Experimental study on common rail direct injection engine by varying fuel injection pressure for investigating and analyzing the performance, combustion characteristics and emission characteristics of the engine.

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Abstract:
In the current situation the diesel engine has to strictly satisfy the economy of fuel standards and environmental constrains in order to meet up the world market competitiveness. Now a days the compression ignition engine plays a very important role in the automobile field. The various attempts from scientists and engineers is to improve the performance of the engine by adopting new techniques like varying fuel injection and controlling parameters such as start of injection timing, fuel injection pressure, injection duration and rate of fuel injection, fuel quality, compression ratio, fuel atomization, flame travel and also the design of the combustion chamber. etc. The above possibilities can be achieved in the common rail direct injection (CRDI) technology. the motion of air in CI engine largely influence the fuel distribution and atomization of fuel in the combustion chamber. This paper covers the experimental investigation of a CRDI system developed for a constant speed single cylinder engine. The main objective of this work is to study the performance and emission characteristics of a CRDI engine by varying the fuel injection pressure, the fuel injection pressure plays a very important role for the better atomization of injected fuel results in complete combustion assist to reduce pollution. The FIP (fuel injection pressure) were varied between 300 to 1400 bar for investigating the performance of the engine. And for investigating the Combustion characteristics and emission characteristics of the CRDI engine. The advanced fuel injection shows the increase in the cylinder pressure, rate of pressure rise and heat release rate(HRR), the longer delay in the ignition period experienced and reduction in the engine emission also observed for the advanced fuel injection pressure.

Keywords. CRDI, Fuel injection pressure, heat release rate , rate of pressure rise, mass fraction burnt, combustion duration, emission duration.

Introduction:

The modern transportation system has a large segment of compression ignition engine also known as diesel engine was developed by Dr Rudol Diesel. Now a days the direct injection diesel engine has a numerous advantage in the matter economic system and high cognition density compared to the spark ignited engine (SI) engine, as well as indirect injection system.optimizing and increasing the injection pressure and compression ratio plays a very important role for the further highly improved CI engine. The mechanical injection system have not offered the flexibility of changing the multiple injection capabilities and injection strategy. In modern diesel engine lepton fuel insertion systems were used, The electronic fuel injection system has a numerous advantages of controlling the intromission parametric quantity such as starting time of injection (SOI). fuel intromission pressure, intromission proportion and multiple intromissions are duly controlled by electrical control unit (ECU) subordinate various locomotive operational and load modalités. which also include common rail direct injection (CRDI) system, part contraption system and unit pump system. Substance intromission into the cylinder mainly depends upon the locomotive velocity and weight condition so the better combustion of the fuel, this requires a separate fuel injector and matter internal organ assembly for apiece piston chamber. CRDI system consists of a fuel reservoir in which the high pressure fuel pump will deliver the fuel to all the cylinders with the help of high pressure solenoid injectors and advanced insistence piping which area unit individually dominated by ECU. Bosch in 1978 has first discovered CRDI system for the fuel injection system in CI engines. In each fuel injectors a stepped piston has provided which helps in ranging the matter intromission pressure level from 200 bars to 2000 bars. At that time the cost of the product were high, a new matter intromission instrumentation named ECCD- U2 were also formulated. This also consists of advanced pressure level electronic relation matter intromission system and common rail system of advanced pressure level but here the maximum fuel injection pressure is 1500 bar can be achieved.

In common rail direct injection system the matter is going to inject immediately into the burning assembly above the piston crown in each cylinder. In passenger vehicles most of the manufacturers uses CRDI technology in order to over come the sluggish Noisy and poor performance in the conventional diesel engines.In CRDI system the ECU gets the input from the various sensors and then the ECU calculates the timing of injection and pressure amount of matter to be dispense into the piston chamber. The components of CRDI system are more intelligent and electrically controls them. They are going to operate automatically by an ECU signal, depending upon the engine load, engine speed and engine temperature conditions so the mechanically operated injectors are replaced with electrically operated solenoid injectors.

Experimental setup:

In this investigation we have used a individual container , invariant velocity, 4 stroke, liquid cooled point-blank intromission diesel motor. The conventional experimental setup is showcase in the illustration.

In this experiment the fuel injection system used was CRDI system. The engine cylinder head were modified in order to install the piezoelectric transducer and a high pressure solenoid injector.

The CRDI matter intromission method belong to a common rail, fuel line of advanced pressure level, solenoid matter intromission, a fuel filter, advanced pressure level matter pump. In this engine we have maintained a constant speed of 1500 rpm of 10HP power. Alternator were used in command to vary the motor weight The exhaust gas analyser were used to determine the composition of the exhaust gases of (AVL44), this device also examines the emissions existing in the motor exhaust fumes. And intake gas travel of the cylinder an volumetric matter travel rate of the cylinder were also measured. A piezoelectric electrical device was mounted in order to measuring the incylinder pressure level. On the engine an optical shaft encoder was mounted which gives 3-output signals (A,B &Z). for engine combustion diagnostics, a high speed collection acquiring arrangement were utilized (LEGION & BROTHERS).

As per the manufacturers recommendation the engine test was carried out with varying the fuel intromission pressure level from 300 Bar to 1400 Bar at different loads. The performance characteristics & discharge contributions of a CRDI engine were calculated by varying the matter intromission pressure level of 300 bar, 500 bar, 650 bar, 1400 bar at different loads. The results were shown in the following section.

Table 1. Technical specifications of the engine.

ENGINE PARAMETERS	SPECIFICATION
Engine Type	Kirloskar, CRDI engine,
No. of cylinder	1 Cylinder
No. of strokes	4-Stroke
Rated power	10HP
Bore	0.08m
Stroke	0.11m
Cubic Capacity	661CC
Con-rod length (m)	0.235
Cycles Averaged	50
Type of cooling	Water cooling
Fuel injection Pressure	2000bar
AFR	14

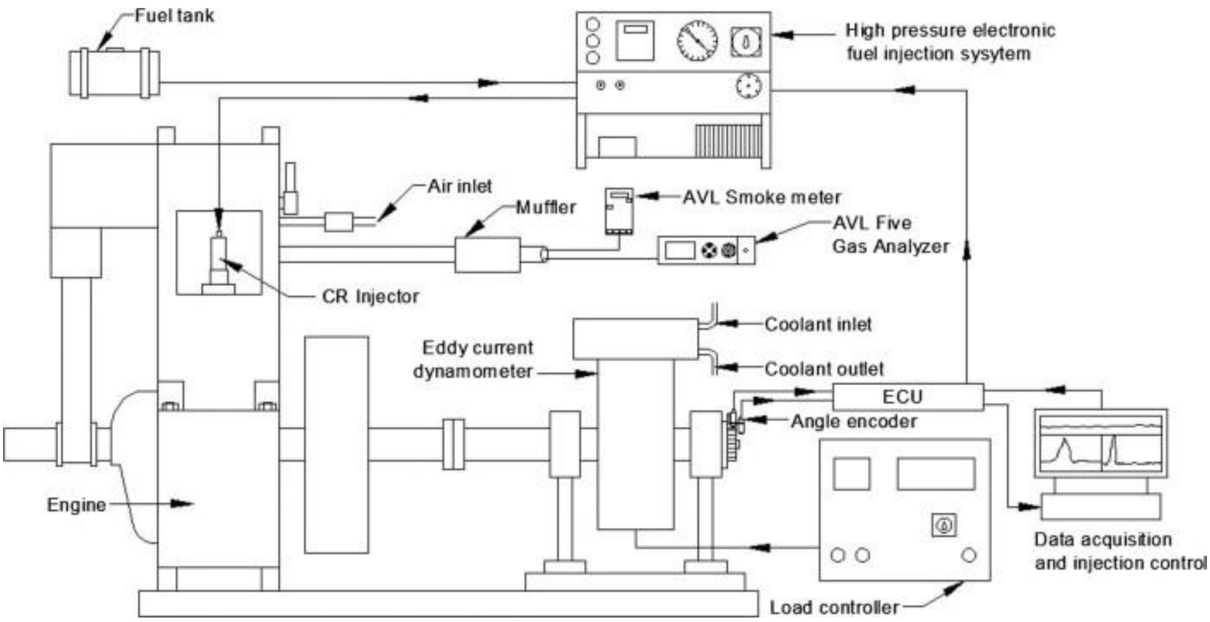

Figure 1. schematic of the experimental setup

3. Results and discussions

3.1 Combustion characteristics

it show a precise role in the analysis of a engine. As it directly influences the combustion characteristics such as emission characteristics, engine performance, vibrations and noise etc. The data were obtained from advanced rate collection acquiring system for 100 uninterrupted engine cycles. In-cylinder pressure level, pressure raise rate, heat energy achievement rate, combustion duration and mass fraction burnt were calculated and differentiated for various FIP & load conditions.

3.1a In-cylinder0pressure: The in cylinder pressure0measurement plays a identical role in the analysis of combustion parameter of a CRDI diesel engine.

The figure 2 shows the in-cylinder pressure versus crank angle for different fuel injection pressure for varying engine loads from no loads to full loads conditions. The matter is dispense at the last of compression stroke in the diesel engine this raises a advanced injection pressure level and during the intromission activity the fuel is broken into a fine spray of very small droplets, heat is supplied to the droplets from the compression air these droplets combine with gas to shape air matter substance and attains a trap of self ignition temperature so ignites the period because the beginning of intromission and beginning of ignition is called ignition delay, for high speed engines the ignition delay is 0.001 seconds and for low speed engine the ignition delay is 0.002 seconds. From the figure it is mostly discovered that varying the FIP leads to high in piston chamber pressure for different loads. It is seen that the engine load of 0 Kw the maximum cylinder pressure rise are seen for 5° BTDC SOI and FIP 1400 bars and engine load for 2.5 kw the in cylinder pressure rise are seen for 10° BTDC SOI and FIP 1400 bar and min for 300 bar for 7.5 Kw the max cylinder pressure are seen for 0° BTDC SOI and FIP 1400 BAR and min 300 bar, so from the above graph it is discovered that the fuel intromission pressure level is more than the rise is cylinder pressure also more so that leads to the complete combustion mainly depends on FIP. and from the above graph it is observed that for FIP 1400 bar the proportion of pressure level outgrowth attained is maximal and for FIP 300 bar the charge of pressure level outgrowth attained is minimum. Owing to the relative colder condition in the combustion chamber. Earlier SOI leads to longer ignition delay. The matter quality intromission is higher into the burning assembly before star of combustion (SOC) and formerly the oxidation starts, the temperature attained is higher in cylinder due to pre-mixed heat release is higher. The peak pressure in cylinder mainly count on the matter portion burned.

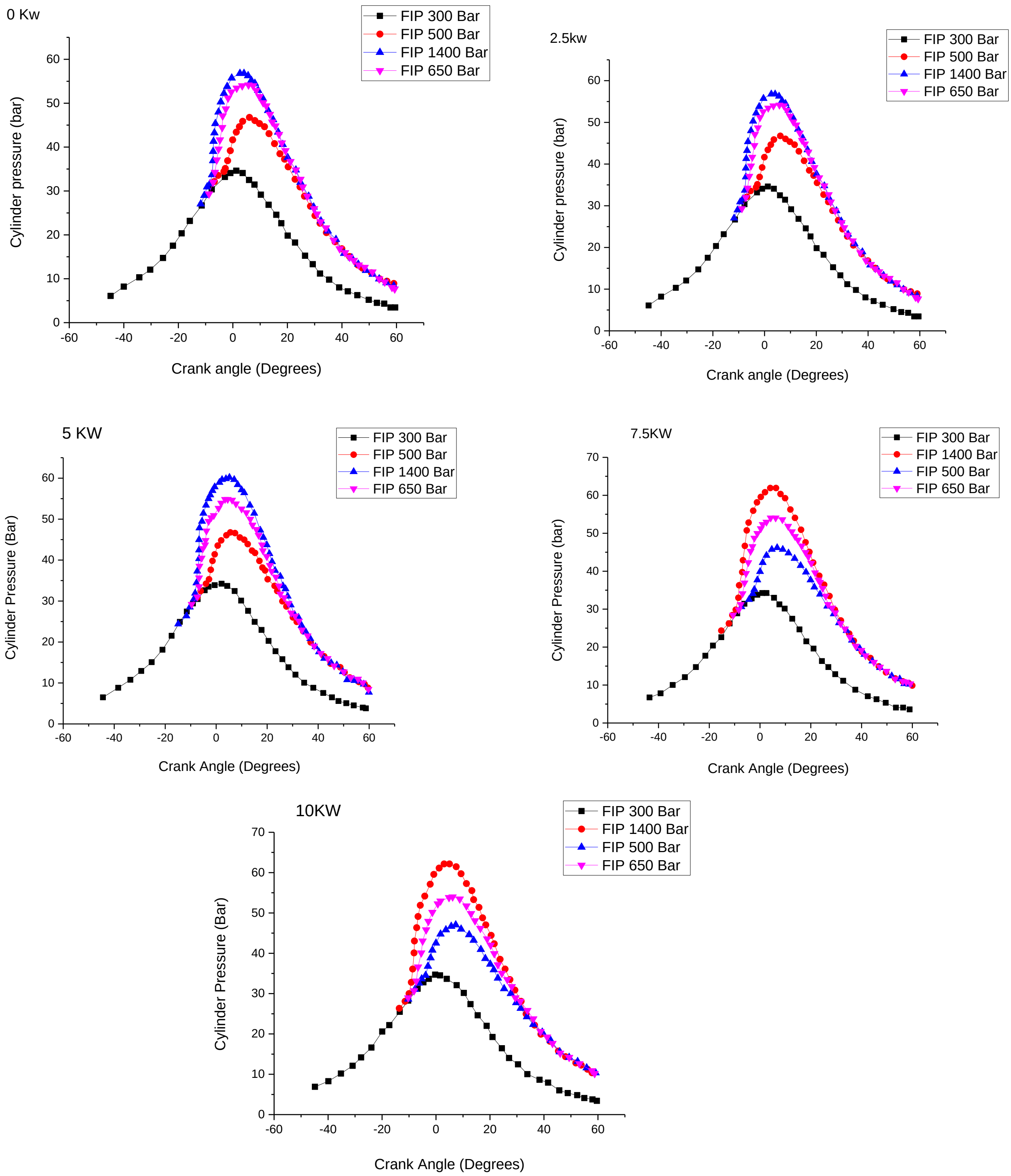

Figure 2. In-cylinder pressure vs crankangle diagram for different FIP at varying engine loads.

3.1b Rate of pressure rise: it is a very important parametric quantity that provide the aggregation regarding the pressure induced by burning and expanding gases due to force transfer in cylinder.

The figure 3 shows the pressure rise rate for different FIP at different engine stacks.During the premixed burning phase the pressure rise rate reaches its maximum.Due to the oxygen amount available for burning and mixing advances the combustion so the pressure rise is affected and during the elaboration movement the rate of pressure rise start decreasing owing to mixing controlled oxidization, the mixing controlled combustion stage occurs in the middle of combustion and the volume occupied by the mechanical device increases during the elaboration stroke. More fuel quantity is available in the combustion chamber during the period of longer ignition delay. So high admixture fuel quality available during the premixed beginning combustion and the product of this premixed charge releases high pressure level rise rate and high heat energy liberation rates. The velocity of flame propagation is a very important parameter for the pressure rise in the cylinder and leads to the different types of abnormal combustion. The pressure rise rate is affected by the several factors and the turbulence and air fuel ratio are most important.

For advanced FIP and SOI timings the pressure rise rate is high than the backward FIP with increasing the engine loads the speed of the flame increases so the rate of pressure rise increases.

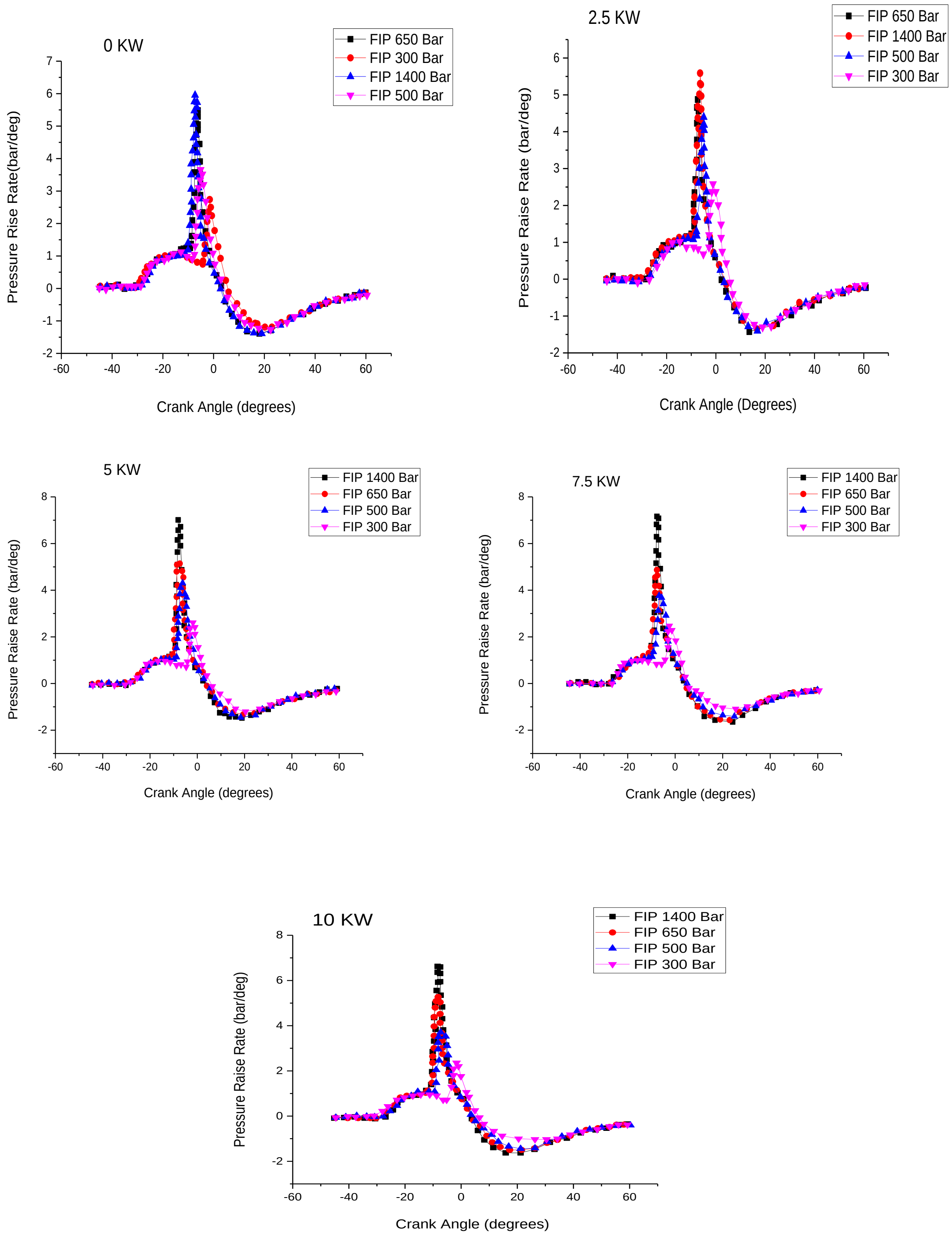

Figure 3. pressure rise rate versus Crank angle for various FIP at different loads.

3.1c Heat release rate: A little quantity of vaporized matter is collected in the burning assembly during the period of ignition delay and at the end of ignition it is going to burn rapidly, how ever the burning process inside the combustion chamber is controlled by chemical kinetics due to lower temperature there after the combustion process goes on increasing if the more amount of matter is dispense in the piston chamber.

The figure 4 shows the heat release rate at different FIP and at different loads.The temperature and pressure level in the burning assembly is always high after the first peak and the chemical substance reaction cannot be controlled because it is very high . then the availability of oxygen ,mixing of matter and air controls the burning process. If the fuel injection pressure increases relatively fine spray of fuel amount is dispense onto the oxidization assembly so from the above graph it is observed that if the FIP increases the heat release rate also increase which results in complete combustion.

From the above graph it is studied that the pressure rise rate decides the heat release pattern which is going to control the noise and vibration generated by the engine. Which is also inter related to diesel knock. So the efficiency of the theoretical cycle is going to improve if the heat release rate moves towards the top dead center, So the efficiency is going to increase if the ignition should take place before top dead center. From the graph it is observed that the heat energy accomplishment proportion is much higher during the first part of oxidation, later on the fuel is going to ignite too slowly because the heat release rate moves away from TDC which reduces the expansion ratio so the cycle efficiency is also affected by heat release rate.

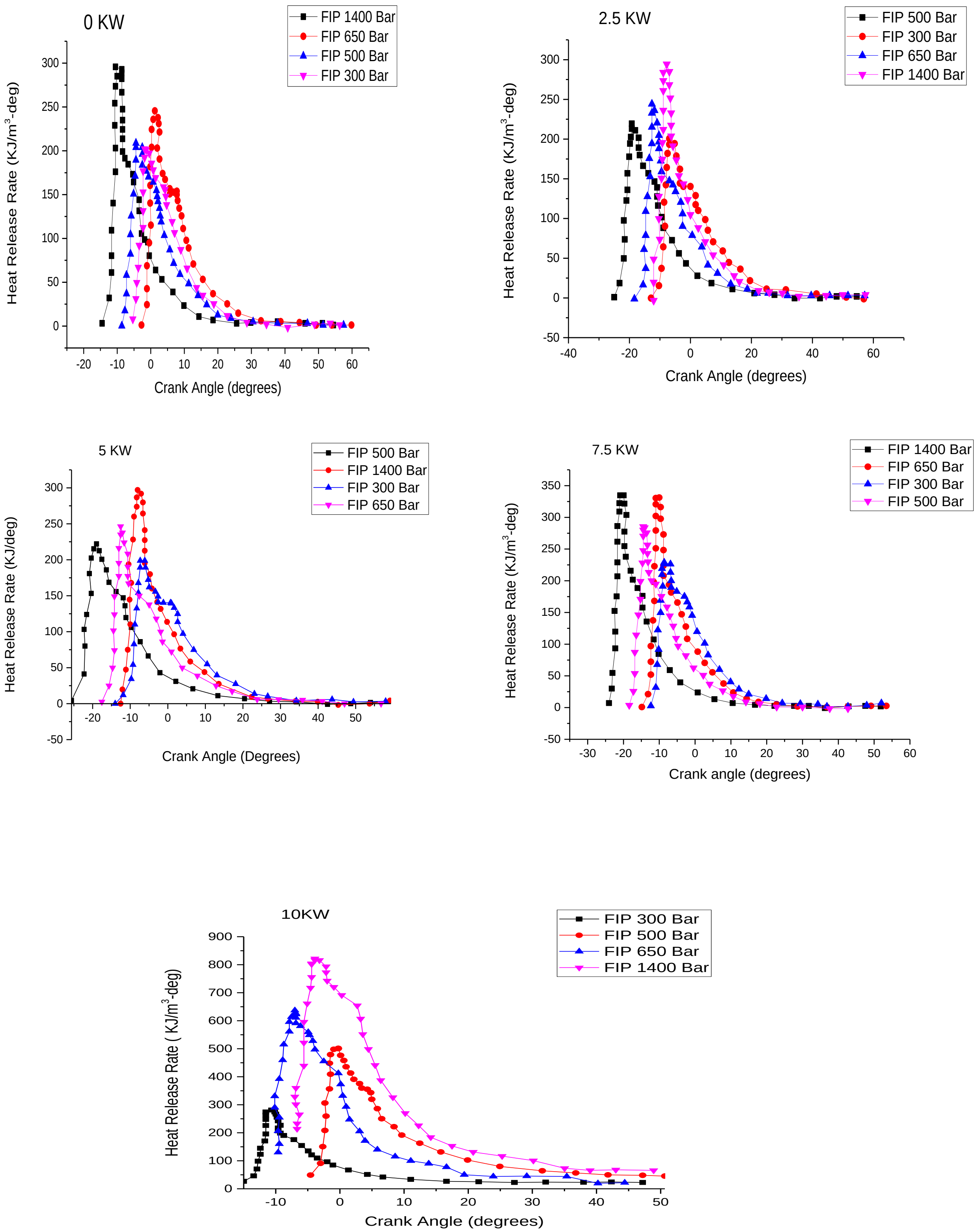

Figure 4. Heat release rate versus crank angle for various FIP at different loads.

3.1d Mass fraction burnt: mass fraction burnt plays a precise role in the combustion characteristics of a CRDI engine. Compare to the retarded matter intromission pressure and timings, the advanced FIP and timing shows the earlier combustion and complete combustion. Timing for mass fraction burnt 8% is called as ‘ start of combustion’ (SOC) & 85% mass fraction burnt is called as ‘end of combustion’ (EOC) and the viewpoint between the these periods I.e. SOC and EOC is called as ‘combustion duration’. it is a period between commencement of oxidization and extremity of oxidation. If the load on the engine increases then position of the crank angle shifts from TDC in command to dispense more airfuel quantity into the piston chamber, this leads to the longer duration of combustion. It is also observed from the figure 5 that if the engine load increases then air and fuel injected into the cylinder is earlier consequence in earlier combustion so mass fraction burnt shifts earlier.

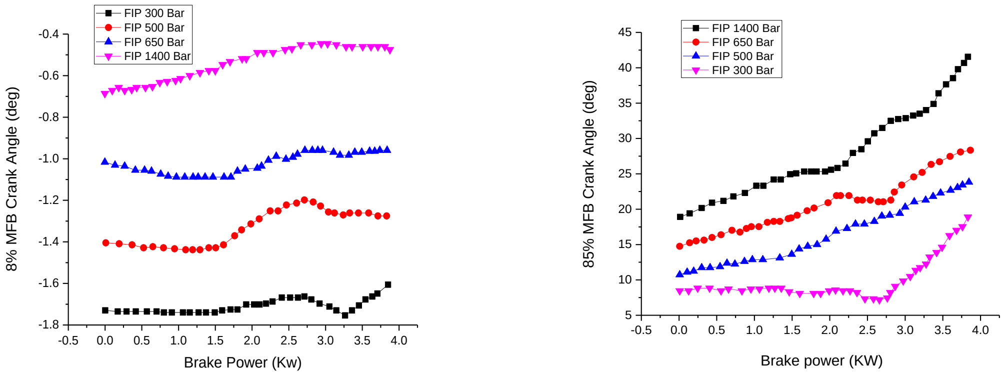

Figure 5. 8% and 85% Mass fraction burnt timings for various FIP at different loads

3.2 Performance characteristics: By performing the various experiments and calculating the parametric quantity such as exhaust gas temperature and brake thermal efficiency and specific fuel consumption of CRDI engine were evaluated. At each load the experiments were dine at 4 times by varied the matter intromission pressure level, the thermal efficiency of the fuel is converted into mechanical energy has showed by the BTE.

3.2a Brake thermal efficiency (BTE): Measurement of brake thermal efficiency is one of the important parameter in test schedule of an engine. From the figure 6 it is discovered that the BTE is increased up to 3.5 kilo watt for FIP 1400 bar and later on it starts decreasing for all FIP and single fuel is being used for all experiments.

From the figure 6 it is noted that at 37°BTDC SOI timing FIP 1400 bar the maximum break thermal efficiency is achieved for all engine loads. This 37°BTDC SOI timing of FIP 1400 bar is optimum timing for research locomotive for every loads at 1500 RPM. In the above research the matter is dispense at different pressure at different timings so the fuel fraction available for the late combustion , controlled combustion and premixed combustion phase are significant in the elaboration movement. This causes the decrease in pressure level power generated by the air fuel mixture pushes the piston in downwards in the expansion stroke, so the volume occupied by the combustion chamber increases and pressure level unit exerted by the combustion gases opposes the plunger to move towards the top dead center in the compression stroke, this leads to the reduction in BTE. Break thermal efficiency is inversely proportional to the break specific fuel combustion of an engine.

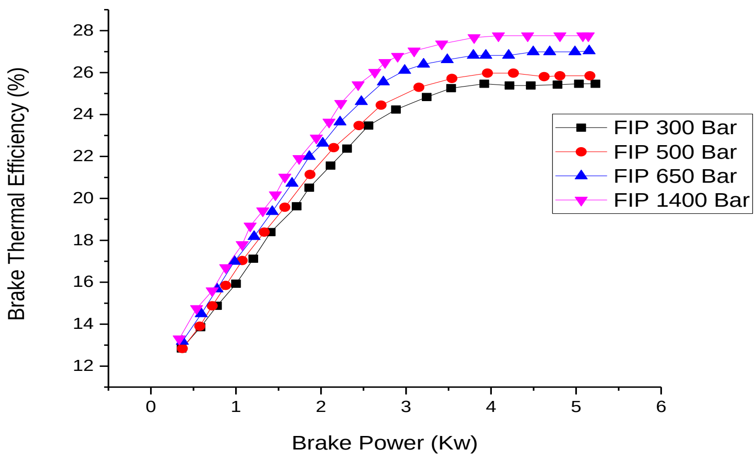

Figure 6: BTE of the engine for various FIP at different loads.

3.2b Exhaust gas temperature: It plays a very important role in the oxidation process of a diesel locomotive engine. If the load on the engine increases then more quantity of fuel is to be dispense into the piston chamber, therefore here the fuel intromission pressure level maintained is at the different pressure for different loads leads to longer fuel injection duration and this reduces the time period of premixed combustion, increases the time taken for mixing controlled combustion and results in late or incomplete combustion. It is observed from the figure 7 that during mixing controlled combustion phase only the combustion take place majorly, so results in increasing the temperature at the exhaust gases.

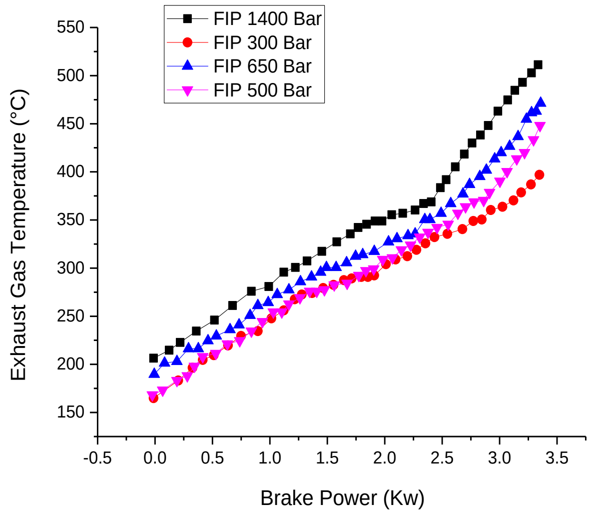

Figure 7. Exhaust gas temperature for various FIP at different loads.

3.2c Specific fuel consumption: Brake specific fuel combustion is determined on the basis of break out put of the engine. It is determined from the figure 8 that the specific fuel consumption decreases. Break power is reciprocally proportionate to the BSFC (Break specific fuel consumption) of an engine. The normal injection timing of the engine is with in 20 to 16° BTDC.

Advancing the timing of the fuel injection results in higher engine cylinder pressure and the injection pressure is very important role for ignition delay period. if the injection time retards this reduces the ignition delay and this causes the start of combustion only after TDC and maximal range of pressure level emergence also decreases results in lost of expansion stroke without giving any useful output power.

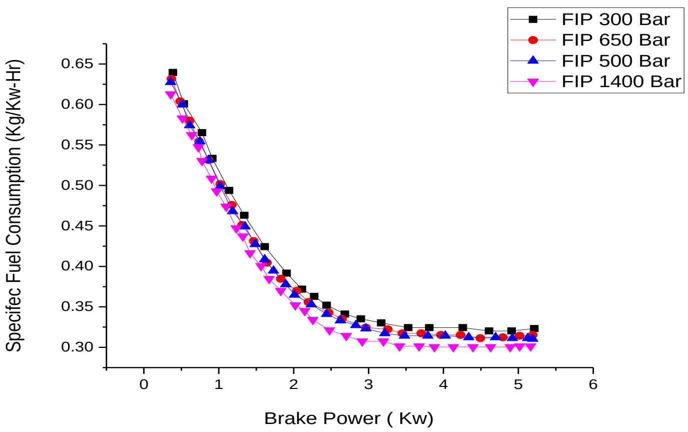

Figure 8. specific fuel consumption for various FIP at different loads

3.3 Emission characteristics

How ever the combustion is incomplete for several reasons and hence we also get deadly poisonous gases like carbon monoxide, unburnt hydrocarbons (UBHC), oxides of nitrogen, particular matters and partial oxidate product in exhaust gases. Hydro carbons is essential in the formation of smog.

3.3a Carbon monoxide emissions: The main reason for formation of carbon monoxide is due to insufficient air and matter intermixture or due to time required for the ending of oxidation is less. However from the figure 9 it Is observed that the CO is also present in the exhaust, even at high FIP has maintained. During the idling conditions the formation of co increases and if the engine speed increases the formation of CO decreases. It is also observed that for lower FIP the formation of CO is more and for higher FIP the formation of CO is less and it is found that the CO percentage is high as 11% for FIP 300 bar the formation of CO is lesser during the acceleration and at study speeds. Because during acceleration, throttle is in open position and availability of oxygen for the combustion is more and during deceleration the throttle is in closed position and the availability of oxygen is less leads to formation of higher CO in exhaust gases. It is impossible to eliminate the CO in the exhaust gases. How ever 0.5% CO is considered as a reasonable goal for the emission. As the engine load increases the air and fuel mixture induced into the cylinder is high this leads to the insufficient mixture of air and fuel mixture takes place so as the engine load increases resulting in formation of higher CO emission.

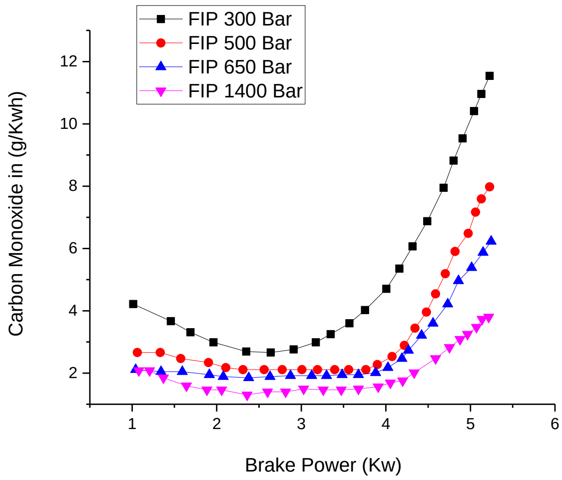

Figure 9. Carbon monoxide for various FIP at different loads.

3.3b BSHC emissions: Un-burnt hydrocarbon emission are the main cause of in complete combustion the formation of hydrocarbon emission are mainly related to the operating variables and engine design. The combustion chamber design and induction chamber design are the two important design variable affects the formation of HC.

The speed of the engine load, air fuel ratio are the operating variable which affects the formation of HC. The design of the induction system and the maintenance of the engine affects the supplying of air and fuel intermixture onto the engine. The induction system design decides the optimum eveness distribution of fuel to all the cylinder and engine maintenance decides for how long the engine is going to operate in the desirable air fuel ratio and the supply of air fuel ratio is also affected by deterioration in the lubrication systems. It is observed from the figure 10 for lower FIP the formation of HC is more and for higher FIP the formation of HC is less, as the engine loads increases more quality of fuel is to be injected into the engine results is richer air and fuel intermixture at various zones in the combustion chamber results in formation of HC emission.

Quench area is another important factor in the engine design . this is the area in which the air and fuel intermixture is going to trapped between cool surfaces called as squish area. The travelling of the flame in the quench area also results in formation of HC emission. The supply of air and fuel ratio into the oxidation assembly also effects the HC. During Stichiometric fuel air mixture, the formation of HC and carbon monoxide are higher and during lean fuel mixture the formation of HC and CO are lesser. The maintenance of an engine is also a very important factor for the formation of HC.

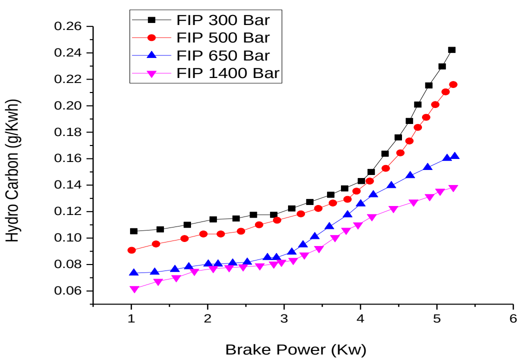

Figure 10. Hydrocarbon emissions for various FIP at different loads.

3.3c Soot emissions. It play a very essential role in the combustion characteristics of CRDI engine. The main cause for the formation of soot is due to incomplete combustion, the metal surface of the combustion chamber is cool and air fuel mixture is imperfect. It is determined from the figure 11 that if the FIP increases the formation of soot decreases and if the FIP decreases the formation of soot increases. Advanced FIP'S results in finer spray of fuel injection into the burning assembly so the time taken for the ignition delay is less and combustion takes place in the premixed combustion phase. If the metal surface of the combustion chamber are cool that takes the heat from the air fuel mixture faster than the burning operation. As a result the air fuel intermixture present in the piston chamber layer does not burn. During exhaust stroke these unburnt mixture present in the cylinder layer are swept out, This results in the formation of unburnt hydro carbons in the exhaust gases. The tolerance in the fuel injection manufacturer and imperfect inlet manifold passage also leads to the formation of soot. By maintaining the proper air fuel mixture and metal surface volume ratio reduces the emission. For FIP 1400 bar the soot formation is 0.90 gm/ kw per hour and for FIP 300 bar the soot formation is 0.12gm/kw.

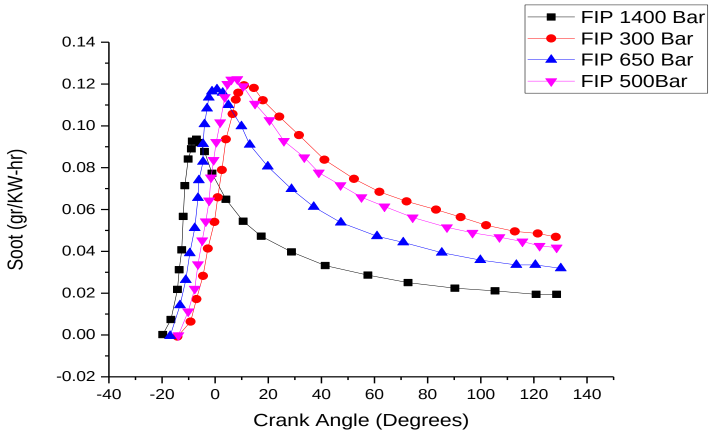

Figure 11. Soot emissions for various FIP at different loads.

3.3d Smoke density: The diesel engine mainly consists of two types of smoke.

1) Blue white smoke

2) Black smoke

The figure 12 shows the smoke density for different FIP. Incomplete combustion in the burning assembly is the main reason for formation of smoke. The causes of smoke are mainly affected by improper air fuel mixing, Incorrect air fuel ratio Injection pressure timing. The types of fuel used and the engine rating . it is observed that the smoke density increases with the increase in engine load. If the engine load increases there is a increase in equivalence of air fuel ratio and phase of mixing controlled combustion is longer. This results in oxygen concentration for the combustion is lesser and the temperature of the combustion is higher, this results in increase in the smoke density. It is so evident from the figure that the FIP plays a very important role in the formation of smoking density. If the FIP increases the formation of smoke density decreases and if the FIP decreases the formation of smoke density increases so the advanced FIP leads to the absolute oxidation of matter due to the finer spray of fuel will be dispense into the cylinder The injection system characteristics such as excess or induced penetration and duration of injection is excessive and improper size of fuel droplets and improper dispersion automation all these factors substantially increase the smoke levels.

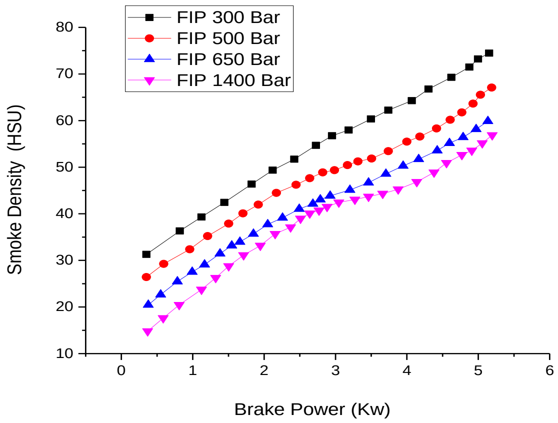

Figure 12. Smoke density for various FIP at different loads

The nitrogen contains about 77% in the air supplied for combustion process. During the combustion process the temperature attained inside the cylinder is around 1500 to 2000° C , but at the lesser temperature the nitrogen does not react with oxygen, if the temperature exceeds to 1100° C the nitrogen reacts with oxygen so produces the very harmful and toxic gases. The above results showed that there is reduction in nitrogen with increasing engine loads and if the FIP increases up to 1400 bar the small droplets of fine spray will be injected into the cylinder resulting in complete combustion. It is been achieved that if the FIP increases then the soot level decreases because of the greater turbulence and finer spray of fuel into the combustion chamber. If the engine load increases the oxygen concentration in the air reduce because of only fuel quality injected into the combustion chamber is higher, ketones and aldehydes were also reduced. At higher loads if the turbulence level increases then the temperature raises for the combustion of richer air fuel mixture is less, so this leads to the longer heat release and combustion duration.

4. Conclusions

- The effect of fuel injectors on different pressure on this engines performance, combustion characteristics and emissions were experimentally investigated.

- Advanced FIP showed high in cylinder pressure, higher heat release rate and higher pressure rise rates due to ignition delays are relatively longer. The total heat release rate in the premixed combustion phase decreases when the engine load increases this is due to the ignition delay reduction.

- For retarded fuel injection pressure the combustion takes place completely during the expansion stroke and for 1400 bar FIP gives best thermal efficiency compare to the other FIP.

- For increasing FIP, the temperature of the exhaust gas were found to increase results in lower BSHC and NOX emission were observed, and smoke density increase due to reduction in the temperature of combustion chamber.

- Soot emission decreases from 1.11 gm\kg fuel to 0.4085 gm\kg fuel when the fuel injection pressure increases from 3000to 1400 bar for relatively more homogeneous mixture and high temperature.

- It can be observed that if the FIP increase from 300 to 1400 bar the peak temperature value goes up from 1535 to 1985 k.

- Increasing the fuel injection pressure in the combustion chamber results in better mixing of air and fuel mixture so this experiences the increase in cylinde peak pressure and heat release energy. The efficiency of the engine is going to increase around 4% for every spraying pressure 1400 bar.

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