Experimental Analysis of Common Rail Direct Injection (CRDI) Engine Performance by Varying the Parameters Injection Pressure, Crank Angle and Its Emission Characteristics

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***Abstract*: Diesel engine are generally used for more torque requirements and need of carrying heavy loads. The attempts from engineers and scientist is to improve the performance of the engine by adopting various methods like engine modifications. There are several parameters which influence the engine performance such as injection angle, injection pressure, injection timing, ignition timing, flame travel etc. CRDI is one technique where diesel can be effectively injected through common rail to generate more power. In all these attempts the complete combustion of the fuel gives more power output, hence the combustion characteristics are important during steady and loading conditions**.

***Keywords*: CRDI system: combustion characteristics: start of injection: heat release rate: emissions: combustion duration**

Introduction A large segment of modern transportation system is powered by direct injection diesel engines, this is due to numerous advantages offered by these combustion systems in terms of excellent fuel economy and higher power density compared to indirect injection system as well as spark ignited gasoline engines. Increasing the fuel injection pressure and optimizing the injection strategies are extremely important for further improvements in highly optimized compression ignition (CI) engines. The flexibility to change the injection strategy and multiple injection capabilities are not offered by mechanical injection systems. On the other hand, in electronic fuel injection systems, fuel injection parameters such as injection pressure, fuel injection rate, multiple injections and the start of injection (SOI) are precisely controlled and regulated with great ease by an electronic control unit (ECU) under different engine operating conditions. Electronic fuel injection systems used in modern diesel engines include unit pump system, unit injector system and CRDI system. In case of unit injector and unit pump systems, fuel injection depends on the engine speed and require separate fuel pump assemblies for each cylinder. CRDI system has a high pressure fuel reservoir (common rail), which will supply fuel by a single high pressure fuel pump. This fuel is then delivered to all the cylinders by using high pressure pipes and high pressure solenoid injectors, which are controlled by ECU individually. CRDI concept was proposed by Bosch in 1978 for diesel fuel injection for the first time (Elben & stump 1978). A stepped piston was provided I each injector, which was able to support the fuel injection pressure ranging from 200 bars to 2000 bars. However the costs were prohibitely high at that time. A new fuel injection system named 'ECCD-U2' was developed which also consisted of an electronic unit injector system and a high pressure common rail. This system could achieve fuel injection pressure up to 1200 bars.
In common rail direct injection, the combustion takes place directly into the main combustion chamber located in a cavity above the piston crown. Today manufacturers use CRDI technology to overcome some of the definitions of conventional diesel engines of which were sluggish and noisy and poor in performance when implemented, especially in passenger vehicles. The CRDI technology works in tandem with engine ECU which gets inputs from various sensors. It then calculates the precise quantity of fuel and timing of injection. The fuel system features components which are more intelligent in nature and controls them electrically. Additionally the conventional injectors are replaced with more advanced, electrically operated solenoid injectors. They are opened by an ECU signal, depending upon the variables such as engine speed, load, engine temperature etc.

I. THEORY

C. syed Aalam [1] carried out a experiment on four stroke single cylinder diesel engine. The fuel injector system of the diesel engine used was the high pressure Common Rail Direct Injection system. From the experiment it was observed that the brake thermal efficiency is improved and fuel consumption reduced due to better atomization. It is also observed that carbon monoxide (CO), unburned hydrocarbons (HC) and smoke emissions are reduced and Nox emissions are increased by increasing the injection pressure.
Avinash kumar [2] agarwal carried out a experimental investigation on simple version of CRDI single cylinder constant speed engine and has done modifications in the cylinder head for accomodating solenoid injector, designing injector drive circuit & development of high pressure stage controls were some of the engine modifications and development. So start of the injection timing (SOI) improved the combustion characteristics. SOI timing were varied between 25^0 to 40^0 BTDC and advanced fuel injectors showed higher heat release rate(HRR) .

N.Senguttuvan [3] carried out the experiment on the selection of material for CRDI fuel injectors. Steel, Brass, alluminium alloy a365 materials were analyzed separately and alluminium is found the best material among the steel and brass for common Rail Injection tube.

D De Serio [4] carried out the experiment on the application of an exhaust gas recirculation (EGR) system in a direct injection diesel engine operating with diesel containing 7% bio diesel (B7). EGR rates of upto 10% was applied with primary aim to reduce oxides of nitroge (Nox). the use of EGR caused a peak pressure reduction during the combustion process and decrease in thermal efficiency mainly at high engine loads and reduction in emissions upto 26% was achieved.

Fan Chenyang [5] carried out the experiment on the performance of CRDI engine fulfilled with pistache seed biodiesel. It was observed that brake specific fuel consumption (BSFC) and brake thermal efficiency(BTE) increased while the brake specific energy consumption (BSEC) decreased with the increase of amount of biodiesel in the fuel mixture in low load conditions. Where as in high load conditions with the propotion of biodiesel increasing BSFC increases.

D.N. Basavarajappa [6] carried out the experiment on performance & emission characteristics if a CRDI engine fuelled with UOME (uppage oil methyl ester) biodiesel at different injection timings and injection pressure . from the experiment it was revealed that UOME bio diesel yielded overall better performance with reduced emissions at retarded injection timing of -10^0 BTDC in CRDI mode of engine operation.

Ravi Shankar Shukla [7] carried out a experiment to evaluate the effect of using diesel plastic oil blends in a CRDI engine and shows the potential of utilizing waste plastic oil extracted by pyrolysis of waste plastic as an alternative fuel for diesel engine. In this study diesel was fuelled with plastic oil diesel blends. The performance and emissions characteristics were evaluated and thermal efficiency of all blends gradually decreases compare to diesel at all load conditions. CO emission were decreasing considerably with increase in percentage of plastic oil in diesel blends.

Mohammed Ibrahim [8] carried out the experiment on the analysis of the performance and emission parameters related to the injection pressure, injection timing and injector location in a modified single cylinder CRDI engine with a compression ratio of 16:1. the main objective of this experiment work was to evaluate the best injection pressure of diesel that was injected into the cylinder.t was observed that the injection pressure of 50Mpa was found to be best in terms of brake thermal efficiency obtained for entire operating range of brake mean effective pressure.

Yahid.M.Jamadar [9] conducted experimental analysis on single cylinder diesel engine by varying injection pressure and see how the injection pressure affects the performance of the CRDI engine. diesel engines are used at larger extent for agricultural applications in INDIA. The advanced technology in CRDI system was used to control the performance and emission parameters in the stationary constant speed diesel engine. it was observed that the engine was converted to CRDI and then performance was enhanced by increasing injection pressure.

.**Dipak Kisan Dond** [10] conducted experiment on the effect of combustion parameters on performance, combustion and emission characteristics of a modified small single cylinder engine by varying compression ratio and injection pressure & start of injection timing and their values on performance emission and combustion characteistics of the small single cylinder CRDI diesel engine for which mechanical fuel injection system retrofitted with a simple version of CRDI engine and it is observed that start of injection timing and injection pressure are the key parameters for improving the combustion characteristics and compression ratio mainly affects the emission characteristics of the engine and yielded improved exhaust emission and performance of the engine.

M.R. Indudhar[11] conducted experiment on the effect of injection pressure and timing on the performance of bio diesel ester of honge oil fuelled CRDI engine, where the bio diesel can be injected at higher pressure, experiments were conducted on CRDI engine fuelled with diesel and optimize the injection timing. where the IT varied from 25 degree before(bTDC) to 5 degree (aTDC) keeping injection pressure of 600 bar, further experiments were conducted on CRDI engine fuelled with diesel and EHO to optimize the injector opening pressure and revealed that maximum BTE was obtained at 900 bar.

Engine specifications:

Experiments were conducted on a Kirloskar AV1, four stroke, single cylinder, air cooled and common rail direct injection (CRDI) system assisted diesel engine. The schematics of the experimental setup are shown in Fig. 3. The rated power of the engine was 5.2 kW and the engine was operated at a constant speed of 1500 rpm and a standard injection pressure of 220 bar. Specifications of the test engine were given in Table 2.

The fuel flow rate was measured on a volume basis using a burette and a stop watch. Thermocouple and a digital display were used to note the exhaust gas temperature. The Hartridge smoke meter was used for measuring of smoke density. NOx, HC and CO emissions were measured by AVL five gas analyzer. The inner cylinder pressure was measured with the help on the legion brothers combustion analyzer. The experiment was carried out with different blends of fuel. Readings were taken when the engine was operated at a constant speed of 1500 rpm for all loads. Parameters such as engine speed, fuel flow, and emission characteristics such as NOx, HC, CO and smoke were recorded. The performance of the engine was evaluated in terms of brake thermal efficiency, brake power, and specific fuel consumption from the above parameters. The combustion characteristics such as cylinder pressure and heat release rate were noted for different blends.

Experimental setup and Engine specification:

ENGINE PARAMETERS	SPECIFICATION
Engine Type	Kirloskar, CRDI engine,
No. of cylinder	Single Cylinder
No. of strokes	Four-Stroke
Rated power	5.2KW
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	190bar
AFR	14

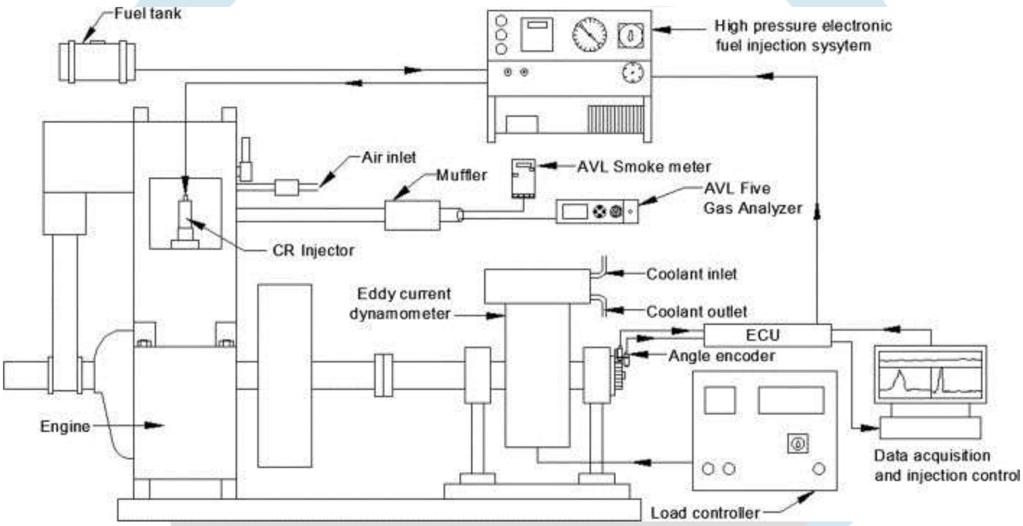


Fig 1: CRDI engine setup

Result and discussions:
Injection pressure is changed from 275 to 1000 bar. Comparison of cylinder pressure changes according to crank angle

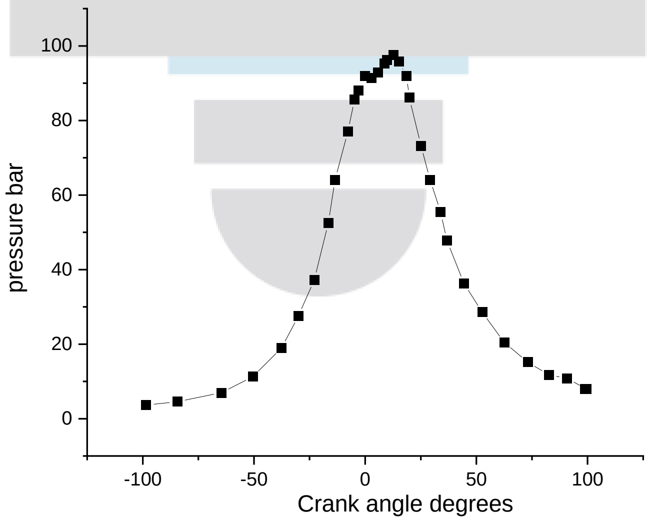
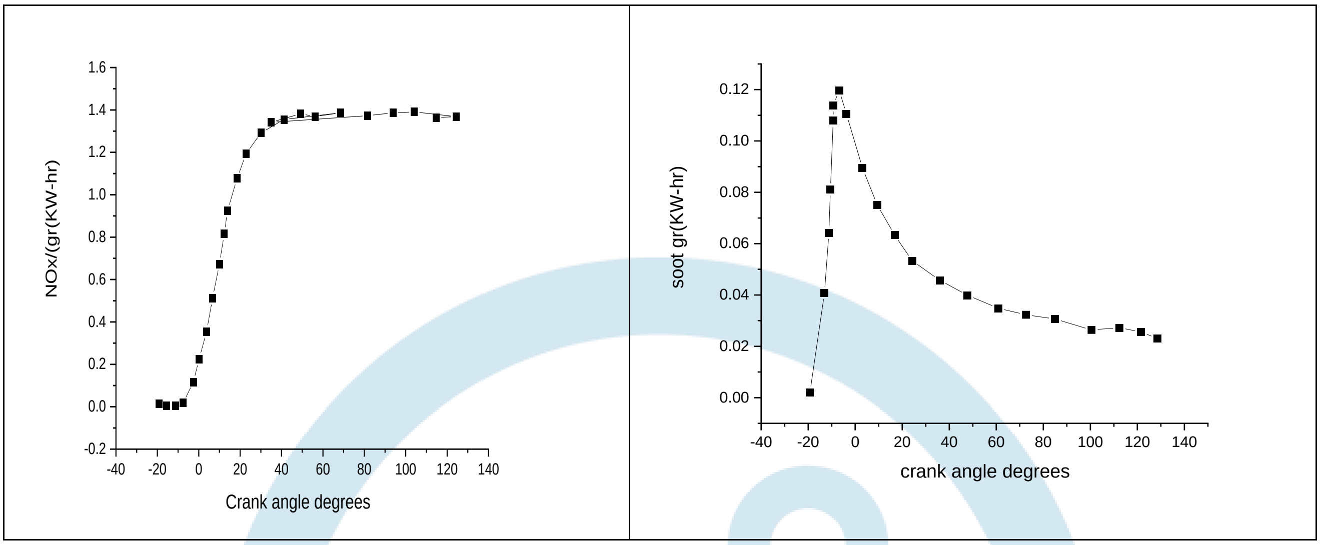


Fig 2: pressure versus crank angle

The measurement of in-cylinder pressure is very important parameter for understanding of engine combustion. It is observed that advancing the SOI leads to higher in cylinder pressure. The higher in cylinder pressure are seen for 30° BTDC SOI. Advanced SOI results in more time available for formation of premixed charge hence larger fraction of fuel is burnt in premixed phase.



The formation of NOx and soot in CI engines is largely dependent on the overall oxygen concentration in the combustible mixture. The variation in mass emissions of NOx for different SOI timing in CRDI engine is shown in the figure. The figure shows there is a overall reduction in the mass emissions with varying injection timing and pressure.

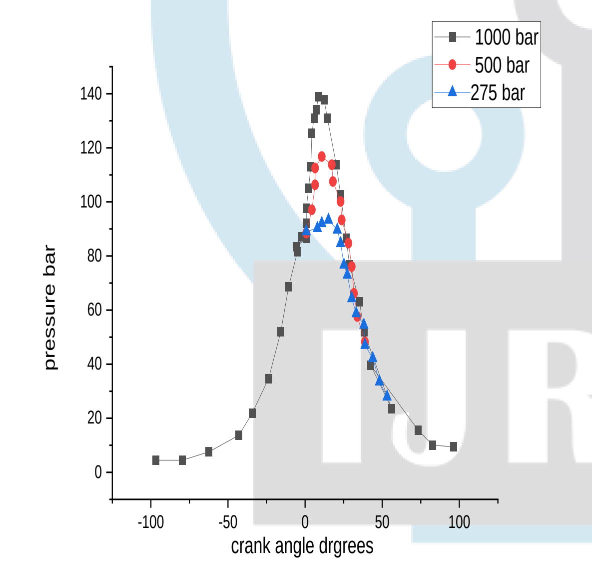


Fig 4: pressure variation versus crank angle at different spraying pressure

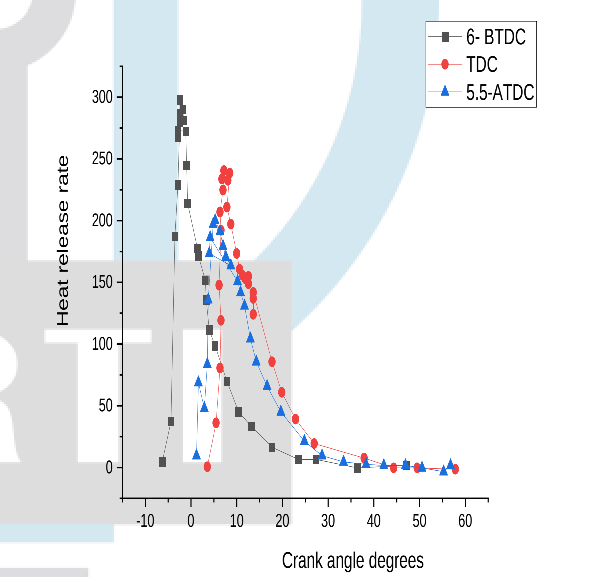


Fig 5: Heat release versus crank angle at different varying pressure

Figure 4& 5 shows energy release in each crankshaft degree for different spraying pressures. As can be seen, by increasing the injection pressure, ignition delay reduces. This means that by increasing the injection pressure, speed of droplets increases. Due to the constant fuel consumption and increase of spraying pressure, sprayed fuel will sprinkled in shorter time and that will cause shorter length of forced combustion, hence is increased the pre-mixed combustion zone.

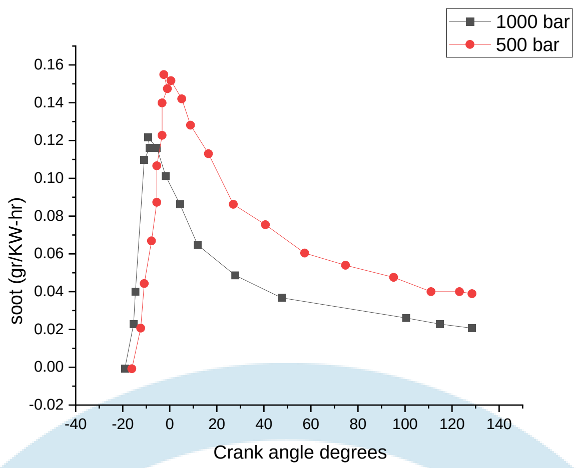


Fig 6: soot formation versus crank angle at different varying pressure

Above figure shows that by increasing the injection pressure from 275 to 1000 bar, soot decreases about 58%. By increasing injection pressure, fuel particles became smaller and in fact atomization of fuel will get better and area of pre-mixing is caused by faster injection.

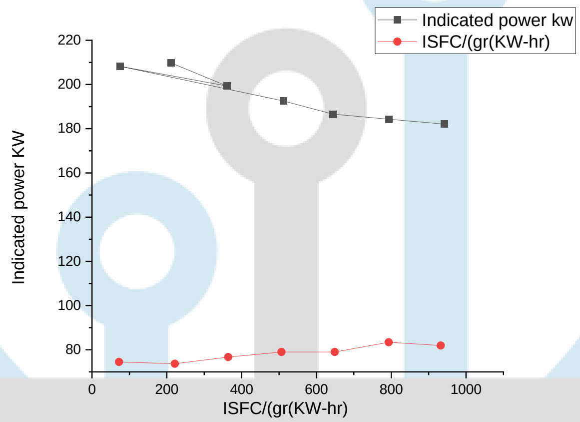
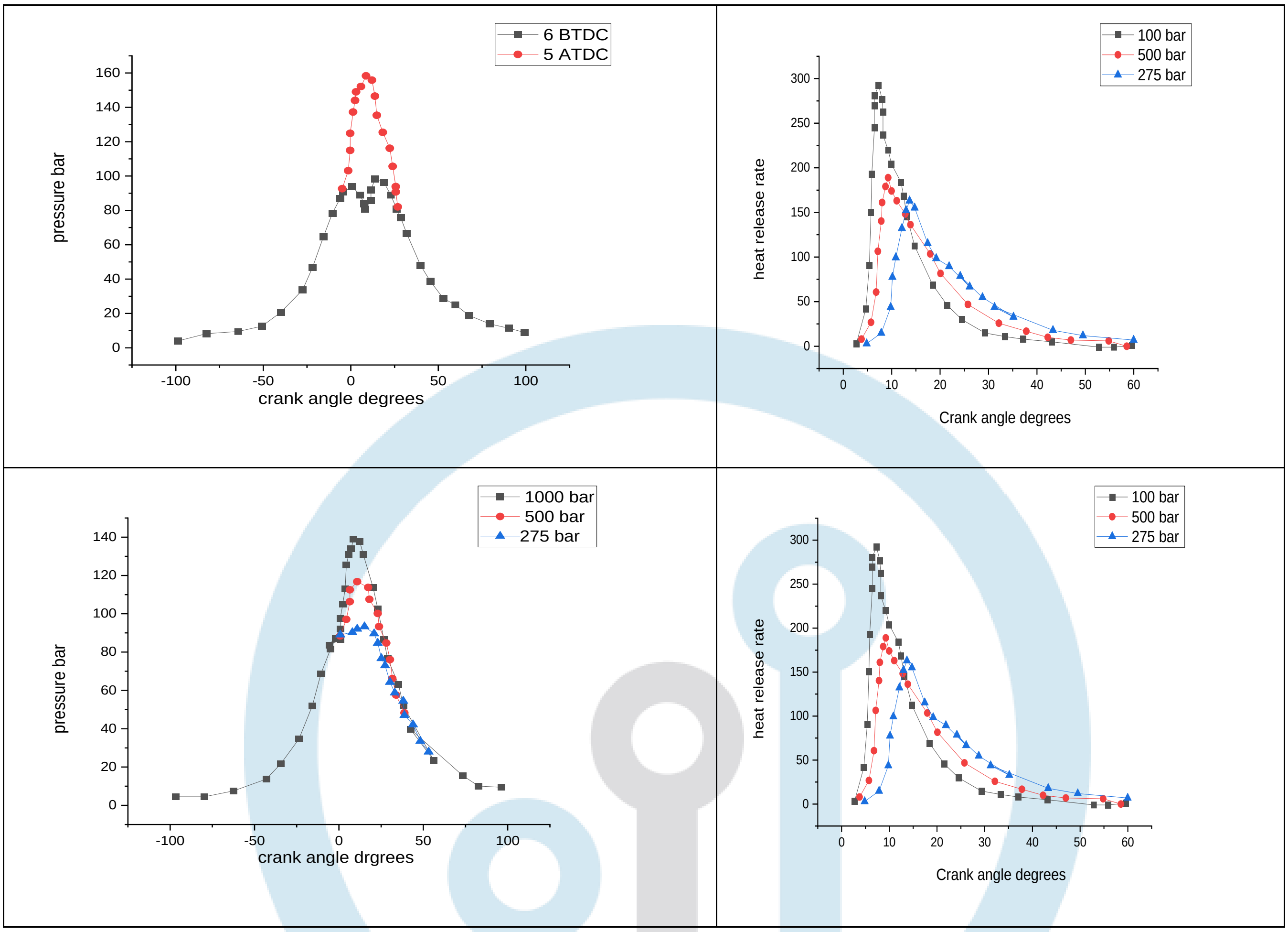


Fig 7: Varying Indicated power versus ISFC.

The above figure shown indicated power of engine and indicatory special fuel consumption.
With increasing injection pressure, indicated power of engine is decreased about 12% and indicated specific fuel consumption (ISFC) of engine is increased.

Figure 8: Pressure and heat release versus crank angle. (a) Pressure cylinder at injection pressure of 100 bar, (b) heat release rate at injection pressure of 500 bar, (c) pressure cylinder at injection pressure of 1000 bar, (d) heat release rate at injection pressure of 275 bar.

The rate of pressure rise is a parameter which gives information about the rate of force transfer due to in-cylinder combustion pressure exerted by varying injection timing and injection pressure. The rate of pressure rise reaches its maxima during premixed heat release. After attaining the maxima, it reduces in the expansion stroke due to mixing controlled combustion, where the combustion is relatively slower in addition to increase in combustion chamber volume due to movement of piston in varying pressure. For varying pressure the rate of pressure rise is much higher than that at retarded SOI timings.
Fig 8 shows the variation in maximum rate of pressure and its crank angle position. As the pressure varies higher in cylinder temperature is seen, which reduces the ignition delay, this leads to relative earlier ignition of premixed charge. The heat release rate at various SOI timings for different pressure. The graph indicates two distinct stages of heat release. The first is immediately after the SOI to a point, where the heat release rate sharps droply. This is due to the combustion primarily due to premixed combustion phase. The second phase starts due to mixing–controlled combustion phase. This is generally a slower heat release phase among the two, therefore, it spreads over a longer combustion duration and is essentially controlled by the rate, at which, the fuel and air can mix together inside the combustion chamber.


6 BTDC
5 ATDC
pressure bar
crank angle degrees
100 bar
500 bar
275 bar
heat release rate
Crank angle degrees
1000 bar
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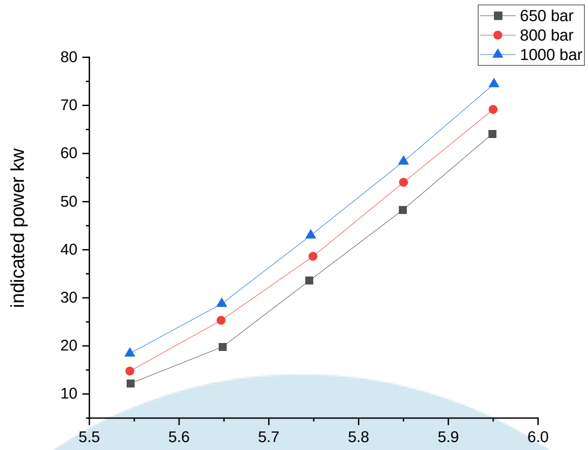

Figure 9: Effect of indicated power and pressures injections on the engine power.

Above figure shows the variation in indicated power and its pressure injections. As the pressure varies relatively higher in-cylinder temperature is seen, which reduces the ignition delay. This leads to relative earlier ignition of premixed charge, hence there will be lesser fuel accumulation in the combustion chamber due to shorter ignition delay, leading to reduction in pressure rise rate with increasing cylinder injection pressure.

Conclusions:

- A good conformity is between predicted in cylinder pressure and exhaust NO_x and Soot emissions.
- Increasing the fuel injection pressure in the combus- tion chamber due to better mixing of fuel and air so that the rate of heatrelease energy and peak pressure increases.

- The injection pressure variation is reviewed and the change of droplet diameter is studied. By increasing the spray pressure, diameter of fuel droplets has been decrease, so small diameters cause faster atomization and evaporation.

- Increasing the spraying pressure generate the output work per cycle. Growing the spraying pressure will produce faster mixture formation, hence combustion delay time was reduced and the maximum energy release was also gone up. By Increasing the spraying pressure from 275 bar to 1000 bar, the soot pollution will experience up to 58% and power up to12% grow.

- With this change, efficiency of the engine will increase around 4% but for every drop 31CA before spraying time the increase of efficiency will be 4% compared with main spraying time of the engine. If starting spray temperature is around 5.51ATDC, temperature inside the combustion chamber will increase therefore the soot was reduced while indi- cated power and NO_x were increased small amounts.

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