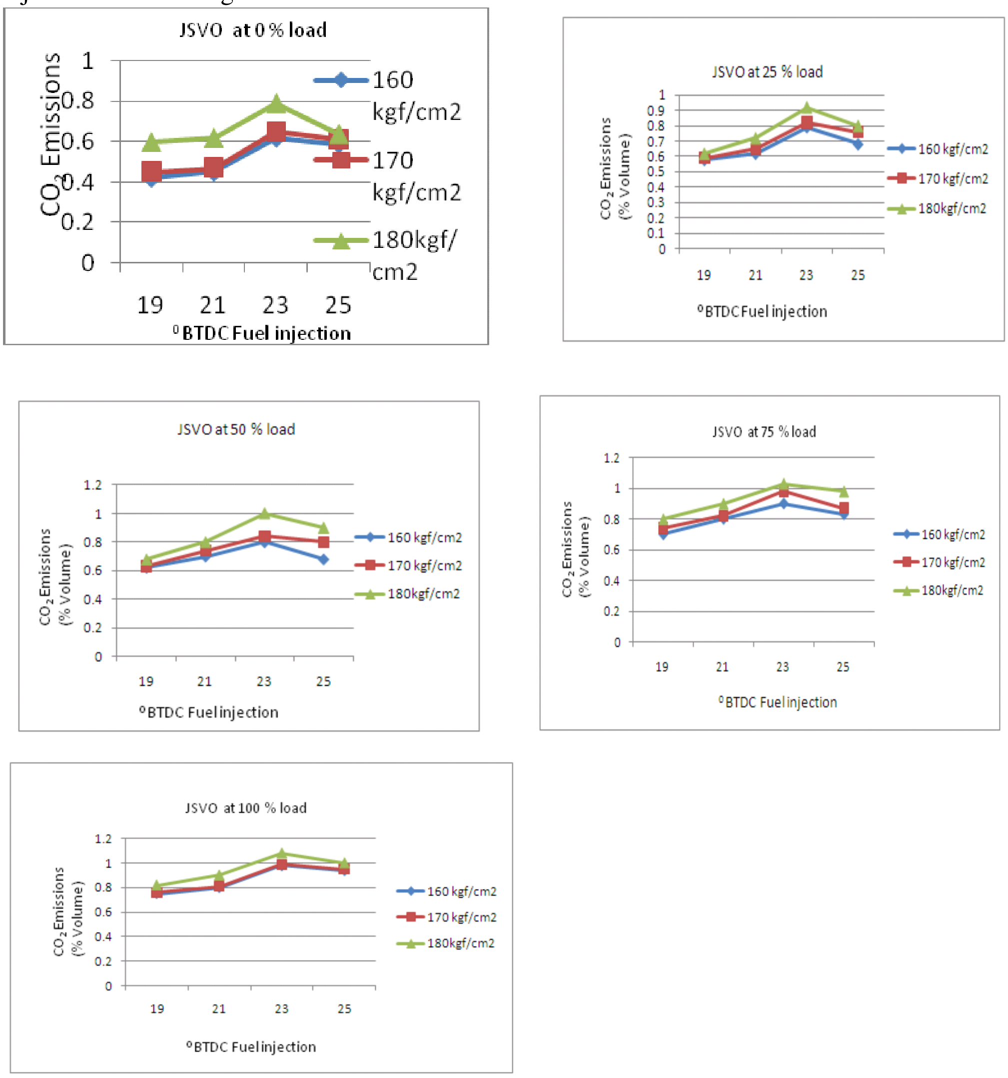


Figure 9 CO_2 emissions of JSVO fuel with various fuel injection pressures at different ^{0} BTDC Fuel injection advance angles.

3. NO_X Emissions:-

The NO_X emissions of diesel and Jatropha biodiesel fuels are plotted in the graph as shown in Fig 10. It shows for both the fuels, the increased engine load promoting NO_X emission. Since the formation of NO_X is very sensitive to temperature, which is responsible for thermal NO_X formation. The graph is plotted between NO_X emission and at varying fuel injection point for the fuel injection pressure of 160 kgf/cm^2 , 170 kgf/cm^2 and180 kgf/cm^2. The NO_X emission is continuously increasing for diesel as the angle of fuel injection is increased from 19^0 BTDC to 25^0 BTDC in step of 2^0 for all load conditions. The NO_X emission is decreasing for Jatropha biodiesel with increasing advance angle of fuel injection up to the angle of 23^0 BTDC at all the load conditions but the NO_X emission starts increasing angle is further increased 24^0 BTDC. It has also been seen that the NO_X emission of diesel fuel at all the angles of fuel injection is lower than the NO_X emission of JSVO. Where there was much excess of air, there was no increase in NO_X emissions with biodiesel and as compared to diesel. Here, there is excess oxygen in the cylinder, but cylinder temperature is not enough to produce thermal NO_X. It is remarkable that the NO_X emission at recommended operating point for JSVO(23^0 BTDC, 180 kgf/cm^2) is least.

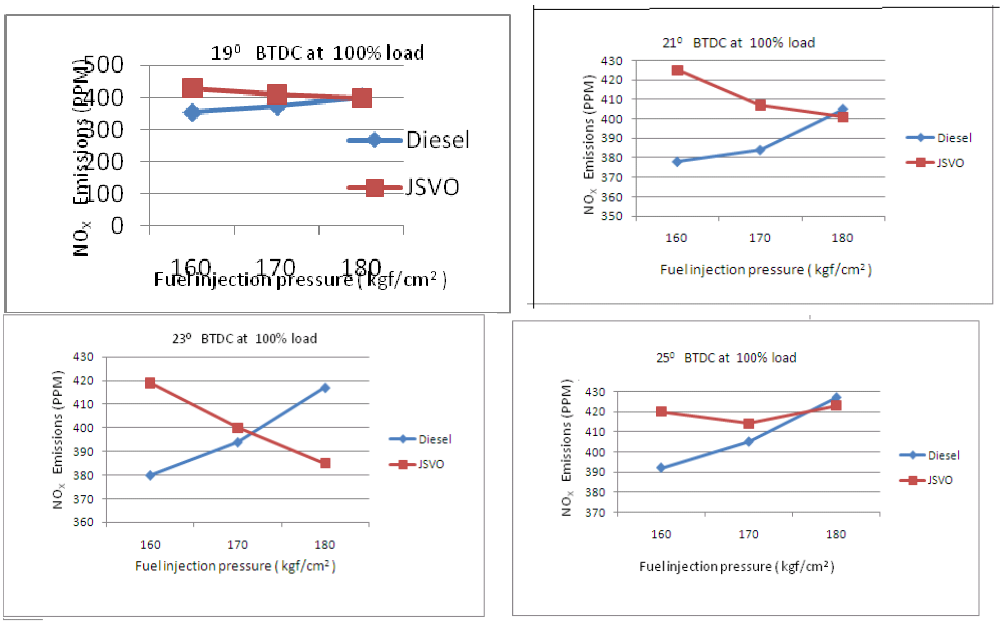
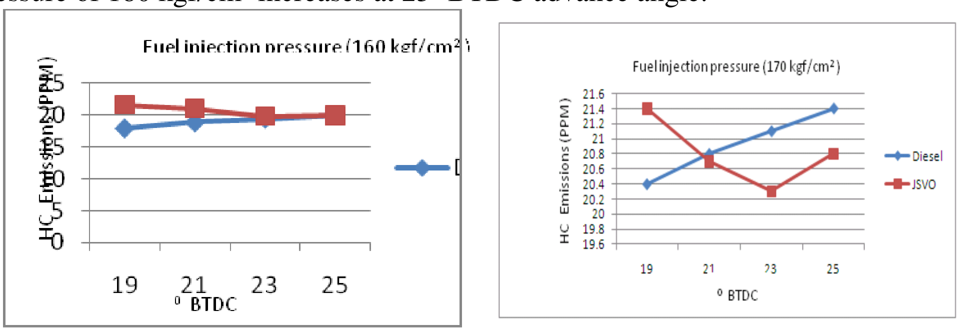


Figure 10: NO_X emissions of Diesel & JSVO fuel with various fuel injection pressures at different ^{0} BTDC Fuel injection advance angles.

4. HC Emissions:

Figure 11 explains that the HC emission of diesel increases as the fuel injection pressure increases from 160 kgf/cm^2 to 170 kgf/cm^2 and subsequently 180 kgf/cm^2. It shows that the combustion quality deteriorates if the diesel is used higher pressure than the design value of this engine. The HC emission of JSVO decreases as the fuel injection pressure increases because the fuel particle size at higher injection pressure is reduced and the combustion efficiency is increased. It has been found that the HC emission even at high value of fuel injection injection pressure of 180 kgf/cm^2 increases at 25^0 BTDC advance angle.



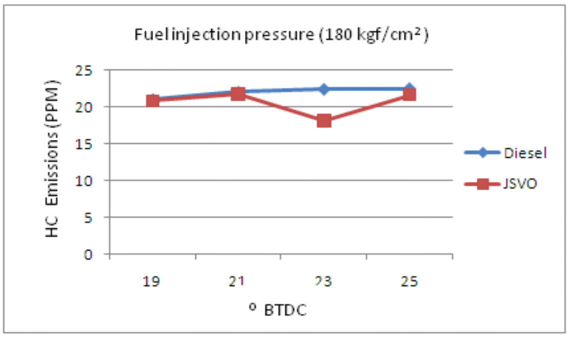


Figure11: HC emissions of Diesel & JSVO fuel with various fuel injection pressures at different ^{0} BTDC Fuel injection advance angles.

5. Smoke Emissions:

The smoke emission is decreasing in the case of JSVO with increase in advance angle of fuel injection up to the angle of 23^{0} C BTDC at all load conditions but the smoke emission starts increasing as the angle further increased to 25^{0} C BTDC. This indicates that the combustion efficiency is improved in case of JSVO as the fuel injection angle is increased up to 23^{0} BTDC but the combustion efficiency deteriorates as the angle further increased as shown in figure 12. It has also been seen that the smoke emission of diesel fuel at all the angles of fuel injection is lower than the smoke emission of JSVO. On comparison this is also observed that the smoke emission of diesel at 100% load conditions are less than the smoke emission of JSVO.

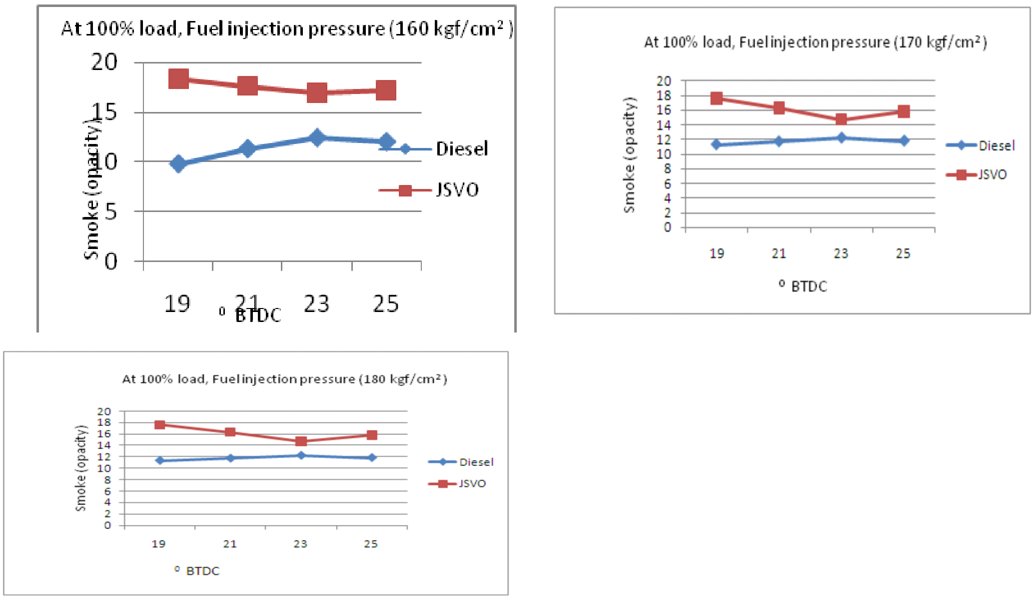


Figure12: Smoke opacity of Diesel & JSVO fuel with various fuel injection pressures at different ^{0} BTDC Fuel injection advance angles.

VI. CONCLUSIONS

The present work carried out with an objective of improving the efficiency of IDI diesel engine when JSVO is fuelled in it. The advanced combustion timing results increased NO_X emission. The increase in NO_X emission of Jatropha biodiesel is attributed to the mono and poly unsaturated fatty acids.
Brake thermal efficiency improves as the fuel injection pressure is increased for the JSVO at full load. AS the fuel injection pressure increases the brake thermal efficiency decreases for diesel at full load.
The CO emissions continuously increasing for diesel as the advance angle of fuel injection is increased. In case of JSVO, CO emissions starts increasing as the angle further increased to 25^{0} BTDC.

The CO_2 emission of JSVO increases gradually as the advance angle of fuel injection is increased up to 23^0 BTDC but the CO_2 emission start decreasing beyond 23^0 of fuel injection which shows the fuel combustion efficiency starts deteriorating.
The NO_X emission is decreasing in the case of JSVO with increase in advance angle fuel injection up to the angle of 23^0 BTDC at all load conditions but the NO_X emission starts increasing as the angle is further increased to 25^0 BTDC.
It is also observed that the HC emission JSVO decreases as the fuel injection pressure increases and it shows that the effect of increasing the HC emission at high advance angle pre dominates the effect of decrease of HC emission at high injection pressure.

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