INVESTIGATION OF PERFORMANCE AND EMISSION CHARACTERISTICS OF CI ENGINE BY CHANGING FUEL INJECTION PARAMETERS: A REVIEW

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Abstract - *This study was conducted to investigate the effects of varying fuel injection timing and fuel injection pressure on C.I. engine. This study touches upon the advancement and retardation methods of fuel injection timing and injection pressure to inspect the engine emission indicators such as carbon monoxide, hydrocarbon, oxides of nitrogen, smoke, particulate matter and carbon dioxide contents. A comprehensive comparative analysis has been made based on various combustion, performance and emission parameters. This study is use further work on the injection parameters*

Key Words: Engine, Emission, Injection timing, Injection pressure, combustion

1. INTRODUCTION

Diesel engines are extensively used and are dominating power sources for road transport sector due to their higher thermal efficiency, operational reliability, robustness, and lower hydrocarbon (HC) and carbon monoxide (CO) emissions. In the last two decades, diesel has emerged as a well-accepted alternative to mineral diesel because its utilization requires insignificant modifications in the engine hardware. With advanced fuel injection systems, fuel injection pressures have risen by an order of magnitude in comparison to older mechanical fuel injection systems. It is therefore very important to investigate the effect of fuel injection pressure on comparative performance, emissions and combustion characteristics of diesel and mineral diesel for effective utilization of diesel in modern CI engines.

Over the past few decades, diesel engines have been explored and studied on the performance, emission and combustion characteristics by many researchers. They investigated that the effect of operating parameters like injection timing and injection pressure on the engine combustion characteristic is quite significant. Injection timing and injection pressure influences major impacts on the performance characteristics of diesel fuelled engines. Injection timing plays an important role in the emission characteristics of diesel engine. Variation in fuel injection timing and fuel injection pressure leads to the divergence in combustion distinctiveness that concerns deviation in the emission characteristics of diesel engine, which have been evaluated in our previous review paper. No previous authors have done the survey on the consequences of variation of both injection timing and injection pressure on powered engines. A substantial number of research studies from highly rated journals in the scientific indexes were selected and surveyed preferentially since the year 1999–2017, on the basis of effects of operating parameters variation on diesel engine combustion characteristics literatures.

Therefore it is important to review the effect of injection timing and injection pressure on the combustion characteristics of a variety of biodiesels for the effective combustion in modern engines.

2. BACKGROUND OF DIESEL ENGINES

Diesel engines are widely used for different applications, ranging from construction and agricultural machinery to cars and light commercial vehicles, heavy goods vehicles, ships and fixed installation engines. The main reason for the wide use of this type of engine is its high degree of efficiency and its resulting fuel economy.

Despite the fact that the same principles of diesel engines are used in different applications, engine operation can vary from application to application. Cars and light commercial vehicles are expected to produce high torque and to run smoothly at high speeds. Heavy goods diesel engines are expected to be fuel-economical, so they use direct injection exclusively and operate at medium to high speeds. Construction machinery and agricultural machinery are the traditional domains for diesel engines. In this domain, durability, reliability, and ease of maintenance are as important as fuel economy. These engines still use mechanical actuators to control different parameters of the engine. Railway locomotives and ship engines are designed for continuous heavy-duty operation. These slow-rotating (400-1500 rpm) engines usually use poor-quality fuel. Since these engines rotate so slowly, they usually achieve high levels of efficiency that represent the highest attainable with piston engines. Diesel engines were even used for aircrafts at the beginning of the twentieth century, since they had an advantage over the spark-ignition engine, which experienced misfire problems due to low atmospheric pressure at high altitudes. Eventually the progress achieved in high-performance fuel-injection spark ignition engines made the diesel engine less attractive in this realm.

The diesel engine is a compression-ignition engine. Ignition of the mixture in these engines occurs due to extreme pressure and temperature during the compression process. Diesel engines operate in four-stroke or two-stroke cycles, and four-stroke cycle engines are usually used in motor vehicles. In a four-stroke cycle, the inlet and exhaust valves control the air that flows in and out of the engine. Each cylinder contains one or two valves to control each action.

The different stages of operation of four-stroke diesel engine are:

a. **Induction stroke** – During this stage, the piston moves from the TC downward, increasing the volume of the cylinder; the intake valves open, allowing fresh air to enter the cylinder.
b. **Compression stroke** – In this phase the piston moves from the BC upwards and compresses the air trapped inside the cylinder to the degree determined by the engine compression ratio. This compression is accompanied by an increase in the temperature of the content of the cylinder (depending on the compression ratio, up to 900°C). When the compression stroke is almost complete, fuel is injected into the hot compressed air.
c. **Power stroke** – During this stage, the piston moves from the TC downward; when the ignition lag time elapses, the mixture of fuel drops, and fuel vapor and air ignite spontaneously due to the intense pressure and temperature in the cylinder. The chemical energy in the fuel is converted to kinetic energy (increasing the pressure in the cylinder), which forces the piston downwards. The amount of energy released by combustion is determined by the amount of injected fuel.
d. **Exhaust stroke** – Before the piston reaches the BC, the exhaust valves open and the compressed burn mixture begins to flow out of the cylinder. The piston starts moving upwards and forces the remaining burnt gas out.

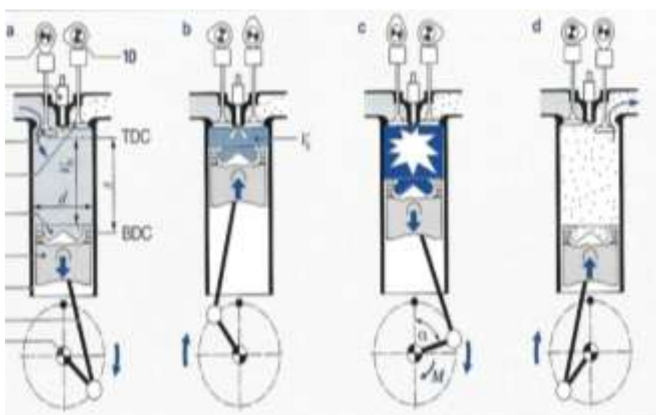

Fig -1: Four-stroke diesel engine (Bosch 2003)

Valve timing affects engine performance significantly. The timing is constant at a specific crank rotation angle, and is carried out by the camshaft that is driven by the crank shaft with the proper transmission ratio, usually by a toothed belt or chain. The valve's timing forces desirable operation position at a specific engine speed, at which the air flow through the valves is optimal and the engine provides the highest amount of power.

The compression ratio has a decisive effect on some of the engine's operating parameters, such as: the engine's cold starting characteristics, the torque generated, fuel consumption, noise, and emission of pollutants. The compression ratio is generally between 16:1 and 24:1 in engines used by cars and commercial vehicles. The compression ratio in spark-ignition engines is limited due to the knocking phenomenon. As mentioned above, higher compression ratio in the cycle means thermal efficiency will increase, pollution formation will decrease and, consequently, the amount of available power from the cycle will increase. This advantage can be attained by using a turbocharger or a supercharger. These accessories increase the pressure of the air entering the cylinder and thus increase the compression ratio of the engine.

The operating conditions of the engine are restrained by several parameters mainly derived from structural considerations. These include maximum engine speed, combustion pressure limits, and exhaust gas temperature limits. The operating conditions are also derived from the designation of the engine. In the last two decades there has been increasing emphasis on air pollution concerns, and the main challenge of engine developers is to comply with ever-tightening air pollution regulations. Air pollution regulations determine a maximum threshold of a variety of pollutants, such as smoke, nitrogen oxides, sulfur oxides and aromatic compounds.

The creation of sulfur oxides and aromatic compounds is mainly determined by the fuel's contents. The creation of smoke and nitrogen oxides is mainly dependent on combustion in the cylinder. Therefore, air pollution standards dictate the operating conditions of the engine. Nitrogen oxides and smoke (particulate matter) are the main pollutants which characterize diesel engines. A decrease in the amount of these pollutants can be achieved by the use of after-treatments which reduce their concentration in exhaust gas or by gaining better control over the combustion process. New air pollution standards have a significant impact on engine operating modes.

Since engine performance and pollution formation depend greatly upon the quality of the diesel fuel, fuel properties are subjected to government regulations. Fuel quality is affected by levels of sulfur and aromatic compounds, cetane number, density, viscosity, boiling point, lubricity, and water content. The cetane number defines the flammability of the fuel, with high numbers indicating high flammability and high quality. The cetane number of commercial fuels is 50-60. The density of the fuel is also an important parameter in assuring appropriate combustion. The metering of fuel in the engine is based on volume, and if the density of the fuel is not uniform, the mass of fuel entering the cylinder will vary, affecting combustion. The viscosity of the fuel affects leakage loss in the fuel injection system; low viscosity leads to high leakage losses in the fuel injection system. The fuel's boiling point affects engine operation at different ambient temperatures; when the ambient temperature is low the fuel has a lower boiling point. However, the boiling point of the fuel is determined by its components, which may affect other characteristics of the fuel. The lubricant properties of the fuel are very important; fuel with low lubricity may damage the fuel injection system. The traditional division between CI and SI engines is that CI engines are designated for heavy vehicles and industrial use, while SI engines are designated mainly for light vehicles (passenger cars).

This traditional division is changing rapidly, and today, in some countries in india, half of the new cars are equipped with diesel engines. During the last two decades, diesel engines have undergone a transformation from noisy, smoking engines to quiet, cleaner and more user-friendly ones. Over the years, diesel engines have evolved in terms of power and torque this could be linked to improvements in the combustion chamber or the addition of turbo chargers/super chargers. Over the past decade the performance of diesel engines increased dramatically. This dramatic improvement could be attributed to the use of electronic control units such as the engine management system. These systems provide the ability to achieve improved control over different engine sub-systems. The sub-system most influenced by the use of the electronic control unit is the fuel injection system.

3. FUEL INJECTION PARAMETERS INJECTION TIMING AND INJECTION PRESSURE CHANGING PROCEDURE:

The injection system varied for each engine, the various types of injection systems used in the research works [1,2,3,4,5,6,7,8,9,10] are listed in Table no3.1. To set the static injection timing for engine, spill method was used generally. An adapter with hypodermic needle termination was used to determine the occurrence of spill. A circular protractor (resolution-0.5) attached to the front end of pulley was used for marking CAD. The injection timing could be varied by many methods as follows,

- In case of combined pump and drive side unit, the coupling flange could be shifted for fuel injection timing adjustment,
- Using pump roller guide, the upward and downward movement of plunger varies the injection timing,
- The most common method followed by researchers is by adjusting the number of shims between the pump and engine, the injection timing was changed in terms of crank angle degree (CAD). By adding the shims, the injection timing was retarded and for advancing the injection timing the shims was reduced.
- Nowadays the research engines has a simple modification setup to vary the injection timing by adjusting the preload of fuel injector spring by regulating the setting screw setup provided with fuel injection pump assembly .

- Injection pressure was varied by regulating the spring tension of the injector with the help of setting screw. It was also varied by adjusting the preload of the spring inside the injector by
- removing and inserting the shims under nozzle spring.

The significant consequences experienced by engine due to the modifications of fuel injection timing and fuel injection pressure have been sorted as follows,

Table.No:3.1 Various Injection Systems description

Ref. No	Injector type	Injection Pressure Mpa	Number of holes	Nozzle Hole Diameter mm	Included spray Angle Degree
1	Electronically controlled common rail injector	20–120	6	0.26	125
2	BOSCH RO-KBL103S15 injectors, with RO-DLLA 150S720 nozzles	17.7	NM	NM	NM
3	Ruggerini RF91 injection system	NM	NM	NM	NM
4	Common rail with piezolectric coupled nozzles	1.65	6	NM	NM
5	Common rail direct injection	20	4	0.2	NM
6	Injector with P type DSLA nozzles	NM	NM	NM	NM
7	Solid Injection System	22	3	0.3	120
8	Solenoid type injector (Bosch)	80	8	0.131	150
9	Mechanical pump–nozzle injection system	22.5	3	NM	NM
10	Port fuel injection system	18	7	NM	78

Advanced injection timing leads to,

- Enhancement in turbulence of mixture
- Earlier and rapid combustion
- Longer ignition delay period
- Lower combustion chamber pressure and temperature

Retarded injection timing contributed to,

- Delayed combustion
- Slow burning rate
- Shorter ignition delay period
- Higher combustion chamber pressure and temperature
- Higher fuel injection pressure serves the following changes,
- Superior atomization of air-fuel mixture
- Rapid combustion rate

Vice versa contributions were provided by lower fuel injection pressure as,

- Sluggish burning rate
- Poor atomization

4. LITERATURE SURVEY

To investigate the effects of alteration of engine design parameters which relates directly to the fuel injection system viz. fuel IP and fuel IT. The combustion is expected to be occurred earlier with advancement in IT due to which more fuel is burnt before the TDC and in-cylinder peak pressure occurs near to TDC and vice versa.

Too much advancement of IT may result adversely due to inadequate temperature for the start of combustion. Retardation in IT within some limits may decrease the NOx emissions without the significant effect on engine performance [11]. The poor atomization of diesel during the injection period may be improved by increasing the injection pressure but NOx emissions may increase due to the better combustion of the fuel [12].

The lean combustion limit for CNG direct injection is influenced on the timings of injection and ignition. Injection timing is a very important parameter for realizing better combustion in CNGDI. For stratified combustion engine, natural gas is injected at the late of compression stroke with suitable injection timing to assist the engine to have stable operation at a very lean overall mixture [13].

With the single-cylinder natural-gas direct injection experiment and compression ratio 8, experiment tested various injection timings. Additionally, the volumetric efficiency is reduced with the advancement of fuel injection timing. Short combustion duration and short heat release duration decrease the level of HC and CO emissions [14].

Furthermore, another experiment using a single cylinder direct injection spark ignition gasoline fuel with stratified operation was tested. Results are shown for the advanced injection timing; non-luminous blue flame was detected. On the other hand, as the injection timing was delayed, a portion of luminous flame was increased [15].

In this paper, combined effects of compression ratio and a number of nozzle holes were taken as operating parameters and the diesel engine performance, the second objective is to find the appropriate input parameters to the CI engine for optimal output behaviors such as performance, emissions and exergy efficiency for specified fuel blends and diesel [16]

5. SUMMARY AND DISCUSSION

5.1 Effects of injection timing on emission characteristics

The variation of emission indicators regarding the injection timing modifications are tabulated in Table no 5.1.

5.1.1 Carbon monoxide (CO)

Deep et al. investigated the effects of injection timing at 23.5 CAD BTDC and reported that CO emission level decreased for that advancing the fuel injection timing [17].

Saad Aljamali et,al. studied the Effect of fuel injection timings on performance and emissions of stratified combustion CNGDI engine that Carbon monoxide (CO) emission is low at 360° BTDC at low speeds but at high speed, it was low at 120 BTDC [18].

L. Labecki , L.C. Ganippa experimented the Effects Of Injection Parameters and EGR on Combustion And Emission Characteristics Of Rapeseed Oil And Its Blends In Diesel Engines, CO increased retarding the fuel injection timing from 9˚ bTDC [20].

Cenk Sayin, Metin Gumus viewed from the Impact of compression ratio and injection parameters on the performance and emissions of a DI diesel engine fueled with biodiesel-blended diesel fuel that the various fuel injection which will lead to a decrease in CO emissions [21].

M.Krishnamoorthi et,al. investigation on performance, emission behavior and exergy analysis of a variable compression ratio engine that the 100% load, B1 blend has been 20% lower CO emissions compared to neat diesel corresponding to CR16 with NH5 [24].

Atul Dhar et,al viewed the Effect of fuel injection pressure and injection timing of Karanja biodiesel blends on fuel spray that report the CO in lows rate at the vary fuel injection timing [25]

5.1.2 Hydrocarbon (HC)

Deep et al. investigated the effects of injection timing at 23.5 CAD BTDC and reported that HC emission level decreased for advancing the fuel injection timing [17]. Saad Aljamali et,al. studied the Effect of fuel injection timings on performance and emissions of stratified combustion CNGDI engine that HC emission is low at 360° BTDC at low speeds but at high speed, it was low at 120 BTDC [18].

L. Labecki , L.C. Ganippa experimented the Effects Of Injection Parameters And EGR On Combustion And Emission Characteristics Of Rapeseed Oil And Its Blends In Diesel Engines, HC increased retarding the fuel injection timing from 9˚ bTDC [20]. Cenk Sayin, Metin Gumus viewed from the Impact of compression ratio and injection parameters on the performance and emissions of a DI diesel engine fueled with biodiesel-blended diesel fuel that the various fuel injection timing which will lead to a decrease in HC emissions [21].

M.Krishnamoorthi et,al. investigation on performance, emission behavior and exergy analysis of a variable compression ratio engine that the maximum HC is observed in B3 fuel and 25% engine load was at CR14 with NH3 [24]. Atul Dhar et,al viewed the Effect of fuel injection pressure and injection timing of Karanja biodiesel blends on fuel spray that report the HO in lows rate at the vary fuel injection timing [25]

5.1.3. Oxides of nitrogen (NO_x)

Deep et al. investigated the effects of NOx seems to be favourable at IT 21° BTDC [17]. Saad Aljamali et,al. studied the Effect of fuel injection timings on performance and emissions of stratified combustion CNGDI engine that the lowest NOx were founded at 120˚ BTDC. [18].

S.Saravanan et, al., experimented the Combined Effect Of Injection Timing, Egr And Injection Pressure In Nox Control Of A Stationary Diesel Engine Fuelled With Crude Rice Bran Oil Methyl Ester, EGR is the most influencing factor at no load and part load to reduce NOx emission with less influence on smoke density while at full load fuel injection timing is more influential [19].

L. Labecki , L.C. Ganippa experimented the Effects Of Injection Parameters And EGR On Combustion And Emission Characteristics Of Rapeseed Oil And Its Blends In Diesel Engines, The NOx emission was reduced by retarding the fuel injection timing from 9˚ bTDC [20]. Cenk Sayin, Metin Gumus viewed from the Impact of compression ratio and injection parameters on the performance and emissions of a DI diesel engine fueled with biodiesel-blended diesel fuel that NOx emissions reduced with decreased IT [21].

G.R. Kannan, R. Anand investigated that the Effect of Injection Pressure and Injection Timing on DI Diesel Engine then an advanced injection timing of 25.5˚ bTDC leads reduction in nitric oxide (NO) [22].

Table. No: 5.1 Effects of injection timing variation on emission indicators.

Ref. no	CO	HC	NOx	PM	Smoke
17	⇩	⇩	favourable at IT 21° BTDC	NM	favourable at 25° BTDC
18	⇩	⇩	⇩	NM	NM
19	NM	NM	⇩	NM	NM
20	⇧	⇧	⇩	NM	NM
21	⇩	⇩	⇩	NM	NM
22	NM	NM	⇩	NM	NM
23	NM	NM	NM	⇩	NM
24	⇩	⇩	NM	NM	⇩
25	⇩	⇩	NM	NM	NM

5.1.4. Particulate matter (PM)

Avinash Kumar, Agarwal et, al. studied the Effect of fuel injection pressure and injection timing on spray characteristics fuelled in common rail direct injection diesel engine test fuel helped in reducing particulate emissions by varying injection timings [23].

5.1.5. Smoke

Deep et al. investigated the effects of injection timing the smoke opacity seems to be favourable at 25° BTDC [17].

M.Krishnamoorthi et,al. investigation on performance, emission behavior and exergy analysis of a variable compression ratio engine that the lower smoke opacity compared to neat diesel for 100% engine loads at CR16, CR17.5 with NH5. [24]. Cenk et al. studied the effects of injection timing on smoke density in the emission and reported that smoke reduced by 1.25% at advanced IT of 25 CAD BTDC and the same increased by 1.02% at retarded IT of 15 CAD BTDC for B5 blend (5% biodiesel volume concentration) [21].

5.2 Effects of injection pressure on emission characteristics

The variation of emission indicators regarding the injection pressure modifications are tabulated in Table no 5.2

5.2.1 Carbon monoxide (CO)

Deep et al. investigated the effects of injection pressure at 200 bar and reported that CO emission level was found to be lowest at original engine configuration [17].

L. Labecki , L.C. Ganippa experimented the Effects Of Injection Parameters and EGR on Combustion And Emission Characteristics Of Rapeseed Oil And Its Blends In Diesel Engines, CO slightly increased retarding with the fuel pressure at 1200 bar [20].

Cenk Sayin, Metin Gumus viewed from the Impact of compression ratio and injection parameters on the performance and emissions of a DI diesel engine fueled with biodiesel-blended diesel fuel that the various fuel injection pressure which will lead to a decrease in CO emissions [21].

Atul Dhar et,al viewed the Effect of fuel injection pressure and injection timing of Karanja biodiesel blends on fuel spray that report the CO in lows rate at the vary fuel injection pressure at 300 bar [25]

5.2.2 Hydrocarbon (HC)

Deep et al. investigated the effects of injection pressure at 200 bar and reported that HC emission level was found to be lowest at original engine configuration [17].

L. Labecki , L.C. Ganippa experimented the Effects Of Injection Parameters and EGR on Combustion And Emission Characteristics Of Rapeseed Oil And Its Blends In Diesel Engines, HC increased retarding with the fuel pressure from 800 to 1200 bar [20]. Cenk Sayin, Metin Gumus viewed from the Impact of compression ratio and injection parameters on the performance and emissions of a DI diesel engine fueled with biodiesel-blended diesel fuel that the various fuel injection pressure which will lead to a decrease in HC emissions [21].

5.2.3. Oxides of nitrogen (NOx)

Deep et al. investigated the effects of injection pressure at 300 bar and reported that NOx emission level was found to be favourable [17]. L. Labecki , L.C. Ganippa experimented the Effects Of Injection Parameters and EGR on Combustion And Emission Characteristics Of Rapeseed Oil And Its Blends In Diesel Engines, NOx decreased retarding the fuel injection pressure at 800 bar [20]. Cenk Sayin, Metin Gumus viewed from the Impact of compression ratio and injection parameters on the performance and emissions of a DI diesel engine fueled with biodiesel-blended diesel fuel that the various of increases of fuel injection pressure which will lead to a increases in NOx emissions [21].

Atul Dhar et,al viewed the Effect of fuel injection pressure and injection timing of Karanja biodiesel blends on fuel spray that report the NOx in lows rate at the vary fuel injection pressure from 300 to 1000 bar [25].

5.2.4. Particulate matter (PM)

Avinash Kumar, Agarwal et, al. studied the Effect of fuel injection pressure and injection timing on spray characteristics fuelled in common rail direct injection diesel engine test fuel helped in reducing particulate emissions by varying injection timings [23].

Similar trend of PM level fall with higher IP was observed by Labecki et al. [20]

5.2.5. Smoke

Deep et al. investigated the effects of injection pressure at 300 bar and reported that NOx emission level was found to be favourable [17].

L. Labecki , L.C. Ganippa experimented the Effects Of Injection Parameters and EGR on Combustion And Emission Characteristics Of Rapeseed Oil And Its Blends In Diesel Engines, smoke increased retarding with the fuel pressure from 800 to 1200 bar [20].

Table.No: 5.2 Effects of injection pressure variation on emission indicators.

Ref. no	CO	HC	NOx	PM	Smoke
17	⇩	⇩	Found to be favourable	NM	Found to be favourable
20	⇩	⇧	⇩	⇧	⇧
21	⇧	⇩	⇧	NM	NM
23	NM	NM	NM	⇩	NM
25	⇩	⇩	⇩	NM	NM

6. CONCLUSION

Most of the authors reported that the advancement in injection timing resulted in the reduction of carbon monoxide, hydro-carbon, particulate matter, smoke and carbon dioxide. In the meantime the oxides of nitrogen show augmentation at advanced fuel injection timing. Contradictory results were reported for injection timing retardation. Many authors concluded that the increase in fuel injection pressure resulted in reduction of carbon monoxide, hydrocarbon, particulate matter, smoke and oxides of nitrogen. Meanwhile Carbon dioxide emission increased for higher injection pressure conditions. For decreased injection pressure, the emission parameters were not varied extensively. This review paper would help to modify the injection parameter by focusing on the required output in combustion parameters.

LIST OF NOMENCLATURE

HC	Unburnt Hydrocarbons
CO	Carbon monoxide
NOx	Oxides of Nitrogen
PM	Particule Matter
rpm	Revolution per minute
SOC	Start of Combustion
TDC	Top dead centre
BTDC	Before top dead centre
ATDC	After top dead center

IT	Injection timing
IP	Injection Pressure
ID	Ignition delay
⇩	Decreases
⇧	Increase
NM	Not Mention

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