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Research Article

Performance and Analysis of Diesel Engine at Various Injection Timings under various Cooling Rates during Shorter Injection Period

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Abstract

An experimental investigation was carried out to find out the effect of injection timing on performance and emissions of a single cylinder, 4 stroke, and compression ignition engine at various cooling rates. Original injection period of the engine was 24o CA and injection starts at 14o CA BTDC, injection timings were reduced to 22o and 20o CA by delaying the starting of injection at 12o and 10o CA BTDC. Several experimental cycles were conducted at various loads i.e., at 0.5, 1, 1.5, 2, 2.5, 3KW load at cooling rates of 3, 4, 6lpm of engine water cooling rate. Emissions such as NOx, CO, CO2, UHC and unreacted oxygen were measured by using multi gas exhaust analyzer.

Keywords: *Injection timing, cooling rate etc.*

Introduction

Cooling rate is an important parameter that can govern performance and emissions of an engine. Increased cooling rate reduces the peak temperatures inside the engine and hence reduce NOx. Increase in cooling rate decreases NO_x but increases UHC and CO. Increasing of cooling rate decreased NO_x emissions relatively at all loads. This is due to the excess cooling rate bring down the peak temperatures and there by decreasing NO_x emissions. Increased cooling rates has increased the HC formation due to reduced engine temperature result in improper or reduced burning potency of the hydro carbons which is left as emission .When compared the results to those of original injection timing, NO_x and CO_2 emissions decreased, smoke opacity, UHC and CO emissions increased for the retarded injection timing (15 °CA BTDC). On the other hand, with the advanced injection timing (25 °CA BTDC), decreasing smoke opacity, UHC and CO emissions diminished, and NO_x and CO_2emissions boosted at all test conditions. In terms of Bsfc and BTE, retarded and advanced injection timings gave negative results for all fuel injection timings in all engine. The experimental test results showed that NO_x and CO_2 emissions increased as CO and HC emissions decreased with increasing amount of ethanol in the fuel mixture. When compared to the results of original injection timing, at the retarded injection timings (21° and 24° CA BTDC), NO_x and CO_2 emissions increased, and unburned HC and CO emissions decreased for all test conditions. On the other hand, with the advanced injection timings (30° and 33° CA BTDC), HC and CO emissions diminished, and NO_x and CO_2 emissions boosted for all test conditions .Experimental results proved that the 3° advancement of injection timing from the standard injection timing proved promising outcomes for biodiesel operated engine, whereas 5° BTDC crank angle degree produced a higher exhaust gas temperature and higher levels of NO_x formation.To Minimize HC, CO, NO_x and soot emissions, SOI timing must be carefully adjusted within a limited range. With the retarded IVC timing, the operating range of SOI becomes wider for clean combustion. The IVC timing should be optimized with consideration of ignition timing and combustion efficiency at different SOI timing in order to improve fuel economy. For purpose of avoiding engine knock, the SOI timing around −20 °CA ATDC and early IVC timing are pursued.(Cenk Sayin et al, 2009; B Lakshmana Swamy et al, 2013; . Cenk Sayin et al, 2008; A. Ming Jia et al 2011).

In overall experiment efforts were made to reduce emissions which cause air pollution with less ditoriation in performance of engine. Air pollution is a serious problem now a days. Air pollution is referred addition harmful foreign particles or additives to the atmospheric air. The most of air pollution to the atmospheric is contributed by automobile engine emissions. The main emissions from the auto motive engine are oxides of nitrogen, oxides of sulphur, carbon dioxide, carbon monoxide, suspended or particulate matter, unused oxygen, and un burnt hydro carbons. Each of these pollutants has their own evil effect on the environment. Hence many efforts are made and many researchers have been conducting to reduce these emissions without effecting the performance of the engine.

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Cooling rate of an IC engine has an adverse effect on emission and performance of the engine. An optimum cooling rate of an engine can attain reduced emissions and increased performance. Ki-Hyung Lee *et al* in his journal Investigation of emission characteristics affected by new cooling system in a diesel engine concluded that At partial load conditions of NEDC drive cycle, HC and CO were reduced by approximately 10 % and 4%, respectively. In the case of decreasing coolant flow, HC and CO were reduced down to 20% during NEDC drive cycle(Kyung-Wook Choi et al, 2009).

Mechanism of Formation of Pollutant

A. Mechanism of formation of Carbon Monoxide (CO)

Carbon monoxide is a colourless poisonous gas. Small amounts of CO concentrations, when breathed in, slow down physical and mental activity and produces headaches, while large concentration will kill. CO is generally formed when the mixture is rich in fuel. The amount of CO formation increases as the mixture becomes more and more rich in fuel. A small amount of CO will come out of the exhaust even when the mixture is slightly lean in fuel because air- fuel mixture is not homogenous and equilibrium is not established when the products pass to the exhaust. At the high temperature developed during the combustion, the products formed are unstable and following reactions take place before the equilibrium is established.

$2C+O_2 = 2CO$

As the products cool down to exhaust temperature, major part of CO reacts with oxygen to form CO_2. However, a relatively small amount of CO will remain in exhaust.

B. Mechanism of formation of Hydrocarbons (HC)

Hydrocarbons, derived from unburnt fuel emitted by exhausts, engine crankcase fumes and vapour escaping from the carburetor are also harmful to health. Hydrocarbons appears in exhaust gas due to local rich mixture pockets at much lower temperature than the combustion chamber and due to flame quenching near the metallic walls. A significant of this unburnt HC may burn during expansion and exhaust strokes if oxygen concentration and exhaust temperature is suitable for complete oxidation. C. Mechanism of formation of nitric oxide (NO) of nitrogen is produced in very small quantities can cause pollution. While prolonged exposure of oxides of nitrogen is dangerous to health. Oxides of nitrogen which occurs only in the engine exhaust are a combination of nitric oxide (NO) and nitrogen dioxide (NO_2). Nitrogen and oxygen react at relatively high temperature. NO is formed inside the combustion chamber in post-flame combustion process in the high temperature region. The high peak combustion temperature and availability of oxygen are the main reasons for the formation of NOx. In the present of oxygen inside the combustion chamber at high combustion temperatures the following chemical reactions will takes place behind the flame (.B Lakshmana Swamy et al, 2013).

$N_2+O_2 = 2NO$

$N_2+2H_2O = 2NO+H_2$

Calculation of chemical equilibrium shows that a significant amount of NO will be formed at the end of combustion. The majority of NO formed will however decompose at the low temperatures of exhaust. But, due to very low reaction rate at the exhaust temperature, a part of NO formed remains in exhaust. The NO formation will be less in rich mixtures than in lean mixtures .The concentration of oxides of nitrogen in the exhaust is closely related peak combustion temperature inside the combustion chamber.

Control of Oxides of Nitrogen (Nox)

Many theoretical and experimental investigation shows that the concentration of NOx in the exhaust gas is closely related to the peak cycle temperature and available amount of oxygen in the combustion chamber. Any process to reduce cylinder peak temperature and concentration of oxygen will reduce the oxides of nitrogen. This suggests a number of methods for reducing the level of nitrogen oxides. Among these the dilution of fuel-air mixture entering the engine cylinder with an inert or non-combustible substance is one which absorbs a portion energy released during the combustion, thereby affecting an overall reduction in the combustion temperature and consequently in the NOx emission level. The following are the three methods for reducing peak cycle temperature and thereby reducing NOx emission.

1. Water injection.
2. Catalyst
3. Exhaust gas recirculation (EGR)

A. Water injection

Nitrogen oxides NOx reduction is a function of water injection rate. NOx emission reduces with increase in water injection rate per kg of fuel. The specific fuel consumption decreases a few percent at medium water injection rate. The water injection system isused as a device for controlling the NOx emission from the engine exhaust.

B. Catalyst

A copper catalyst has been used to reduce the NOx emission from engine in the presence of CO. Catalytic converter package is use to control the emission levels of various pollutants by changing the chemical characteristics of the exhaust gases. Catalyst materials such as platinum and palladium are applied to a ceramic support which has been treated with an aluminium oxide wash coat. This results in as extremely porous structure providing a large surface area to stimulate the combination of oxygen with HC and CO. This oxidation process converts most of these compounds to water vapour and carbon dioxide.

C. Exhaust gas recirculation (EGR)

EGR is commonly used to reduce NOx in S.I. engines as well as C.I. engines. The principle of EGR is to recirculate about 10% to 30% of the exhaust gases back into the inlet manifold where it mixes with the fresh air and this will reduces the quantity of O2 available for combustion . This reduces the O2 concentration and dilutes the intake charge, and reduces the peak combustion temperature inside the combustion chamber which will simultaneously reduce the NOx formation. About 15% recycle of exhaust gas will reduce NOx emission by about 80%. It should be noted that most of the NOx emission occurs during lean mixture limits when exhaust gas recirculation is least effective. The exhaust gas which is sent into the combustion chamber has to be cooled so that the volumetric efficiency of the engine can be increased. EGR ratio is defined as the ratio of mass of recycled gases to the mass of engine intake. Also %EGR is From above three methods, EGR is the most efficient and widely used system to control the formation of oxides of nitrogen inside the combustion chamber of I.C. engine. The exhaust gas for recirculation is taken through an orifice and passed through control valves for regulation of the quantity of recirculation . Normally exhaust gas recirculation is shut off during idle to prevent rough engine operation

Experimental procedure

Series of several experimental cycles were conducted with varying conditions of cooling rates and iterations were done with varying injection timings number and the results were compared.

The exhaust gas analyzer used is MN-05 multi gas analyzer(4 gas version) is based on infrared spectroscopy technology with signal inputs from an electrochemical cell. Non-dispersive infrared measurement techniques were used for CO, CO2, and HC gases. Each individual gas absorbs infrared radiation absorbed can be used to calculate the concentration of sample gas. Analyzer uses an electrochemical cell to measure oxygen concentration. It consists of two electrodes separated by an electrically conducted liquid or cell. The cell is mounted behind a polytetra fluorethene membrane through which oxygen can diffuse. The Device therefore measures oxygen partial pressure. If a polarizing voltage is applied between the electrodes the resultant current is proportional to the oxygen partial pressure.

The engine used in the present study is a Kirloskar AV-1, single cylinder direct injection ,Water cooled diesel engine with the specifications given in Table 1. Diesel injected with a nozzle hole of size 0.15mm.the engine is coupled to a dc dynamometer. Engine exhaust emission is measured. Load was varied from 0.5 kilo watt to 3 kilo watts. The amount of exhaust gas sent to the inlet of the engine is varied. At each cycle, the engine was operated at varying load and the efficiency of the engine has been calculated simultaneously. The experiment is carried out by keeping the compression ratio constant i.e., 16.09:1.

Table of engine specifications

Table: 1 specifications of engine

Type	Four- stroke, single cylinder, Compression ignition engine, with variable compression ratio.
Make	Kirloskar AV-1
Rated power	3.7 KW, 1500 RPM
Bore and stroke	80mm×110mm
Compression ratio	16.09:1, variable from 13.51 to 19.69
Cylinder capacity	553cc
Dynamometer	Electrical-AC Alternator
Orifice diameter	20 mm
Fuel	Diesel
Calorimeter	Exhaust gar calorimeter
Cooling	Water cooled engine
Starting	Hand cranking and auto start also provided

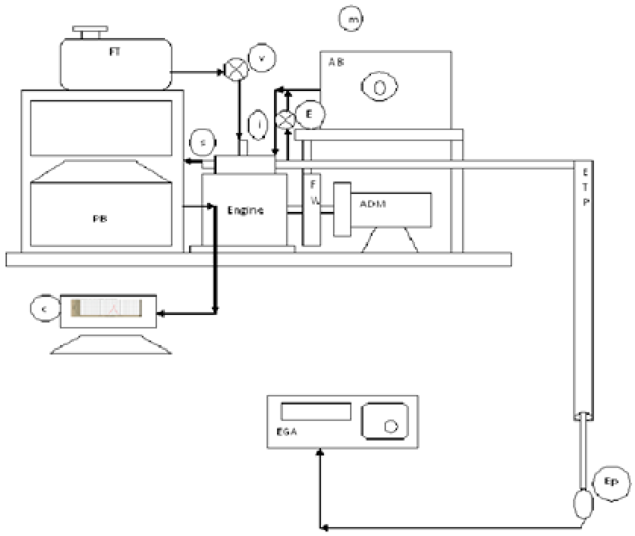

Fig: 1 block diagram of experimental set up

Parts: AB-air box ,m- measurement of air by mano meter , Fw-fly wheel, ADM-alternator dynamometer, i-fuel injector,C-computer for P-θ interface,v-valve for fuel control, EGA-exhaust gas analyser, s-piezo electric sensor for p-θ interfacing,PB- panel board, EP-exhaust gas probe, FT-fuel tank

Nomenclature

Table 2: Nomenclature

NO_X	Oxides of nitrogen
CO	Carbon monoxide
CO_2	Carbon dioxide
HC	Unburnt hydro carbons
PPM	Parts per million
CR	Cooling rate in LPM
%vol	Percentage of volume
BTDC	Before Top Dead Centre
CA	Crank Angle

Brake thermal efficiency

From the graph below it is clear that injection timing 22° BTDC at cooling rate 6LPM has shown highest performance at all the loads whereas 24° BTDC has shown a least performance which is to 41% of the performance of pure diesel at 3LPM. Chart1 shows the comparative data of all the brake thermal efficiencies. To have some clear picture on effect of cooling rate on various injection timings chart2 considers the brake thermal efficiency at peak loads.

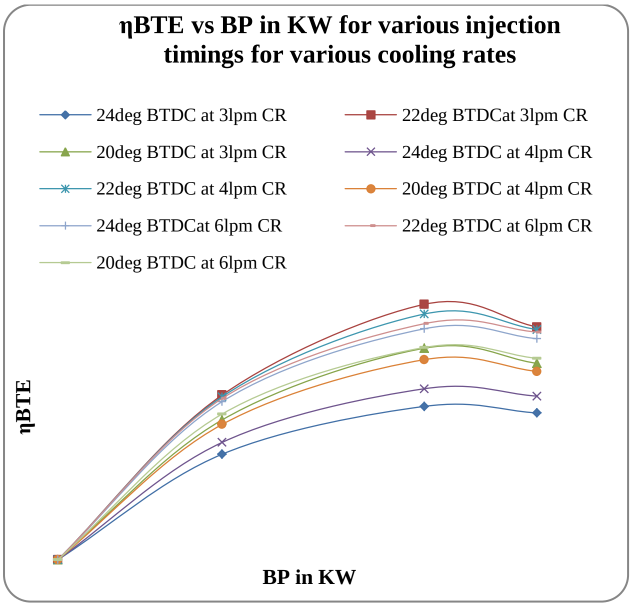

Chart1: ηBTE vs BP in KW for various injection timings for various cooling rates

From chart2 we infer that injection timings 22⁰ & 20° BTDC was performing 10%more than that of the normal injection timing at peak load conditions.

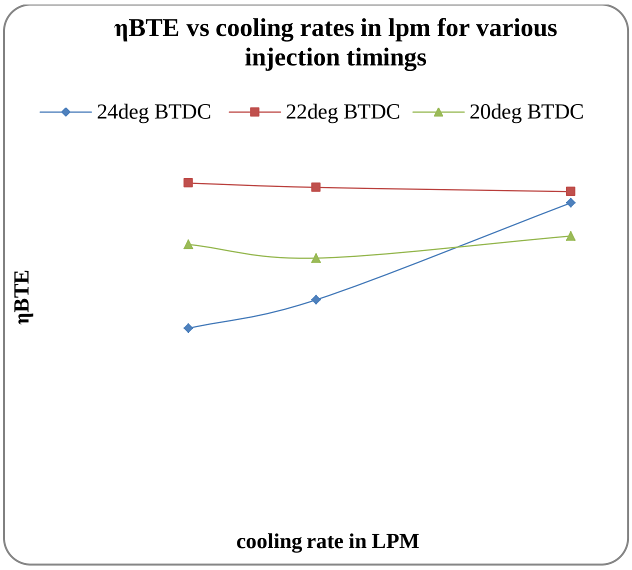

Chart2: ηBTE vs cooling rates in lpm for various injection timings

Volumetric efficiency

Chart3 gives the inference that normal injection timing at 4LPM cooling rate has shown higher volumetric efficiency. Any how the trend of varying volumetric efficiency has stood very general, chart4 gives a clear picture of the effect of cooling rate on volumetric efficiency.

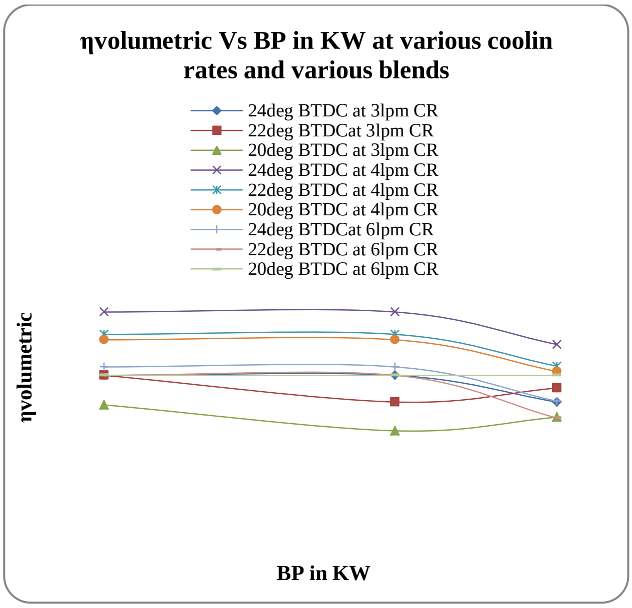

Chart3: ηvolumetric Vs BP in KW at various cooling rates and various injection timings

Chart4 shows that at all cooling rates volumetric efficiencies were not much different with respect to the injection pressure.

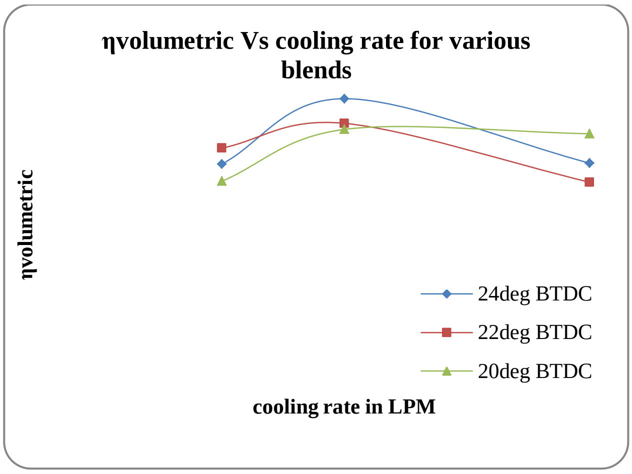

Chart4: ηvolumetric Vs cooling rate for various injection timings

Brake Specific Fuel Consumption

Chart5 shows 22⁰ BTDC at 3LPM shows lowest brake power and normal injection timing showing highest BSFC at 3LPM.

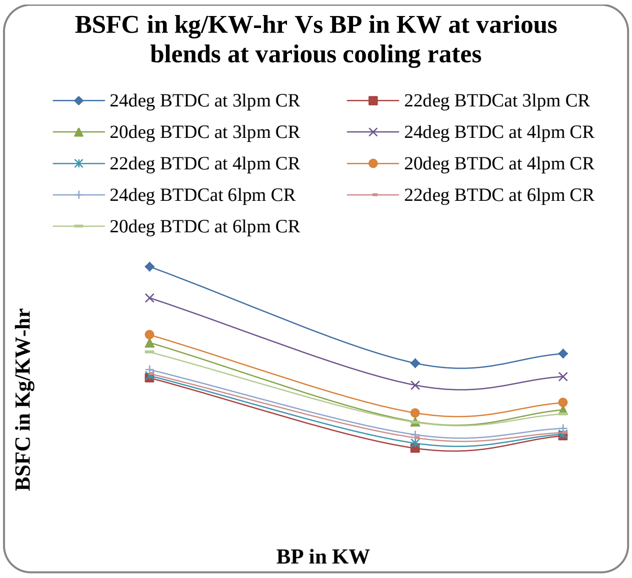

Chart5: BSFC in kg/KW-hr Vs BP in KW at various injection timings at various cooling rates

Taking only the values at peak loads chart6 shows normal injection timing showing BSFC less to that of22^o and 20^o BTDC where they has shown no substantial rise or fall in the BSFC at all the cooling rate.

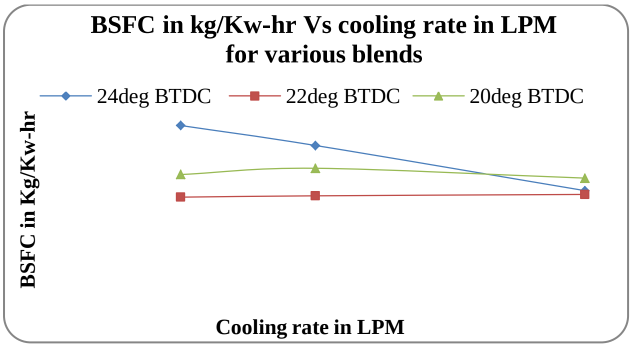

Chart6: BSFC in kg/Kw-hr Vs cooling rate in LPM for various injection timings

Emissions

NO_x emissions

From chart7 we infer that shorter injection timings have

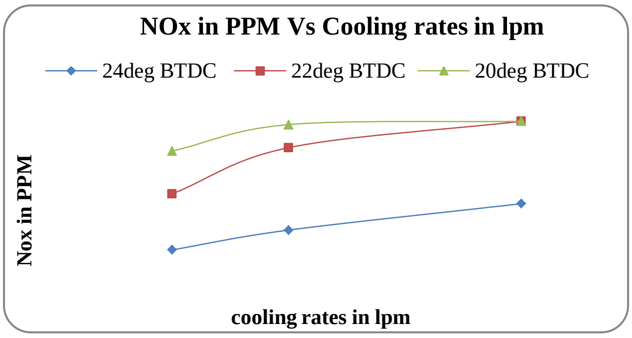

Chart7: NOx in PPM Vs Cooling rates in lpm

increased the tendency of NO_x formation when compared to that of normal injection timing. It was found that there was 18% increase in NO_x due to reduced injection timing.

CO emissions

From chart8 we infer that injection timing 22^o BTDC has shown lowest emissions of CO when compared to that of normal injection timing and 20^0 BTDC.

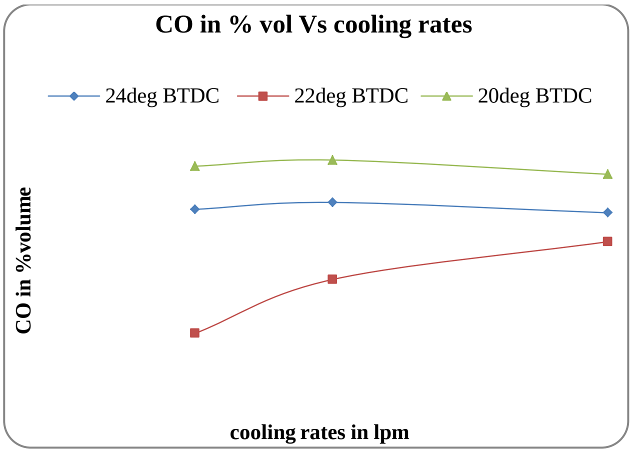

Chart8: CO in % vol Vs cooling rates

HC emissions

From chart9 we infer that 20^{o}BTDC has over all of less HC emissions. Where as, 22^o BTDC was showing 23% less HC emissions compared to that of normal injection timing.

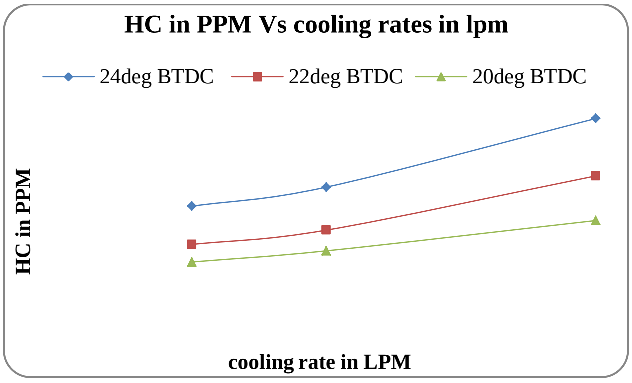

Chart9: HC in PPM Vs cooling rates in lpm

Conclusion

From the above obtained results the following conclusions were drawn

- injection timing 22^o BTDC at cooling rate 6LPM has shown highest performance at all the loads whereas 24^o BTDC has shown a least performance which is to 41% of the performance of pure diesel at 3LPM. Chart1 shows the comparative data of all the brake thermal efficiencies. To have some clear picture on effect of cooling rate on various injection timings chart2 considers the brake thermal efficiency at peak loads. We infer that injection timings 22^0 & 20^o BTDC was performing 10%more than that of the normal injection timing at peak load conditions.

- Normal injection timing at 4LPM cooling rate has shown higher volumetric efficiency. Any how the trend of varying volumetric efficiency has stood very general, chart4 gives a clear picture of the effect of cooling rate on volumetric efficiency.
- 22^0 BTDC at 3LPM shows lowest brake power and normal injection timing showing highest BSFC at 3LPM. Taking only the values at peak loads chart6 shows normal injection timing showing BSFC less to that of22^o and 20^o BTDC where they has shown no substantial rise or fall in the BSFC at all the cooling rate.
- We infer that shorter injection timings have increased the tendency of NO_x formation when compared to that of normal injection timing. It was found that there was 18% increase in NO_x due to reduced injection timing.
- We infer that injection timing 22^o BTDC has shown lowest emissions of CO when compared to that of normal injection timing and 20^0 BTDC.
- We infer that 20^oBTDC has over all of less HC emissions. Whereas, 22^o BTDC was showing 23% less HC emissions compared to that of normal injection timing.

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