

(Research Paper)

MMIS & Its Effect of Brake Power on Temperature Range of Single Cylinder HSDI CI Engine

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Abstract

High Emission Standard Requirements with good performance and economic fuel consumption is the basic requirement which has to be fulfilled by modern internal combustion engines. From past many decades, combustion in diesel engine have been a keen interest for researchers due to introduction of electronic fuel injection system which is able to provide more controlled combustion process in the engine. Further, cylinder pressure and temperature can be reduced to a safe limit by application of multiple injection technique. Mechanical Injection system was used for performing multiple injections by doing modification in single cylinder HSDI diesel engine. Exhaust gas, lubricating oil and cooling water temperatures and its effect has been studied by varying injection timing with single injection. Engine with MMIS (Mechanical Multiple Injection System) shows better performance and reduction in overall engine temperature which will reduce the cooling cost of engine. The experimental test cycle follows IS: 10000 (Part VI) – 1980 and results are observed at fixed speed of 3000 rpm.

Keywords— MMIS, multiple injection, pilot injection, HSDI, exhaust gas temperature, cooling water temperature, lubricating oil temperature.

1. Introduction

Engine operation and efficiency are highly affected by fuel injection technique. Normally leaner mixture is preferred for diesel engines. Pure air is drawn into chamber which is followed by compression process to attain sufficient pressure and temperature for igniting diesel and at the end of compression, fuel is injected via fuel injection system. Starting and end of injection, duration of injection, injection characteristics, injection pressure, injection direction and the number of injection jets per stroke are the main parameters that directly or indirectly affect the combustion in the cylinder and therefore are the subjects of progressive research. As mentioned above, due to introduction of electronic control units combined with electromechanical actuators, it is now possible to have precise control over the injection parameters. In a past decade, only mechanical injection systems were controlling the injection in diesel engines.

Since mechanical actuators are incapable to deliver high frequencies which is necessary for high-accuracy injection, electrical injection systems provided a good solution for controlling rough injection which was responsible for the diesel engine's bad reputation as sturdy, noisy and polluting.^[06] In present research, the effect of modification of cam shaft design for allowing multiple injections (pilot + main) strategies in small HSDI direct injection diesel engine with constant speed of 3000 RPM are studied.

2. Multiple Injections

Multiple injections were first experimented in 1937. Currently the advanced common rail fuel system (CRDI), which is capable of performing as many as five injections per stroke, which is necessary for optimum performance and reduction in emission for diesel engines.

Multiple injection is defines as Pre-injecting specific amount of fuel before main injection in the combustion chamber. It is just like splitting up single time injection quantity into number of small injection quantity at pre-defined and more than one crank angles during one combustion cycle. It also results in more uniform combustion which lowers the overall cylinder temperature, leading to lower NOx emissions.

3. Delay Period

The delay period is the duration between the beginning of fuel injection and starting of actual combustion. Specifically for C.I. engine delay period can be divided into two parts.

- *Physical delay:* This is the time required for the atomized fuel to mix properly with the compressed air and to prepare a combustible charge. This delay can be minimized by using high injection pressure, better turbulence and by multiple injections.
- *Chemical delay:* The time between the completion of physical delay and actual beginning of ignition. Chemical delay totally depends upon physical and chemical characteristics of fuel.

For C.I. engine, physical delay plays vital role then chemical delay. As delay period is reduced, combustion efficiency is increased. Multiple Injection Strategy is capable of reducing physical delays in combustion which will give more uniform heat release rate.

4. Conventional Single Lobe Cam Fuel Injection System

A Figure 1 shows conventional mechanical fuel injection system in which cam operates fuel pump which supply high pressure fuel to the injector through fuel line. In this system single lobe fuel cam give single upward lift to the plunger during one combustion cycle and at the end of compression stroke single time injection occurs into the combustion chamber of engine (Figure 3).

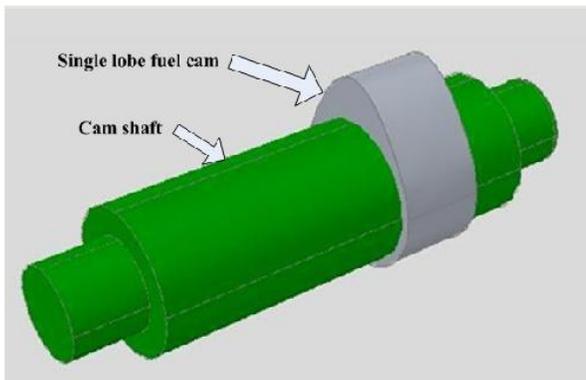


Figure 1. Single Lobe Cam

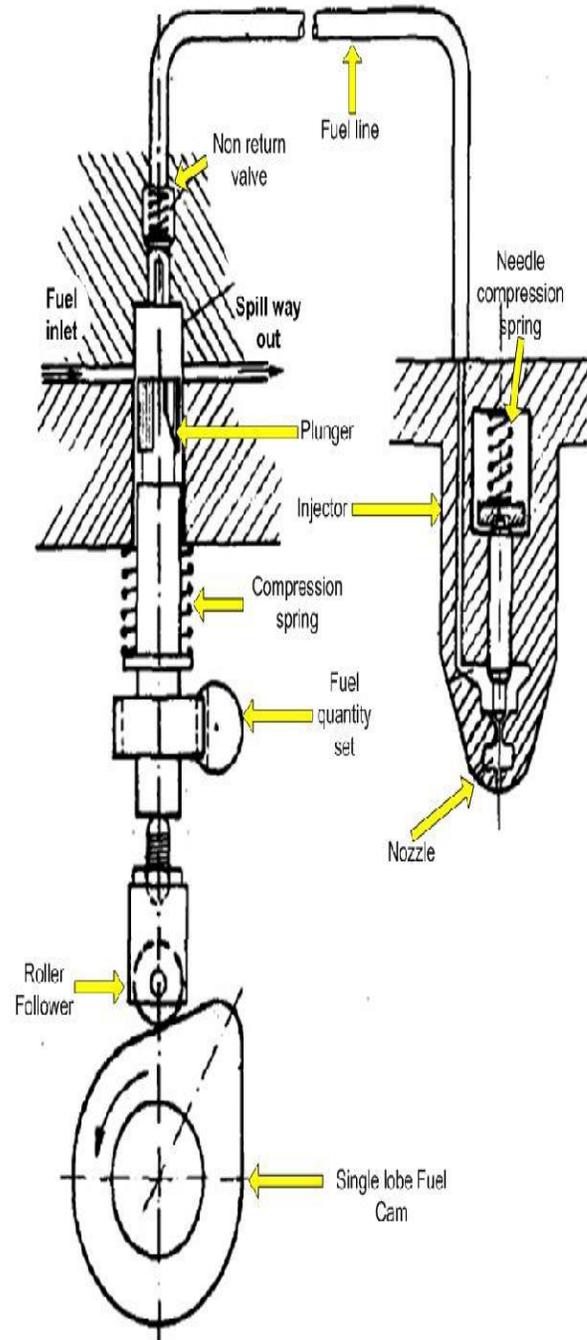


Figure 2. Single Lobe Cam Fuel Injection Systems [8]

Fuel pump Plunger roller rests over fuel lobe cam. As cam shaft rotates, cam lobe lift up the plunger which pressurizes the fuel and send to the injector through fuel line. As the pressure of fuel increase above nozzle opening pressure, the fuel injected through nozzle into combustion chamber. In conventional fuel cam design there is single lobe cam which gives single time injection into engine combustion chamber.

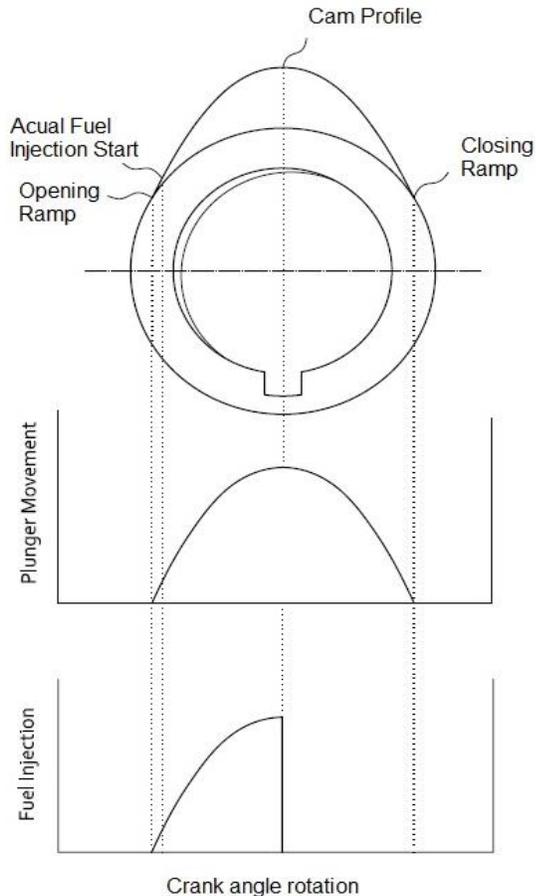


Figure 3. Conventional Single Lobe Fuel Cam

5. MMIS (Mechanical Multiple Fuel Injection System)

The Current research includes method of multiple injections by modification in routine mechanical fuel injection system. All conventional mechanical fuel injection system uses a camshaft which uses a cam lobe surface to give desired profile of rectilinear motion.

Current investigation work will provides the concept of mechanical multiple injection system by designing multi lobe cam which gives multiple injections of fuel in definite period of crank angle. Multi lobe provides progressive vertical movement of plunger which results multiple injections of fuel.

In two lobe of fuel cam (Figure 4), the first opening ramp gives pilot injection then pre-defined dwell period restrict the fuel injection and second ramp does the main injection of fuel into the combustion chamber. Two times progressive vertical motion of the plunger results two times fuel injection in single combustion cycle.

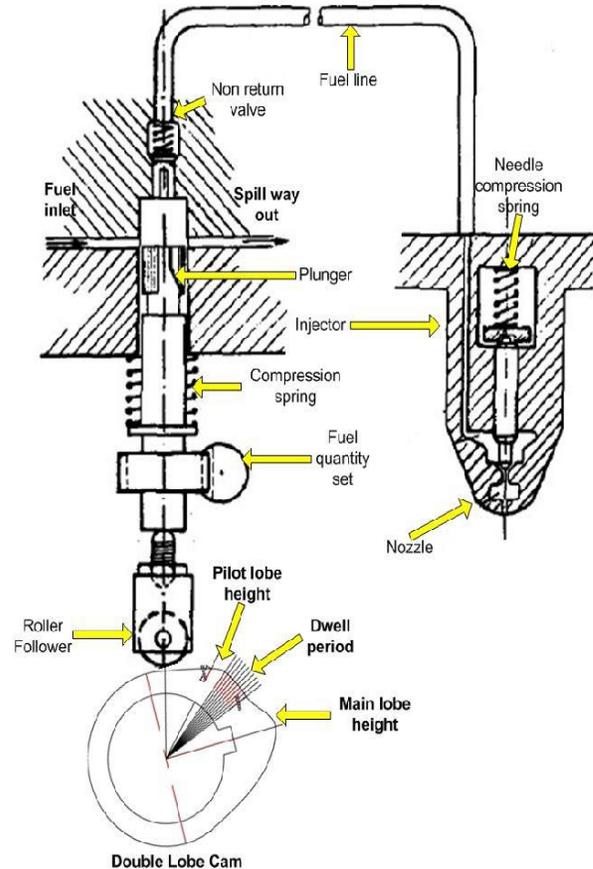


Figure 4. Multi Lobe Cam Fuel Injection System [8]

This technique can be explained as following steps:

- First Ramp – Fuel pump plunger must travel above inlet port and also overcome free run of pump. Free run is the height of plunger travel to build up the pressure of fuel without any fuel injection. When the plunger travels above the free run limit of pump then pilot injection of fuel inside the combustion chamber occurs.
- Dwell period. – In this period cam profile follows constant radius from base circle. In effect of the dwell period vertical progress of the plunger ceases. Due to which the pressure of fuel in the system decreases below the nozzle opening pressure (N.O.P.) which closes the nozzle seat by the needle. Due to above reasons there is no injection of fuel occurs in the combustion chamber.
- Main lobe. – After dwell period of predetermined crank angle there is second ramp profile of the fuel cam which gives again raise of the plunger. This vertical movement of plunger again increases the pressure of fuel in the system and as the pressure

rise beyond nozzle opening pressure the second injection of fuel in combustion chamber occurs.

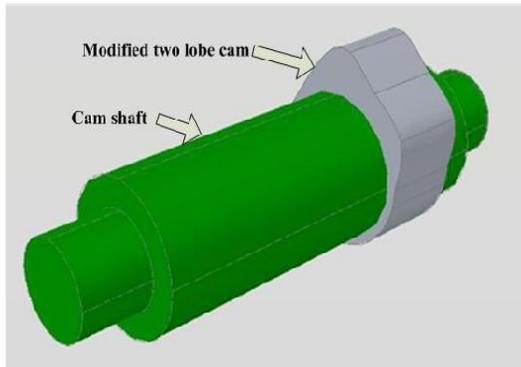


Figure 5. Multi Lobe Cam

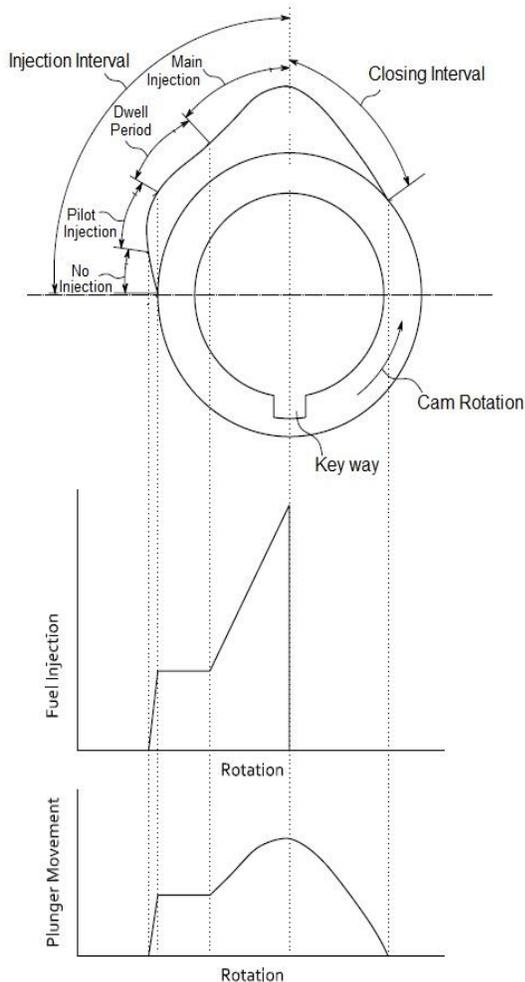


Figure 6. Modified Two Lobe Fuel Cam

Figure 6 shows modified two lobe fuel cam for multiple injections. Two lobes of fuel cam design contain pilot-dwell-main lobe profile. As explain in above theory plunger of fuel

pump move upward as per pilot lobe height design which gives pilot injection into the combustion chamber. After pilot lobe cam follows dwell period which stop injection. Then main lobe gives second injection as pressure rise because of vertical movement of fuel pump plunger. These cam profile design reciprocate plunger in two stepped motion and hence double injection can be achieve. Multiple injection is depends upon design of fuel cam design.

Above mentioned mechanical method of injection system will eliminate use of electronic multiple fuel injection system along with their drawbacks. Further, these mechanical multiple injection technique can be directly adopted for mass production in industry without increasing routine engine manufacturing expenditure.

6. Experimental Set-up and Procedure



Figure 7. Experimental Set-up
 Courtesy: P.M. Diesels Pvt. Ltd.

To study the performance characteristics, single cylinder water cooled HSDI diesel engine was used. Certain modifications in current engine was required, which includes modified cam shaft designed particularly for multiple injection at pre-defined interval of timing. The engine crankshaft is directly coupled with a hydraulic dynamometer acting as a variable load system. Different Parameters were recorded by using various gauges and instruments. Digital tachometer was used to measure the engine speed. Exhaust gas, cooling water as well as lubricating oil temperature was recorded with the help of K-Type thermocouple with digital temperature indicator. The testing method of engine was as

per IS standard: 10000 (Part VI) – 1980 at constant speed of 3000 rpm.

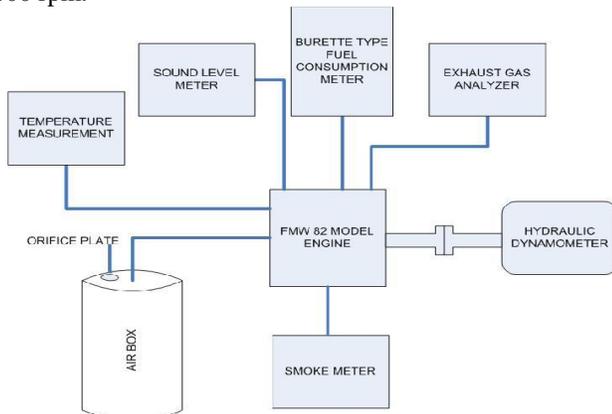


Figure 8. Schematic Diagram of Experiment Set-up

The experimental investigation was carried out for different injection timing (28°, 30°, 32°, 34°, 36° CA) before TDC (Top Dead Center). The engine testing was done for different injection timing by changing load conditions like 0%, 40%, 60%, 80%, 100%, and 110% over load condition in six steps. The specifications of the test Engine are listed in Table 1.

TABLE 1. CHARACTERISTICS OF HSDI ENGINE USED FOR EXPERIMENT

Bore Dia. (mm)	82
Stroke Length (mm)	68
Volume Displaced (cm ³)	359
No. of cylinder	ONE
Compression ratio	18 : 1
Engine Speed (RPM)	3000
Injection type	Direct Injection
Lubricating oil grade	SAE20W40

Measurement included the parameters like brake specific fuel consumption, brake power, air flow rate, inlet air and exhaust gas temperatures, dry/wet bulb temperatures, lubricating and cooling water temperatures and barometric pressure. The instruments used for measurements with their accuracy are listed in Table 2.

TABLE 2. INSTRUMENT SPECIFICATIONS

Sr. No.	Measurement	Instrument	Accuracy
1	Engine speed	Digital tachometer	±1 rpm
2	Engine load	Hydraulic dynamometer	0.1 N.m
3	Diesel consumption	Liquid level burette	0.1 ml
4	Lubrication oil temperature	Thermo couple + transmitter	0.1%
5	Cooling water temperature	Thermo couple + transmitter	0.1%
6	Exhaust gas temperature	Thermo couple + transmitter	0.1%

7. Results and Discussion

7.1 Effect of Brake Power on Exhaust Gas Temperature:

It can be noticed from figure. 9 that by varying injection timing, exhaust gas temperature rises with increase in load. Multiple Injection shows significant reduction in temperature than single injection. The reason can be explained that due to the shorter ignition delay in multiple injection mode, complete combustion can be achieved. Total mass of fuel burning inside is segregated into two parts which gives smoother combustion process.

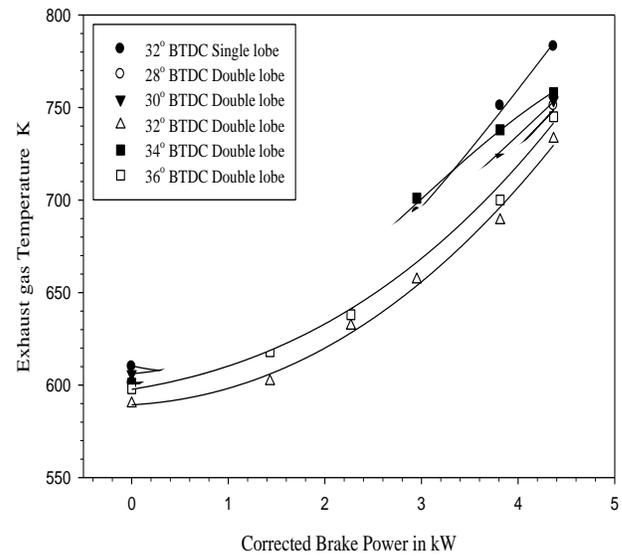


Figure 9. Effect of Brake Power on Exhaust Gas Temperature

Maximum reduction in exhaust gas temperature up to 4% was observed from multiple injections of 32° advance BTDC at given load condition. The exhaust gas temperature decreases in the range from 3.2% to 8.3% at multiple injection timing of 32° BTDC compare to single time injection.

7.2 Effect of Brake Power on Lubricating Oil Temperature:

Figure 10. Shows the graph which indicates that the lubricating oil temperature rises with the rise in load for different advance degree of multiple injections.

32° BTDC was the best injection angle timing for maximum reduction of temperature for full load condition. Maximum reduction of about 5.3% in oil temperature was observed compare to single injection at 100% load condition. Maximum reduction from 2.5% to 5.3% at 32° BTDC was observed from all load condition.

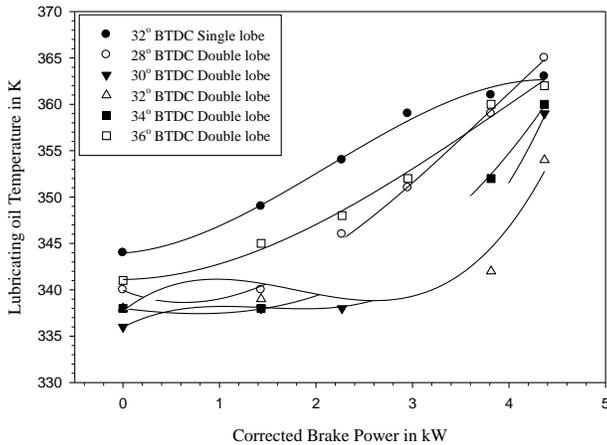


Figure 10. Effect of Brake Power on Lubrication Oil Temperature

7.3 Effect of Brake Power on cooling water outlet Temperature: Comparison of brake power and oil temperature is shown in figure 10. Graph shows that the cooling water temperature increases with increase in load with multiple and single time injections. Optimum amount of cooling water temperature rises of 2% was noticed at multiple injections advance of 36° BTDC at pre-defined load condition. The value of cooling water temperature increases from 4.2% to 7.5% at advance timing of 36° BTDC compare single time injection.

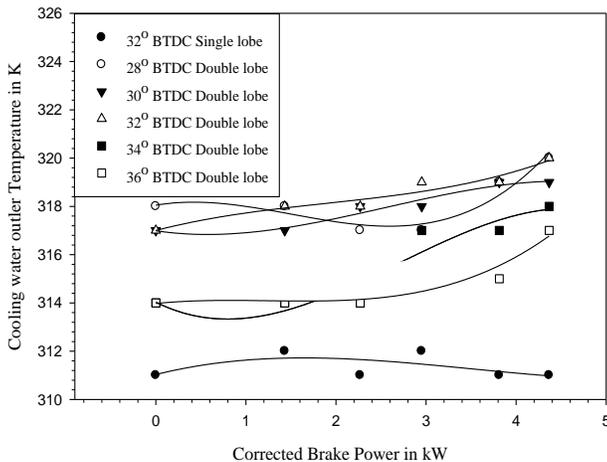


Figure 11. Effect of Brake Power on Cooling Water Temperature

8. Uncertainty Analysis

The present investigation is focused to measure single cylinder 4 stroke HSDI engine performance using multiple injection system. Moreover, effect of both multiple injection

and single injection is measured. Performance parameters considered are Brake Thermal Efficiency, Volumetric Efficiency, Mechanical Efficiency, Brake Specific Energy Consumption, Brake Specific Fuel Consumption, and Exhaust Gas Temperature.

In order to obtain experimental data some measurements have been made like time taken for 50 ml of fuel consumption, fuel quantity, exhaust gas temperature, cooling water temperature, lubrication oil temperature, engine speed, load on engine. Due to limitation of the instruments used for data collection and measurement purpose there will be some degree of inaccuracy.

TABLE 3. PERCENTAGE AND AVERAGE UNCERTAINTY FOR VARIOUS INJECTION TIMING

Injection Timing	Brake Power	
	Percentage Range in %	Average in %
32° BTDC Single Lobe	0.031- 0.033	0.032
28° BTDC Double Lobe	0.032- 0.032	0.032
30° BTDC Double Lobe	0.031- 0.032	0.032
32° BTDC Double Lobe	0.032- 0.033	0.032
34° BTDC Double Lobe	0.031- 0.032	0.032
36° BTDC Double Lobe	0.032- 0.032	0.032

Uncertainty is the best approach for estimation of the prediction of amount of the error. The methodology of accounting uncertainty in experimental results, applied in the current research, is suggested by S. Kline et al. [7].

9. Conclusions

This research investigated mechanical multiple injections system in diesel engines as a technique for achieving better control of combustion and to reduce exhaust emissions. For carrying out this research, a special experimental set-up was built with the courtesy of P.M. Diesels Pvt. Ltd. With this set up different injection timings with varying load conditions were characterized and analyzed. The main results and observations from the experimental set-up are as follows:

- The Pilot injection generates sufficient heat, which raises overall temperature inside the cylinder and thus shortens ignition delay time for main injection. Particular quantity of fuel and dwell time of pilot injection would enable reduction in ignition delay time and the heat release rate can be precisely controlled.
- By Mechanical multiple injections, amount of exhaust gas temperature decreases by 4% have been observed for crank angle of 32° advance BTDC at designed load condition. The reduction in exhaust gas temperature varies from 3.2% to 8.3% at

optimum multiple timing of 32° BTDC compare to base line of single time injection.

- The maximum reduction in oil temperature has observed for timing of 32° BTDC at 100% load condition. At multiple injection timing of 32° BTDC, reduction in temperature varies from 2.5% to 5.3% observed for all load condition.
- The rise in cooling water outlet temperature up to 2% is observed for multiple injections of 36° advance BTDC at 100% load condition. The value varies from 4.2% to 7.5% at multiple timing of 36° BTDC compare to single time injection.

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