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### EFFECT OF INJECTION PRESSURE ON PERFORMANCE AND EMISSION OF DIESEL HYDROGEN OPERATED C.I ENGINE

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#### ABSTRACT

The use of alternative fuels for diesel engine has received renewed attention during the last decade. In recent years many countries are used diesel engine as a power source for different purpose like generating electricity, agriculture and transportation. These engines consumes heavy quantity of fuel, where these engines produce bulk power as well as there also produces the different types of toxic emissions that harmful to the living beings and environment. The best method of tackling these problems are by using gaseous hydrogen fuel inducted in the intake manifold along with air. In this experimental investigation, the hydrogen was inducted into the intake manifold along with air, while diesel was injected directly inside the cylinder. The fuel injection pressure is one of the most important factors controlling the combustion process, engine performance and engine emission. In this study, a Direct Injection (DI) diesel engine was tested with dual-fuel (hydrogen-diesel) mode operation with various injection pressures (180bar, 200bar, 220bar). The performance and emission characteristics was evaluated and compared with neat diesel operations. Experiments are carried out on a diesel engine with hydrogen inducted into the intake manifold along with air and diesel was injected directly inside the cylinder. The hydrogen flow rate was kept constant at 20 LPM and engine was run for different load conditions with constant speed of 1500 rpm. The fuel injection pressure was set for 180bar, 200bar, 220bar and the engine performance, emission and combustion parameters are evaluated. The supply pressure of hydrogen gas to the engine was reduced to 2 bar from 120 bar by using pressure regulator. Performance parameters such as brake specific fuel consumption and brake thermal efficiency are calculated based on experimental results of the engine. Emissions such as carbon monoxide (CO), oxides of nitrogen (NO<sub>x</sub>) and Unburned Hydrocarbons (UHC) are measured. It is found that maximum brake thermal efficiency obtained with 20LPM hydrogen enrichment of injection pressure 180bar, 200bar, 220bar are 30.15%, 27.62%, 26.59%. The BSFC decreased for injection pressure of 180bar compared to diesel and other injection pressures. In this experiment it was observed that the HC, CO and NO<sub>x</sub> emissions are decreased for 180bar injection pressure compared to diesel and other injection pressure namely 200bar and 220bar. But the cylinder pressure and heat release rate are lower for diesel, compared to other injection pressures.

**Keywords:** Diesel engine, hydrogen fuel, injection pressure, performance and emissions.

#### 1. INTRODUCTION

Both the development of global economy and the improvement of human society are based on the development of vehicles in this on-wheeler. Vehicles can bring the goods and passengers to any where they should to and want to go; at the sametime, vehicles also can release the exhaust pollutants to anywhere they can and cannot arrive. The conventional vehicles' operation is mainly depending on the combustion of the hydrocarbon fuels within the cylinder, and the combustion of hydrocarbon fuels will produce amount of air emissions, such as carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), Oxides of nitrogen (NO), oxides of sulphur (SO), unburned / partially burned hydrocarbon (UBHC), smoke and particulate matter (PM), and other toxic metals. Those emissions can cause many environmental problems and then pose dangers to the earth and the humanity. But the environment deterioration, the sky rocketing growth of the vehicle population accelerates the depletion velocity of the fossil energy sources and then weakens the global economy deadly.

The gigantic issues on energy depletion and environment deterioration rought by the vehicle industry are more remarkable in India, and they already have been the obstacles of the sustainable development. The current way of meeting the world's energy consumption relies primarily on fossil fuel. While fossil fuel is being depleted, there is an urgent need to carry out research and develop viable alternative fuels as a substitute for petroleum based fuels to meet the increasing energy demand with the minimum environmental and economical impact, thereby reducing the reliance on crude oil derived fuels. Among the various alternative fuels being studied, hydrogen is often recognized as a promising option put forward by the governments for a sustainable energy system. Being considered as a carbon free fuel, hydrogen has a few advantages over other alternative fuels,



## International Journal of Engineering Researches and Management Studies

forexample, it results in less fuel- based particular matter (PM), hydrocarbon (HC), carbonmonoxide(CO) and carbondioxide(CO) emissions. There are also some other positive features documented in the literatures such as low ignition energy, wide flammability range, and high burning velocity. These unique combustion characteristics of hydrogen have made it very suitable for ultra- lean and low temperature combustion operations in internal combustion (IC) engines with near zero engine out emissions.

### 2. OBJECTIVES

- ♦ To develop the dual fuel (diesel – hydrogen) CI engine.
- ♦ To conduct the base line test with diesel fuel.
- ♦ To conduct the test with diesel- hydrogen fuel with various injection pressure and compare the performance, combustion and emission with base line reading.

### 3. METHODOLOGY

- Selection of the test engine
- Modification of inlet manifold
- Conducting experiments with the standard diesel fuel
- Installation of the hydrogen supply line with suitable safety devices and a flow meter.
- Conduct experiments with various injection pressure (180bar, 200bar, 220bar).
- Induct the hydrogen slowly through inlet manifold by flow rate of 20LPM as constant for all the injection pressure.
- Measure the fuel flow rate, exhaust gas temperature and emission.
- Measurement of cylinder pressure and heat release rate.
- Comparing the experimental results obtained by duel fuel mode and neat diesel operation.
- To be arrived the conclusion from the observed reading.

### 4. EXPERIMENTAL INVESTIGATION

Experiments were conducted in a single cylinder, four stroke, water-cooled, diesel engine (Make: Kirloskar AV-1). The engine was coupled to an eddy current dynamometer. The engine was run at a constant speed of 1500 rpm. The specifications of the engine used are given in Table 4.1.

*Table 4.1 Specification of the Engine*

Engine make	Kirloskar AV-1
Type	Vertical, single cylinder, water cooled
Max. power	3.7 kW at 1500 r/min
Displacement	550 CC
Bore × Stroke	80 × 110 mm
Compression ratio	16.5:1
Fuel injection timing	23° bTDC

#### Experimental Setup and Procedure

A crank angle encoder was fitted to the crank shaft to measure the crank angle. The cylinder pressure was measured by a piezoelectric pressure transducer (Make: Kirloskar, Type 6056A) mounted on the cylinder head. The pressure signal was sent to data acquisition system and combustion data like cylinder pressure and heat release rate (HRR) were obtained. The oxides of nitrogen (NO<sub>x</sub>), carbon monoxide (CO) and hydrocarbon (HC) emissions were measured with non-dispersive infrared analyzers (NDIR) (Make: HORIBA-Japan). The gas analyzers were calibrated with standard gases before test. Initially, the engine was operated with neat diesel fuel to obtain reference data. Further, the engine was tested with dual fuel mode like addition of hydrogen with inlet air in addition to pilot diesel injection. The hydrogen gas was inducted in the inlet manifold in flow rate 20 LPM of injection timing 23°bTDC and for various injection pressure 180bar,200bar,220bar respectively. The hydrogen flow line consists of hydrogen cylinder, pressure regulator, flame arrester, flow meter and flow control valve shown in figure 4.1.



*Fig. 4.1 Experimental Setup with Hydrogen Flow line*

The pressure of hydrogen stored in a high-pressure storage tank was reduced from 250 bar to a pressure 2 bar using a pressure regulator. Hydrogen was then passed through a flame arrestor and flame trap which arrest any backfire of the engine. It also acts as a non-return valve. Then the hydrogen is passed through the digital gas flow meter, of range 20 LPM. The combustion, performance and emission characteristics were evaluated for 20Lpm hydrogen flow rate of various injection pressures and compared with neat diesel fuel operation.

#### **Devices Installed for Hydrogen Admission**

##### ***Hydrogen Cylinder***

Hydrogen is stored in a cylinder at a pressure of about 140bar. This pressure is reduced to a pressure of 2 bar using a pressure regulator. The figure 4.2 shows the photographic view of hydrogen cylinder.

##### ***Flame Arrestor***

Flame arrestors are used as a safety device:

1. To stop the spread of an open fire
2. To limit the spread of an explosive event that has occurred
3. To protected potentially explosive mixtures from igniting
4. To confine fire within an enclosed, controlled, or regulated location



*Fig 4.2 Photographic view of Hydrogen cylinder*

Two types of flame arrestor are used in this experiment setup. They are:

- a. Water-based flame arrestor.
- b. Air-based flame arrestor.

***Water- based flame arrestor***

In this device water is used to arrestor flame formation in the hydrogen supply line. In this device, the hydrogen enters into it through  $\frac{1}{4}$ " tube and this tube is immersed in the water. This device is a cylindrical shaped container with  $\frac{3}{4}$  of it filled with water. The outlet is taken from the top of the container and is allowed into the next device which is known as air-based flame arrestor. This device arrestor flame formation by cooling It using water. The water in the closed cylindrical container removes the heat from the hydrogen flow and cools it. By removing the heat in the hydrogen gas flow it arrests flame formation. The photographic view of the water-based flame arrestor is shown in the Figure 4.3.



Fig 4.3 Photographic view of water-based flame arrestor

### 5. RESULTS AND DISCUSSION

Performance analysis, Emission analysis and Combustion analysis are carried out in the results and discussion.

#### Performance Analysis

##### Brake Thermal Efficiency

Figure 5.1 shows the variation in the brake thermal efficiency (BTE) with brake power for different fuel injection pressure. The 20 LPM hydrogen addition and injection pressure of 180bar given a brake thermal efficiency of 30.15% compared to diesel 24.79% at full load. The results showed that brake thermal efficiency decreased for further increasing of injection pressure namely 200 and 220bar. Hence in higher injection pressure the wall wetting taking place and hence no perfect mixing of air and diesel in combustion chamber. This is the reason for reduction of BTE for 200 and 220bar injection pressure compared to 180bar injection pressure

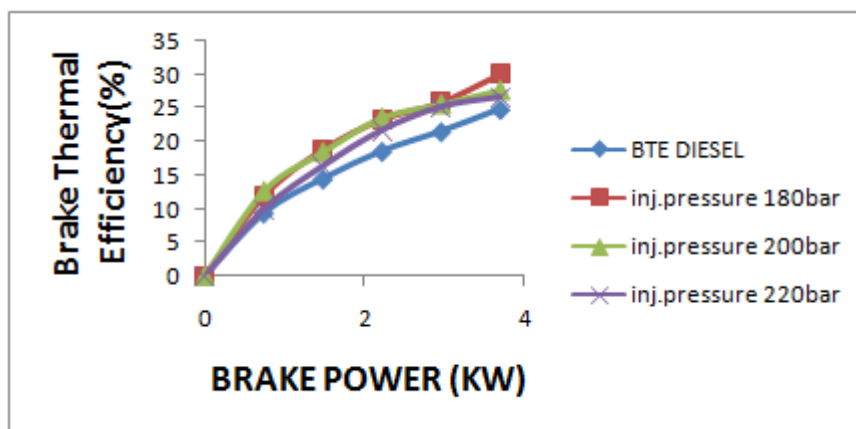


Fig 5.1 Brake Power vs. Brake Thermal Efficiency



# International Journal of Engineering Researches and Management Studies

## Brake Specific fuel consumption

Figure 5.2 shows the variation in the brake specific fuel consumption (BSFC) with brake power for different fuel injection pressure. The 20LPM hydrogen addition and injection pressure of 180bar given a brake specific fuel consumption of 0.263kg/kwhr compared to diesel 0.324kg/kwhr at full load. The results showed that brake specific fuel consumption increased for further increasing of injection pressure namely 200 and 220bar. Hence in higher injection pressure the wall wetting taking place and hence no perfect mixing of air and diesel in combustion chamber. The brake specific fuel consumption for all the three injection pressure 180bar, 200bar and 220bar are decreased compared to diesel.

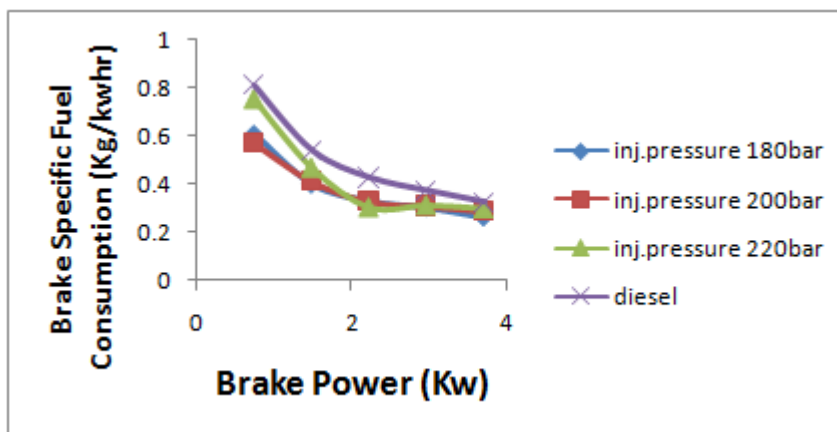


Fig 5.2 Brake Power vs. BSFC

## Emission Analysis

Nitrogen Oxides (NOx) Emission: Figure 5.3 shows the variation of nitrogen oxides (NOx) emission with brake power. The NOx formation occurs at peak combustion temperature and higher oxygen concentrations. NOx formation is lower with 20Lpm and injection pressure 200 and 220 bar compared to neat diesel and 180 bar injection pressure. The reason for reduction of NOx emission is due non uniform mixture of fuel and air in higher injection pressure.

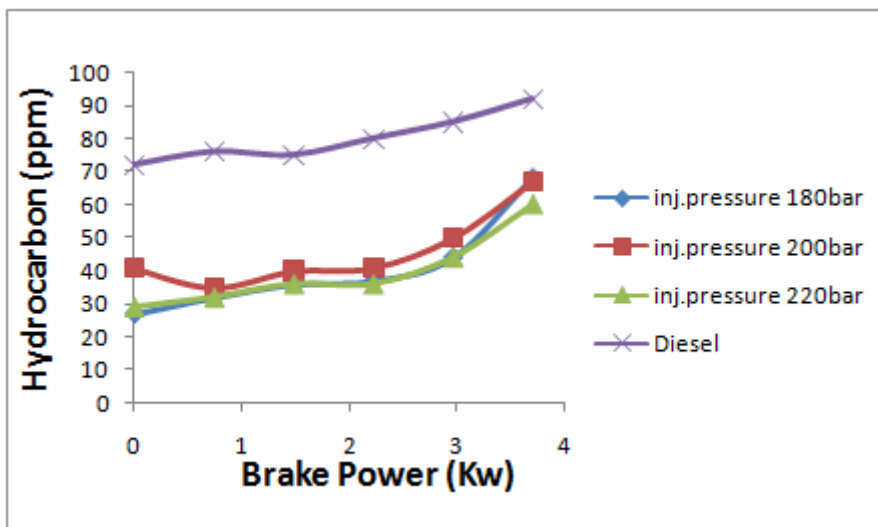


Fig 5.3 Brake Power vs. NOx Emission

## Hydrocarbon (HC) Emission

Generally the unburned hydrocarbon emission decreases with all fuel injection pressure with hydrogen addition, compared to neat diesel operation. The absence of carbon in hydrogen fuel reduces HC emission to a



## International Journal of Engineering Researches and Management Studies

greater extent. The variation of HC emissions with Brake power for different fuel injection pressure is shown in Figure 5.4. The injection pressure 180bar resulted in lower HC emission, compared to other fuel injection pressure. This is because of complete air mixture taking place in 180 bar injection pressure.

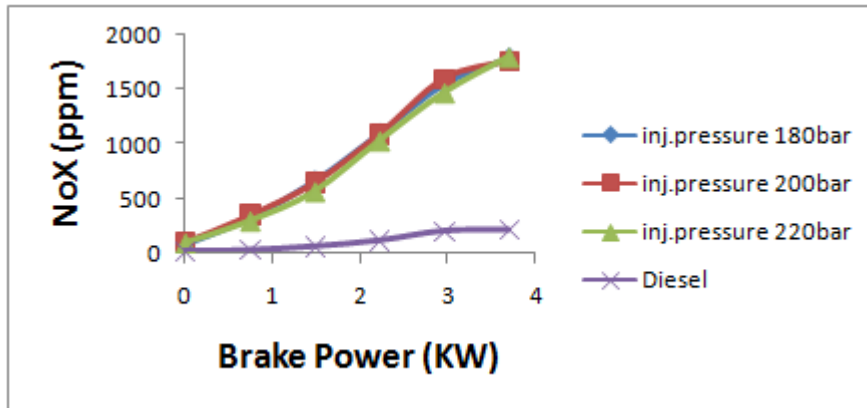


Fig 5.4 Brake Power vs. HC Emission

### Exhaust gas temperature

The variation of exhaust gas temperature (EGT) with brake power for different fuel injection pressure is shown in Figure 5.5. It is observed that exhaust gas temperature for 20LPM H<sub>2</sub> and 200bar diesel fuel injection increased averagely compared to neat diesel and other fuel injection pressure at full load. The highest exhaust temperature for with 200bar fuel injection pressure and neat diesel are 437°C and 421°C respectively. This is due to better mixing of H<sub>2</sub> with air resulting in complete combustion of fuel with the increase in temperature around combustion chamber. The late combustion of fuel air mixture in exhaust pipe also reason for increase in exhaust gas temperature.

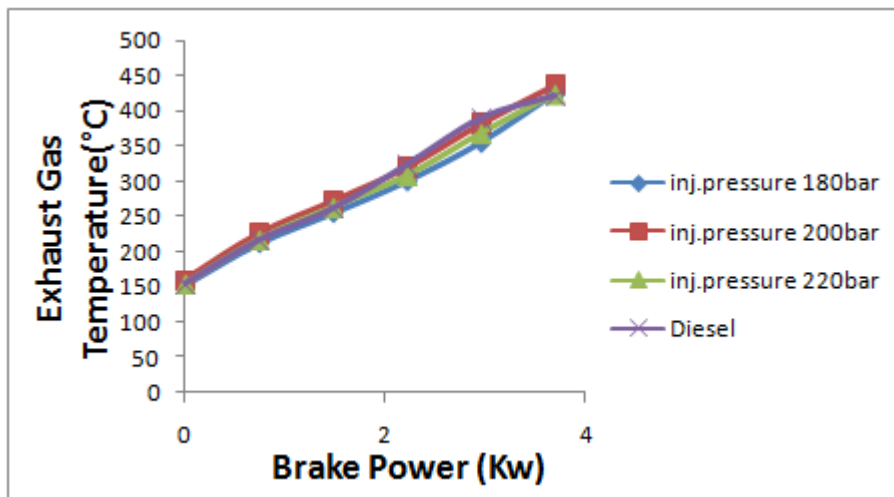


Fig 5.5 Brake Power vs. EGT

### Carbon monoxide emission

The variation of carbon monoxide with engine brake power and different fuel injection pressure are shown in Figure 5.6. With 20 LPM and 200 bar fuel injection pressure the CO emission is lower than other fuel injection pressure and neat diesel operation at full load. But in part load condition the CO emission level for 180 bar injection pressure is low compared to other injection pressure. This is due to rich fuel accumulation in full load condition. The reduction CO in hydrogen operated dual fuel engine is due to the absence of carbon in hydrogen fuel. At no load since the engine is operated at lean equivalence ratio, a reduction in CO is observed for



## International Journal of Engineering Researches and Management Studies

hydrogen dual fuel operation. But the oxygen concentration reduces significantly and in addition due to lesser reaction time it results in a significant increase in CO formation rate that makes the overall CO concentration to increase at full load compared.

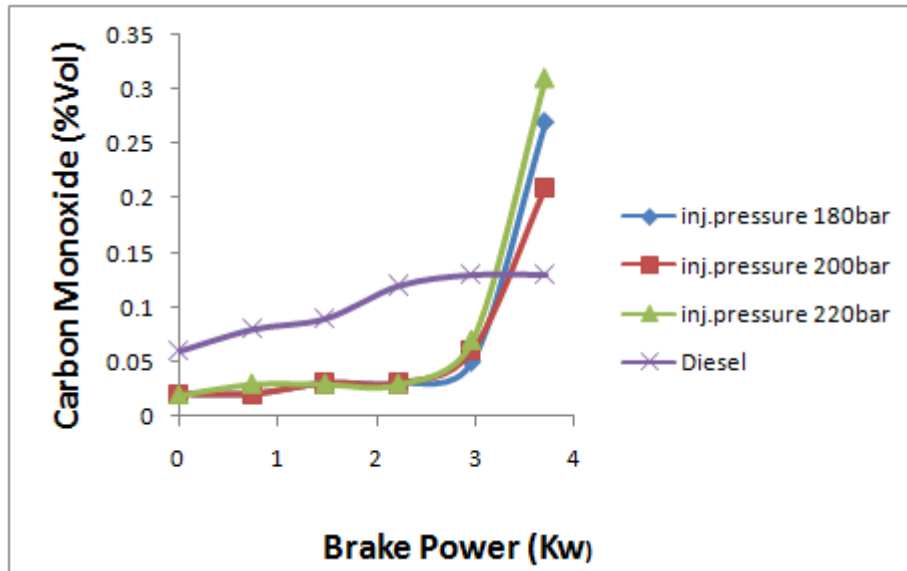


Fig 5.6 Brake Power vs. CO Emission

### Combustion Analysis

#### Cylinder pressure

Figure 5.7 shows the variation of cylinder pressure with crank angle. It is observed that the cylinder pressure decreased for diesel fuel operation compared to 20LPM with different fuel injection pressure at full load. The peak pressure for diesel and 180bar fuel injection pressure are 59.85bar and 64.88 bar respectively. The reason for increase in peak pressure for hydrogen added diesel fuel operation is due to better premixed combustion, compared to other fuel injection pressure with 20 Lpm hydrogen additions. The peak pressure for other fuel injection pressure is almost same.

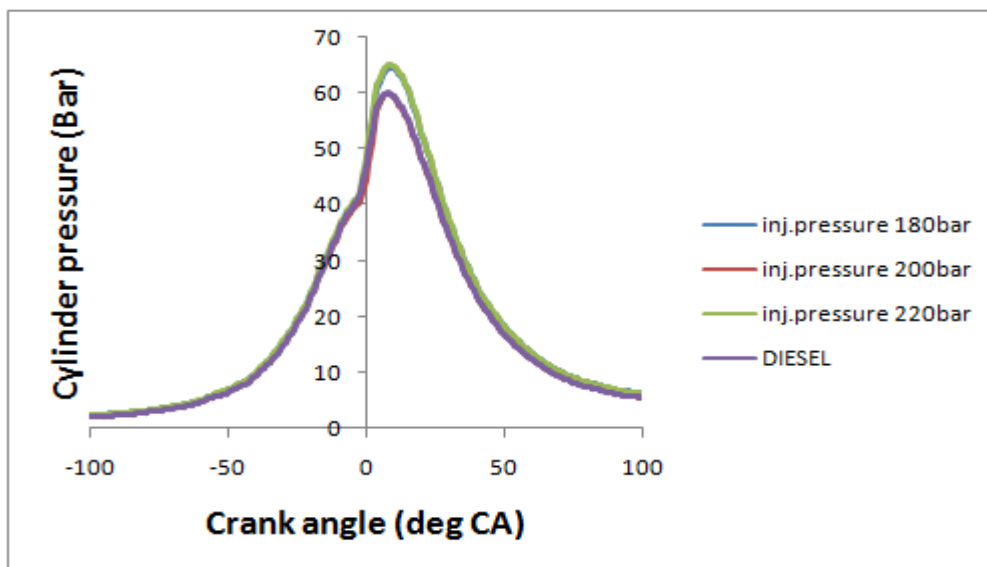


Fig 5.7 Comparison of Crank angle vs. Cylinder pressure





## International Journal of Engineering Researches and Management Studies

### Heat Release Rate

Figure 5.8 shows the variation of heat release rate (HRR) diesel and 20LPM hydrogen enrichment with different injection pressure at full load. It is observed that the heat release rate increase for hydrogen added diesel fuel operation compared to diesel at full load. The HRR for diesel and 180bar fuel injection pressure are 38.66J/deg CA and 48.64 J/deg CA respectively. The reason for increase in heat release rate for hydrogen added diesel fuel operation is due to better premixed combustion, compared to other fuel injection pressure with 20 LPM hydrogen addition. The reduced heat release rate for fuel injection pressure (200bar) is due to late diffused combustion of fuel air mixture.

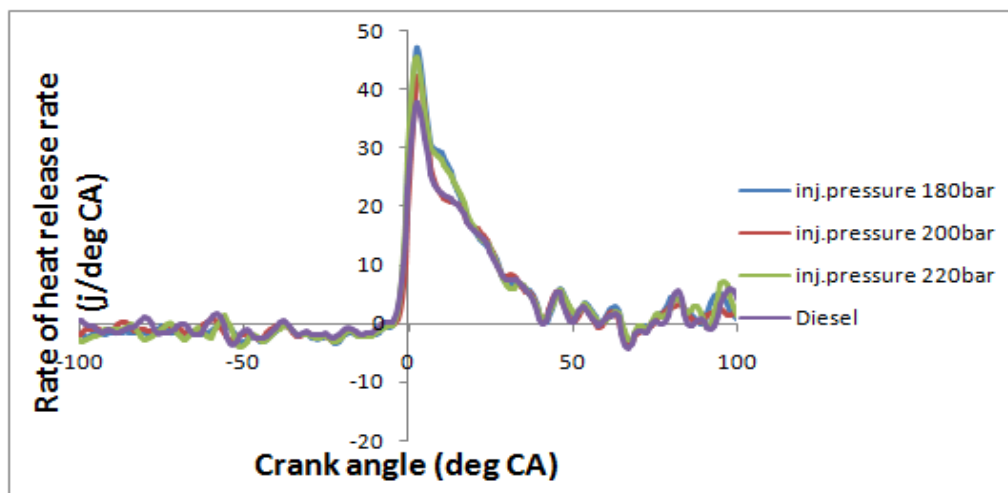


Fig 5.8 Comparison of Crank angle vs. Heat Release Rate

## 6. CONCLUSIONS

Based on the experimental results for the single cylinder direct injection diesel engine with different injection pressure (180 bar, 200 bar, 220 bar) and addition of hydrogen enrichments as 20 LPM (constant), the following conclusions are drawn:

- ★ The brake thermal efficiency of diesel engine of injection pressure 180bar with 20 LPM hydrogen enrichment is increased compared to neat diesel and other injection pressure.
- ★ The BSFC decreased for fuel injection pressure of 180bar compared to diesel and other injection pressures.
- ★ The exhaust gas temperature for injection pressure of 200bar is higher with 20 LPM hydrogen addition, compared to neat diesel operation and other injection pressure.
- ★ The HC, NOx and CO emission decreased for injection pressure of 180 bar with 20LPM hydrogen addition compared to neat diesel operation and other injection pressure.
- ★ The cylinder pressure and heat release rate increased for 180 bar injection pressure with 20 LPM hydrogen addition, compared to other operation.

Finally, it is concluded that out of all the three injection pressure (180bar, 200bar, 220bar) with 20 LPM hydrogen induction proved that the injection pressure of 180bar is best operation for low exhaust emission and higher brake thermal efficiency.

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