Performance and emissions of a glow plug assisted low heat rejection C.I Engine using Ethanol as fuel with Additives

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Abstract: In this present experimental investigation proposal the single cylinder, four strokes 5.2kW Kirloskar, water-cooled DI diesel engine with a bore of 87.5 mm and stroke of 110 mm and a compression ratio of 17:1 isselected for the experimental investigation. The copper crown piston is selected as best among other piston crown and Iso-amyl nitrate considered as best additive and experiments are carried out with Ethanol as fuel. The specific tendency of alcohols to ignite easily from a hot surface makes it suitable to ignite in a diesel engine by different methods. The advantage of this property of alcohols enables to design and construct a new type of engine called surface ignition engine. Ethanol is very susceptible to surface ignition, this method is very suitable for this fuels. The hot surfaces which, can be used in surface ignition engine are electrically heated glow plug with hot surface engine and the further the engine is modified as Low heat rejection (LHR) engine. A Partially stabilized Zirconia is used as a thermal barrier coating to provide as adiabatic engine. Hence the experiments are carried out on the normal engine on the copper piston crown material with additive (Iso amyl nitrate) on GHSI engine and in LHR engine using Ethanol as fuel to determine the performance, emissions and the combustion parameters.

Key word; Ethanol; Iso amyl nitrate; copper crown piston, Glow plug hot surface ignition (GHSI) Engine; low heat rejection (LHR) Engine;

I. INTRODUCTION

Energy is one of the most significant inputs for growth of all sectors including agricultural, industrial services and transport sectors. Energy has been at the centre stage of national & global economic development since several decades. The demand for energy, around the world is increasing exponentially, specifically the demand for petroleum-based energy. Petroleum derived fuels, actually, exceeds the demand of any other fuels or energy resources. The world consumption for petroleum and other liquid fuel will grow from 85 million barrels/day in 2006 to 107 million barrels/day in 2030.Under these growth assumptions, approximately half of the world's total resources would be exhausted by 2030. Also, as per many studies, the world oil production would peak sometime between 2007 and 2030. Therefore, the future energy availability is a serious global concern. Another, major global concern is environmental degradation or climate change such as global warming. Global warming is related with the greenhouse gases which are mostly emitted from the combustion of petroleum fuels. In order to control the emissions of greenhouse gases, Kyoto Protocol targets to reduce the greenhouse gas emission by a collective average of 5% below 1990 level of respective countries. The

Intergovernmental Panel on Climate Change (IPCC) concludes in the Climate Change 2007 that, because of global warming effect the global surface temperatures are likely to increase by 1.1°C to 6.4°C between 1990 and 2100**.**

1.1 Energy Crisis

There is a realization throughout the world that the petroleum resources which are non-renewable, are limited and are being consumed at an alarming rate. The growing demand for energy and gradual extinction of fossil fuels has lead to an energy crisis. Most of the power in industries and transportation is derived from oil and coal. Special mention is needed for automobiles where almost all of the fuels for combustion engine today are derived from petroleum, a non renewable source of energy, which is nearing its end at an unprecedented pace. The globe today uses about 147 trillion kWh of energy which is expected to rise in the coming future the expected rise in the world consumption of energy up to 2030. A major chunk of this rise will be due to the developing countries, which are bound to grow by leaps and bounds.

1.2 Alternate fuels

The power used in the agricultural and transportation sector is based on diesel fuel and hence it is essential to develop alternatives for diesel. A number of steps have been taken for promoting the conservation of petroleum products. These include improving energy efficiency of refineries and increasing fuel efficiency in the transport sector. Moreover the engine exhausts accumulate the pollution into the atmosphere. Alternative fuels especially for diesel are needed to diminish the impacts of exhaust gas pollution on the environment and depleting fossil fuel reserves. Such alternatives should be compatible with existing engines, associated equipments like fuel injector etc. and fuel transportation, storage and delivery.

There are some important properties to be considered while deciding alternative fuel for the existing engines.

(i) Investment cost: Additional investment on existing engine must be small to ensure that the operation is competitive with petroleum fuel.

(ii) Modification of existing engines: Engine modification should be simple, inexpensive and easily reversible. Such modification should not affect the use of traditional diesel fuel in order to preserve engine compatibility for the use of two fuels. Switch over of operation from alternative fuel mode to diesel mode should be easy.

(iii) Environmental compatibility: While using alternative fuel the engine Performance is expected to improve significantly with regard to regulated emissions and unregulated emissions.

(iv) Manufacturer's warranty: The alternative fuel must guarantee that the lifetime of the equipment, its reliability and operational capability is not modified. Maintenance, repair and fuel costs must be similar to that of conventional fuel and the alternative fuel must be readily available.

1.3 Alcohol as fuel in internal combustion engines

The use of alcohols as fuels for Internal Combustion Engines in future, especially in Diesel engines, has suggested considerable interest. Alcohols by their nature do not make good C.I engine fuel. But they have peculiar property of igniting over a hot surface at a low temperature in spite of their high self-ignition temperature. It is this tendency of alcohol that has been exploited, in developing the surface ignition engine. Most of the literature available deals with the use of alcohols in surface ignition engines working at Diesel engine compression ratios. Almost all the power plants tested are modified versions of Diesel engines with facility to accommodate the hot surface apart from the changes in the fuel system to allow greater flow rates. Though the researchers claim that the Diesel engines may be converted to alcohol engines without losing efficiency and emission standards, in most of their studies, the detailed performance and combustion characteristics were not disclosed.

Presently, alcohols are attractive alternate fuels because they can be obtained from both natural and manufactured sources. Methanol and ethanol are two kinds of alcohols that seem most promising due to following factors.

1. It is a high octane fuel with anti-knock index numbers of over 100. Engines using high octane fuel can run more efficiently by using higher compression ratios. Alcohols have higher flame speed
2. It produces less overall emissions compared to gasoline.
3. When alcohols are burned, it forms more moles of exhaust gases, which gives higher pressure and more power in the expansion stroke.
4. It has high latent heat of vaporization which results in a cooler intake process. These Raises the volumetric efficiency of the engine and reduces the required work input in the compression stroke.
5. Alcohols have low sulphur content in the fuel.
6. Reduced petroleum imports and transportation.

The demerits are:

1. Alcohols have low energy content or in other words the calorific value of the fuel is almost half.
2. Combustion of alcohols produces more aldehydes in the exhaust. If as much alcohol fuel was consumed as gasoline. Aldehyde emissions would be a serious problem.
3. It has poor cold weather starting characteristics due to low vapor pressure and evaporation
4. Alcohols have poor ignition characteristics in general.
5. Alcohols have an almost invisible flame, which is considered dangerous when handling fuel.
6. There is the danger of storage tank flammability, due to low vapor pressure. Air can leak into storage tanks and create combustible mixtures.
7. There is a possibility of vapor lock in fuel delivery systems.

1.3.1 ETHANOL

Ethanol's chemical and physical properties are very much similar to those of Methanol. Most of the Ethanol is made from the fermentation of grain, primarily corn. This process has not been economically feasible for the production of Ethanol as a primary fuel but economic reasons provided by the federal government as well as some corn producing stages have encouraged the use of Ethanol in the form of gasohol (a mixture of 90% gasoline and 10% Ethanol). The problem in using Ethanol as a primary alternative fuel is that the process of making Ethanol from the fermentation of grain uses more energy than is obtained from the Ethanol when burned as a fuel. Compared with Methanol, Ethanol is not well suited for use in unmodified compression ignition engines. It has poor self- ignition characteristics; therefore its use in Diesel engines requires some means for providing ignition. For single – fuel operations this normally requires use of a spark plug or Glow plug, fuel additive ignition improvers, or enhanced auto – ignition through the use of exhaust gas recirculation. In dual fuel operation, ignition of the Ethanol is insured by use with a fuel having good self – ignition characteristics, such as Diesel fuel.

1.4 Use of Alcohols in Diesel Engines

The various differences in physical and chemical properties between alcohol fuels and gasoil, as described above, necessitate special measures to get alcohol fuels to burn in diesel engines. Of major importance among the fuel properties are the low cetane values of the alcohol fuels and consequently their high auto-ignition temperatures. The cetane values of methanol and ethanol for example are 3 and 8 respectively. These are by far lower than that of gasoil which range from 40 to 50. Those values are also much lower than 30 -a value which is considered as the minimum cetane number for satisfactory engine performance. The low cetane value of alcohol fuels, together with their high auto-ignition temperatures necessitate changes in either the composition of the fuels or the configuration of the engine in order to get the fuels to burn satisfactorily in compression-ignition engines. Various techniques have been used by a number of researchers in an attempt to ignite maintain combustion of alcohol fuels in diesel engines (1,2,3,4,5). Stipulated earlier on, all the techniques used fall into two categories: 1). Fuel management techniques in which the fuel is manipulated in various ways to improve its ignition characteristics. 2). Engine management techniques, in which the engine is modified to enable ignition of the low cetane alcohol fuels. Some of the prominent techniques are described below.

1. Use of very high compression ratios.
2. Use of ignition accelerating fuel additives.
3. Alcohol – Diesel emulsion.
4. Dual fuel system.
5. Surface ignition system

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1.4.1 Use of very high compression ratios

The normal compression ratio used in CI engines 16-20, is insufficient to self-ignite alcohols. It is necessary to raise it to 25-27 to achieve compression ignition of Methanol or Ethanol. Such a high compression ratio makes the engine very heavy and hence this solution is not generally favored.

1.4.2 Use of ignition accelerating fuel additives.

For gasoil, cetane number is controlled by the source of the crude, by the refining process and by additives that improve ignition. Substances that increase the tendency to knock in SI engines generally enhance ignition in CI engines. Ignition improving additives include organic peroxides, nitrates, nitrites and various sulphur compounds (6). Those which are most commonly used commercially are the alkyl nitrates (isopropyl nitrate, primary amyl nitrates, primary hexyl nitrates, octyl nitrate). The important practical uses for additives are in upgrading the ignition characteristics of poorer quality gasoil and, in comparatively larger quantities of the additives, in enabling the use of alcohols in compression-ignition engines. Use of ignition improving additives in alcohol fuels has two advantages: firstly, they enable alcohol fuels to be used in the unmodified diesel engines; and secondly, they offer the possibility for total substitution of gasoil in diesel engines. An additive content of up to 15% by volume would normally be required to enable ignition of alcohol fuels in CI engines. The current cost of these additives is, however, high enough to preclude or make their utilization in this way uneconomical at present day's oil prices

1.4.3 Alcohol – Diesel Emulsion

Another solution which has been investigated is the use of alcohol- Diesel oil emulsions, Alcohols can be mixed with gasoil. They can also be suspended in gasoil in the form of minute droplets to make an emulsion. The two fuels, however, do tend to separate, and an alcohol/gasoil emulsion is fairly unstable. These mixtures and emulsions have been reported to burn satisfactorily in diesel engines, and substitution of up to 20% of alcohol by volume is possible. Higher levels of substitution are limited by severe loss of performance (7, 8, 9)

1.4.4 Dual injection System

Dual injection techniques comprise two separate injection systems, one for gasoil and the other for alcohol fuel. Combustion is started with a pilot injection of gasoil before a larger quantity of alcohol is injected through the main nozzle. The pilot injection acts as an ignition source for the alcohol fuel. Up to 95% (vol) substitution of gasoil has been reported by some researchers (10). This method, however, requires expensive engine modifications, which include complex fuel control and metering systems. To ensure satisfactory life, the alcohol fuel injection system will also require additives for lubrication.

1.4.5 Fumigation.

This is a technique whereby alcohol fuel is introduced into the engine with the intake air. This method requires less engine modification than with dual fuel injection systems and has been used by a number of researchers (1). Up to 50% (vol) substitution of gasoil is possible, with the level of substitution limited by the onset of detonation of the air-fuel mixture. Accurate control of the fuel flow has been reported necessary in order to prevent misfire at light loads and knocking at high loads (11). Since the air intake is reduced owing to the inclusion of alcohol fuel, the maximum power output is reduced below that for gasoil only.

1.4.6 Surface ignition system

Alcohol fuels have very low resistance to ignition on hot surfaces. While this can have undesirable effects in SI engines, such as pre-ignition and running on, surface ignition has been used by a number of researchers including Nagalingam et al (12) to ignite alcohol fuels in diesel engines. The technique offers possibilities for complete substitution of gasoil with alcohol fuels. Research on this method has mainly used a glow plug as the heating source. The position of the fuel injector in this case is an important factor. It has to be located ahead of the glow plug in the direction of swirl in order to prevent direct impingement of fuel droplets on the glow plug direct impingement of fuel droplets on the glow plug would lead to quenching of the glow plug, resulting in loss of ignition (13). This method aims to solve the difficulty of auto-ignition of alcohol fuel and can provide 100 % replacement of diesel fuel.

A brief review of literature is presented in the chapter 2.

1.5 Objective of this work

In this context of escalating problems of fuel (energy) crisis and environmental pollution, the ethanol fuel is tried as substitutes/ alternatives for diesel. After a careful review of literature, the present work is planned with the following objectives. The experimental work is carried out on A four stroke Compression Ignition Engine, the normal diesel engine is converted into hot surface ignition engine using a Glow plug hot surface and tested by providing copper piston crown material by using Ethanol fuel with iso-amyle nitrate as additive to improve the ignition quality of the selected fuel and the existed engine also converted in to Low Heat Rejection And an objective to find the best results in terms of performance, emissions and combustion parameters.

II. Literature review

Ethanol can be produced by biomass conversion pathways. The sugar and starches of agricultural crops can be easily converted to ethanol by anaerobic fermentation. Cellulose, together with hemi-cellulose and lignin, are the major constituents of wood. The cellulose and hemi-cellulose are polysaccharides which are complex polymers of sugars, and can be used as feedstock for ethanol production, provided that they can be hydrolyzed to simple sugars.

The experiments of Tadashi Muruyama et al. (14) with Ethanol for good combustion revealed that the Glow plug has to be located in a stagnant zone without direct impingement of the fuel and that only the fuel vapour must touch the hot surface. At no load operation above 1200 rpm, combustion difficulties were noticed because of large temperature drop of the hot surface due to heat transfer to the relatively cold cylinder gases. The injection advance would be more critical than temperature of the Glow plug at high speeds. At low loads, the tests also indicated lower brake thermal efficiency, higher HC and un-burnt fuel and noise. It was found that, there was no difference in performance of the engine up to 10% water in Ethanol.Eugene Ecklund et al. (15) with Ethanol for good burning uncovered that the Glow plug must be situated for vapor should touch the hot surfaces. At no load over 1200 rpm, ignition challenges were seen on account of huge temperature drop of the hot surface because of heat exchange to the generally cool cylinder gases. The infusion advance could be more basic than the Glow plug temperature at higher speeds. At lower loads, the tests likewise demonstrated low brake thermal effifciency, high HC emissions. It was discovered that, there was no distinction in performance of the engine up to 10% water in Ethanol. Bang-Quan He et al. (16) concluded from their experiments that with the addition of ethanol to diesel fuel all the fuel properties have been changed. The emission characteristics of five fuels are measured on a diesel engine. At high loads, the blends reduce smoke significantly with a small penalty on CO, acetaldehyde and unburned ethanol emissions compared to diesel fuel. NO*x* and CO2 emissions of the blends are decreased significantly. At low loads, the blends have slight effects on smoke reduction due to overall leaner mixture. With the aid of additive and ignition improver all the engine emissions decreased drastically. Bio-based oils are effective in increasing fuel lubricity. Hardenberg et al. (17) included 1% castor oil in a 95% ethanol fuel that is used successfully in buses in Brazil. They concluded that minimum viscosity and lubricity of ethanol-diesel blends are required in order to ensure that fuel injection system durability is not compromised relative to diesel fuel usage and that engines are able to start reliably when hot. Shipinski et al. (18) have highlighted some important fuel handling and combustion problems by using different fuels in diesel engines. The performance of the fuel injection system as a whole is affected by the viscosity, volatility, specific gravity and compressibility of the fuel. Further, change in ignition delay, compressibility and injector output necessitate change in the injection timing with change in fuel. Fuel properties affect spray characteristics, ignition delay and duration of combustion. Thus, the fuel injection system has to be optimized for each fuel. Noboru Miyamoto et al. (19) have conducted the tests on Glow plug and spark plug assisted Diesel engines with fuels like Methanol and ethanol. They found that an increase in the Glow plug temperature resulted in inferior performance at full output. This was because of lengthening of the combustion duration and shortening of the ignition delay. With alcohols, NO_x emission was reduced. It was observed that even at a Glow plug temperature of 600^0C, the starting of the engine was satisfactory. Murayama et al. [20 & 21] conducted different tests to know the suitability of spark assisted, hot surface and dual fuel methods to burn Methanol and Ethanol. The various factors which effect the combustion in the hot surface ignition engine were identified as amount of fuel, injection timing, Glow plug temperature and water content in the fuel. The best performance was observed by them when the Glow plug was located in a stagnant region. They have come to a conclusion that the Glow plug or the spark plug methods is the best for neat alcohol utilization. Between these two, the Glow plug method has better multi fuel capability. According to Yui et al. (22) the surface temperature of the Glow plug was found to have an effect on No_x, CO and HC emissions and Cyclic fluctuation of mean effective pressure. The distance between the Glow plug and nozzle was found to be very critical. This distance must be the shortest in order to have a maximum brake thermal efficiency and minimum fluctuation in mean effective pressure. Increase of the number of nozzle holes created a more uniform mixture in the cylinder, which results in higher brake thermal efficiency for good performance, the intake swirl had to be low at low loads. It is interesting to observe that, almost all fuels exhibit this type of property of surface ignition. Among all the fuels the alcohols are highly susceptible to surface ignition (23 & 24). Ricardo et al. (25 & 26) was one of the earliest to notice this phenomenon of surface ignition in SI engines. He found that pre-ignition is caused by detonation with petrol as fuel in the above engine, but with Methanol as a fuel, no detonation is traced. To have a deeper concept, Ricardo et al. (27) used a variable compression E60 engine, where a pre-igniter whose temperature could be controlled was fitted inside the cylinder head. He studied the temperature requirements of each fuel to undergo pre-ignition, at various compression ratios, mixture strengths etc., and rated their resistance accordingly. He found that as expected, alcohols showed minimum resistance to pre-ignition. To analyze the surface ignition tendency of various fuels, Bowditch and Yu (28) conducted similar experiments by using an electrically heated chromel wires. They used various fuels under various engine operating conditions by maintaining a constant hot wire temperature. Berg et al. (29) and Bindel (30) have identified the need for correct injection timing of the fuels since the pilot fuel must be injected prior to the injection of alcohol fuel. Early injection of the alcohol fuel resulted in misfire and a consequent increase in exhaust emissions. Havement et al. (31) and Panchupakesan et al. (32) added a carburettor to a diesel engine and used alcohol as the primary fuel. Small amounts of diesel or vegetable oil was injected through the conventional injection system to ignite the air-alcohol mixture. Furuhama et al. (33) conducted experiments on a single cylinder DI diesel engine with only piston insulation which results poor performance in LHR engines may not be adequate for a fully insulated engine. This is due to low temperatures in the combustion chamber and results poor combustion. Sun et al. (34) concluded from their experiments that with decrease in premixed combustion by 75% in an insulated engine increase the brake specific fuel consumption by about 9%. In order to decrease in ignition delay in LHR engine, 25% gasoline is mixed with diesel which results a decrease in BSFC. This can also be done by increasing the injection pressure. In both the cases altering fuel composition and injection pressure to change the rate of heat release improved BSFC of the insulated engine. In order to have the full benefits of LHR engine, the combustion system is to be modified to maintain a desirable heat release profile. Miyairi (35) developed a Low heat rejection diesel cycle simulation consists of heat transfer model, gas flow model and two zone combustion model. The heat transfer model is used to determine convective and radiative heat transfer between the combustion gas and the cylinder valves. With the combustion model the chemical Kinematics, temperature phenomenon and the chemical equilibrium compositions are determined. The gas flow model is used to determine the gas flow rates between the intake system, the cylinder and the exhaust system. The simulation is to run at different loads, speeds and with different insulation materials such as PSZ and ZrO2 etc. The investigation indicates improved thermal efficiency ranging from 2% to 2.7 %compared to the base engine. The gain in the thermal efficiency depends on the type of insulation material and their thickness. The investigations also indicate that materials which are low thermal conductivity and low heat capacity are advantageous in the tradeoff between thermal efficiency and NO emissions. Hoag et al. (36) carried experiments with constant air-fuel ratio on 450 KW Cummins V903 engine with Partially Stabilized Zirconia (PSZ) as the insulation material and compared the same with base engine. The results are recorded with a specially designed data acquisition system. From the results they concluded that the performance parameters vary directly with respect to degree of insulation. Thring (37) carried investigations on ceramic coated single-cylinder water cooled DI diesel engine with turbocharger (TC) and Turbocompound equipment (TCO). The engine performance and emissions are measured with data acquisition system and concluded that an improvement in the specific fuel consumption of about 7% in turbocharged (TC) engine and about 15% in turbo compounded (TCO) engine. The CO emissions reduced drastically by proper combustion and due to high temperature in the cylinder NOx emissions increased by 15%. Cheng et al. (38) modified single cylinder diesel engine where piston and cylinder head insulated with 1.52 mm of PSZ. From the results they concluded that the insulated engine shows poor performance, higher BSFC, low compression ratios, degradation of combustion process, higher surface temperature and exhaust at all tested loads. This is due to slower and non-optimized combustion, which is evidenced by the presence of soot formation. Thermal Barrier Coatings (TBCs) in diesel engines lead to advantages including higher power density, fuel efficiency, and multifuel capacity due to higher combustion chamber temperature (900℃ vs. 650℃) (39, 40).Using TBC can increase engine power by 8%, decrease the specific fuel consumption by 15-20% and increase the exhaust gastemperature 200K(41). Although several systems have been used as TBC for dif-ferent purposes, yttria stabilized zirconia with 7-8 wt. % yttria has received the most attention. Several important factors playing important roles in TBC lifetimes including thermal conductivity, thermal, chemical stability at the ser-vice temperature, high thermo mechanical stability to the maximum service temperature and at last but not least the thermal expansion coefficient (TEC). As general, Winkler et al. (42&b43) reported ten years of experience for the role of ceramic coatings on a diesel engine (Cummins) in reducing automotive emissions and improving combustion efficiency

III. Experimental work

In the present experimental work the single cylinder, four strokes 5.2kW Kirloskar, water-cooled DI diesel engine with a bore of 87.5 mm and stroke of 110 mm and a compression ratio of 17:1 is used. The engine load is applied with eddy current dynamometer. For the reduction of heat to the cooling water .the plain engine is modified as Glow plug hot surface ignition (GHSI) engine and further it fitting with a PSZ coated cylinder head and liner it is called Low heat rejection (LHR) engine.

Figure 3.1: **shows pictorial view of engine and dynamometer.**

Figure 3.2: shows normal aluminium piston

Figure 3.3: shows the copper crown

Figure 3.4: Partially Stabilized Zerconia Coated Cylinder Head

IV. Results and discussions

4.1 Performance of Glow Plug Hot Surface Ignition Low Heat Rejection Engine

The experiments are carried out on the normal engine on the copper piston crown material with additive Iso amyl nitrate on GHSI engine and in LHR engine using Ethanol as fuel to determine the performance, emissions and the combustion parameters, which are presented below.

4.2 Brake Thermal Efficiency

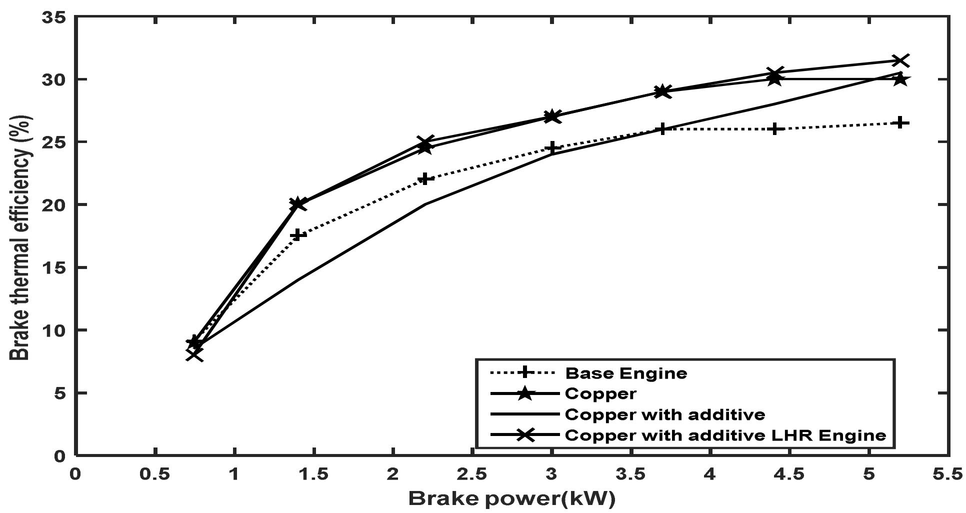

Figure 4.1: Variation of Brake thermal efficiency with power output for copper piston crown GHI-LHR Engine with Iso-amyle Nitrate additive Ethanol as fuel.

Figure 4.1 shows the variation of brake thermal efficiency with brake power output. Over a wide range of operation, the brake thermal efficiency of copper piston crown material GHSI with additive LHR shows maximum thermal efficiency is about 31.5%. The copper piston crown material GHSI engine with and without additive has brake thermal efficiencies are 30.5%, 30% and the brake thermal efficiency for base engine is 26.5%. The copper piston crown material GHSI engine with additive in LHR engine has a percentage improvement of 5% at rated load over normal engine, which can be attributed to the positive ignition of the injected Ethanol spray by the ceramic Glow plug under all conditions. The ability of the LHR engine to prepare the injected Ethanol spray into readily combustible mixture in very short time is multiplied by the improvement with ceramic Glow plug with copper piston crown material additive.

4.3 Brake Specific Fuel Consumption

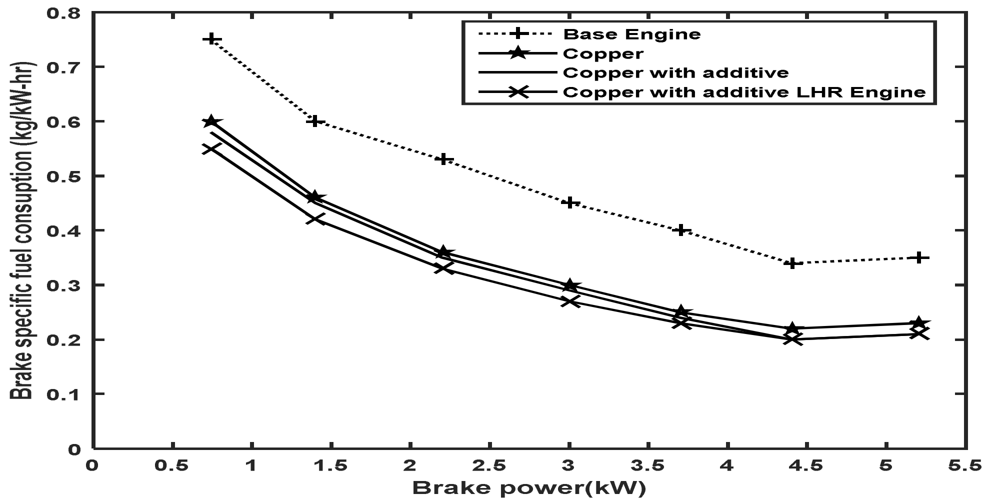

Figure 4.2: Variation of brake specific fuel consumption with power output for copper piston crown GHI-LHR Engine with Iso-amyle Nitrate additive Ethanol as fuel.

The variation of Brake specific fuel consumptions with power output is illustrated in figure 4.2. All the configurations have lower brake specific fuel consumption compared to base engine. The copper crown piston GHSI Iso-amyl nitrate with LHR gives lower bsfc is about 0.21 kg/kW-hr at full load over wide range of operation. The brake specific fuel consumption principally depends upon the consistent mixture formation and complete combustion of the fuel. With the better vaporization of the fuel, the charge becomes homogeneous and the combustion of fuel can be improved. The heat within the combustion chamber will increase and the combustion potency is improved. The rise in combustion potency provides fuel economy. The copper crown piston acts as a good heat reservoir, with its better thermal properties. This will increase the temperature of the incoming air and any the combustion potency.

4.4 Volumetric Efficiency

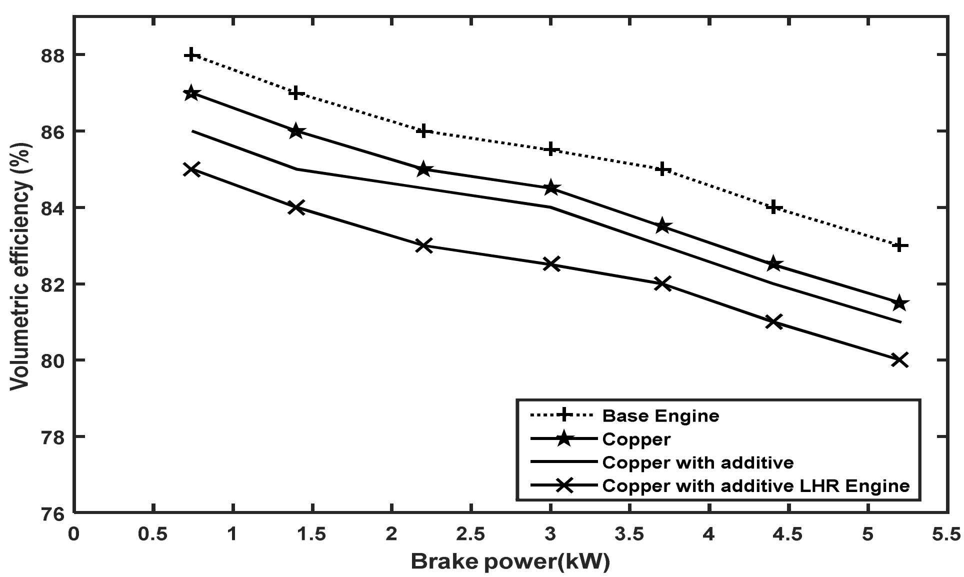

Figure 4.3: Variation of Volumetric efficiency with power output for copper piston crown GHI-LHR Engine with Iso-amyle Nitrate additive Ethanol as fuel.

The general trend is that the volumetric efficiency drops with increase in power output. At standard condition, the volumetric efficiency varies from 88% at no load to 83% at full load. With copper configuration the volumetric efficiency comes to 85% at no load and to 80 % at full load. The volumetric efficiency has a bearing on power output. Because of insulation, the combustion chamber surface temperature increases, and there will be more heat loss to incoming air, resulting in a drop in volumetric efficiency. Since the incoming air density suffers, the combustion phenomenon is also affected. Therefore in insulated Engines, the drop in volumetric efficiency is a major problem.

4.5 Hydrocarbons

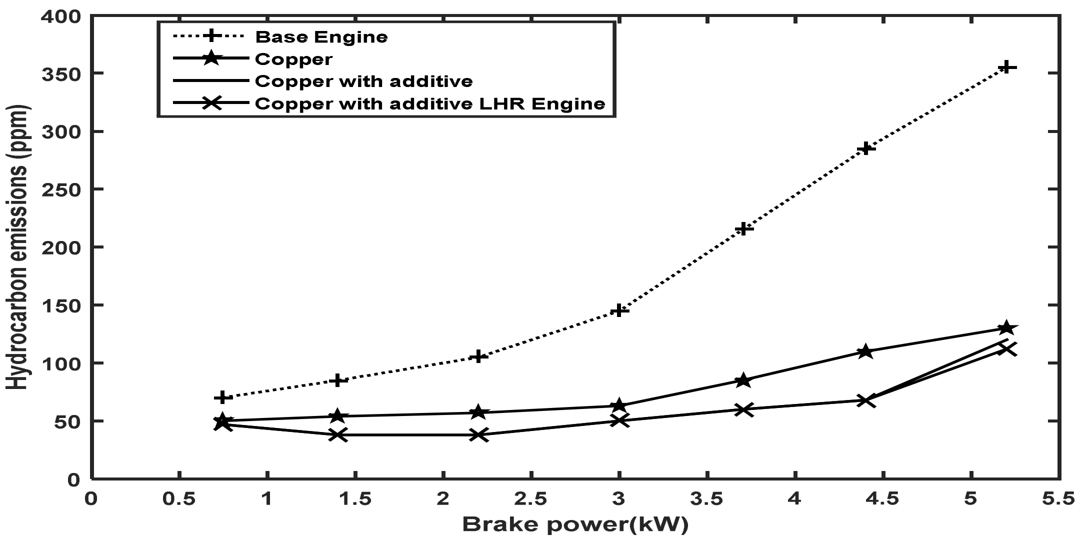

Figure 4.4: Variation of Hydrocarbons with power output output for copper piston crown GHI-LHR Engine with Iso-amyle Nitrate additive Ethanol as fuel.

Figure 4.4 shows higher HC emission levels for normal base engine is about 355ppm and copper coating GHSI engine with additive in LHR engine shows lower HC emissions is about112ppm. As compared to normal GHSI engine, copper piston crown material GHSI engine with additive in LHR engine shows maximum reduction in HC emission level. At rated load, the reduction in HC emission level over the corresponding copper crown is about 112ppm.

4.6 Carbon Monoxide Emission

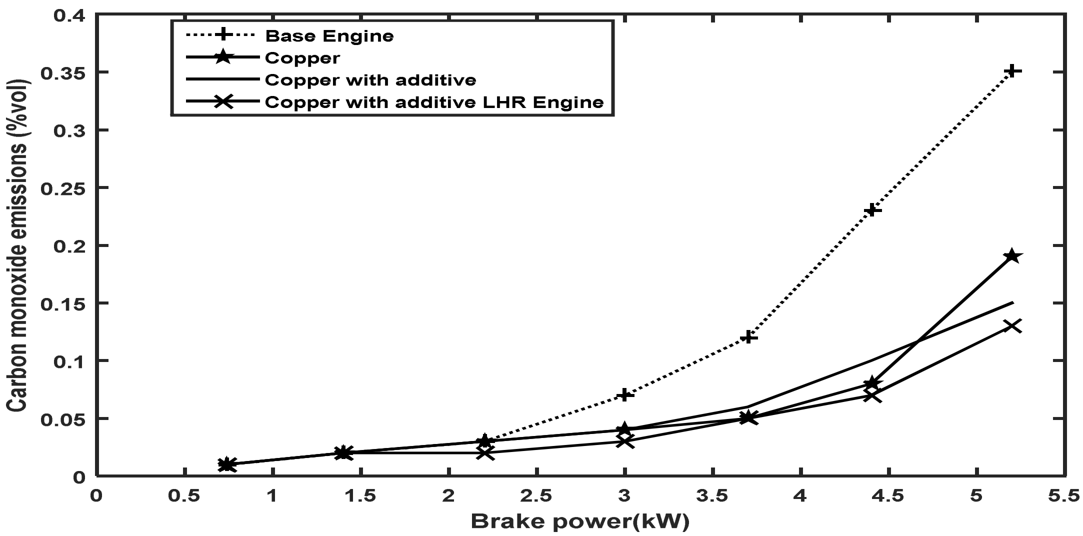

Figure 4.5: Variation of CO emission with power output for copper piston crown GHI-LHR Engine with Iso-amyle Nitrate additive Ethanol as fuel.

The variation of CO emissions with brake power output is shown in figure 4.5. The normal GHSI engine indicates higher level of CO emissions when compared to copper piston crown material GHSI engine with additive in LHR engine and is about 0.13% by volume at rated load. The reduction is less pronounced at part loads than at rated loads.

4.7 Carbon dioxide Emission

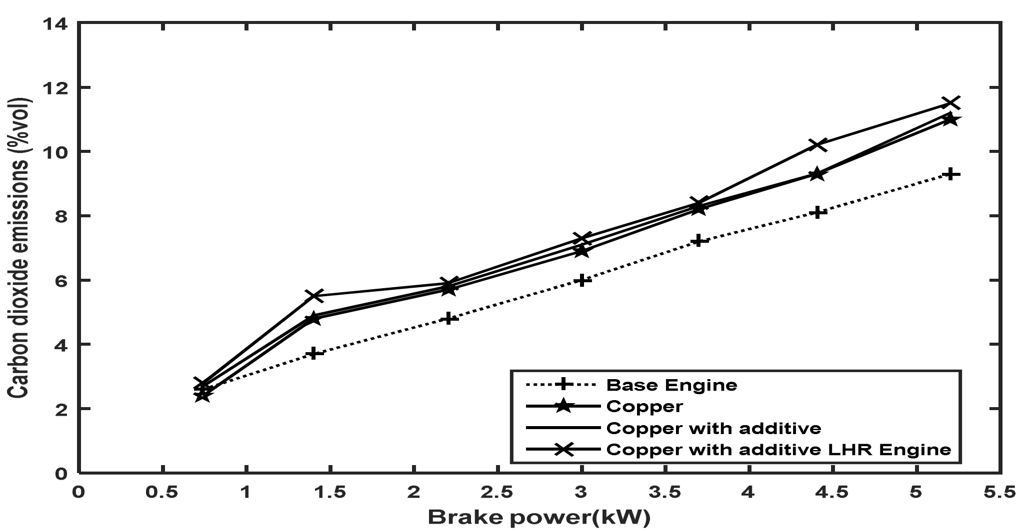

Figure 4.6: Variation of Carbon dioxide with power output for copper piston crown GHI-LHR Engine with Iso-amyle Nitrate additive Ethanol as fuel.

The variation of carbon dioxide with power output is illustrated in figure 4.6. Because of better and complete combustion in the insulated engines, Carbon dioxide levels are higher for copper piston crown GHSI with iso-amyl nitrate additive LHR engine is about 11.5%. It indicates that the level of Carbon dioxide in the exhaust is highest for Copper piston crown configuration. Higher Carbon dioxide in the exhaust is an indication of complete or better combustion.

4.8 Nitrogen Oxide Emissions

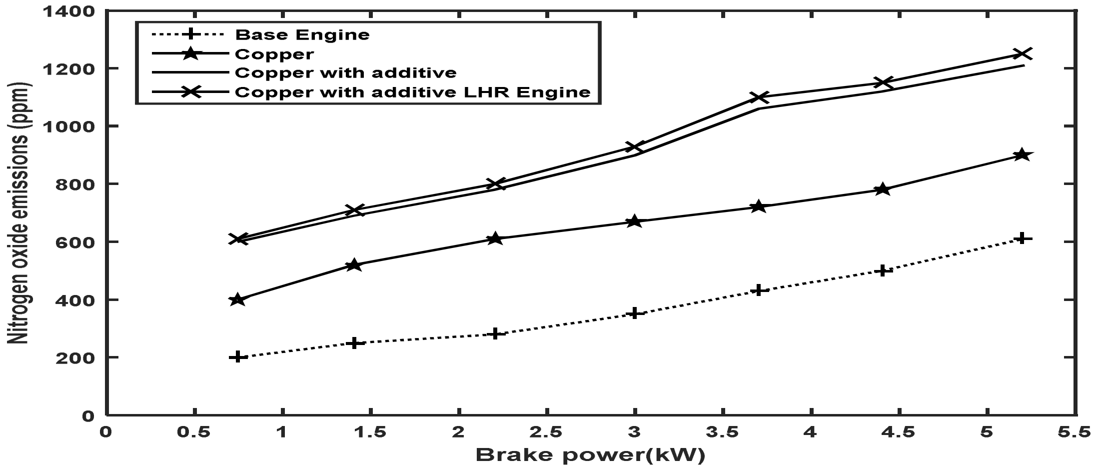

Figure 4.7: Variation of NOx emission with power output for copper piston crown GHI-LHR Engine with Iso-amyle Nitrate additive Ethanol as fuel.

The variation of Nitrogen oxides with power output is illustrated in figure 4.7. Because of better and complete combustion in the insulated engines, Nitrogen oxide levels are higher for insulated engines. It indicates that the level of nitrogen oxide is highest for Copper GHSI with additive LHR configuration is about 1250ppm. Higher nitrogen oxide in the exhaust is an indication of complete or better combustion.

4.9 Smoke emissions

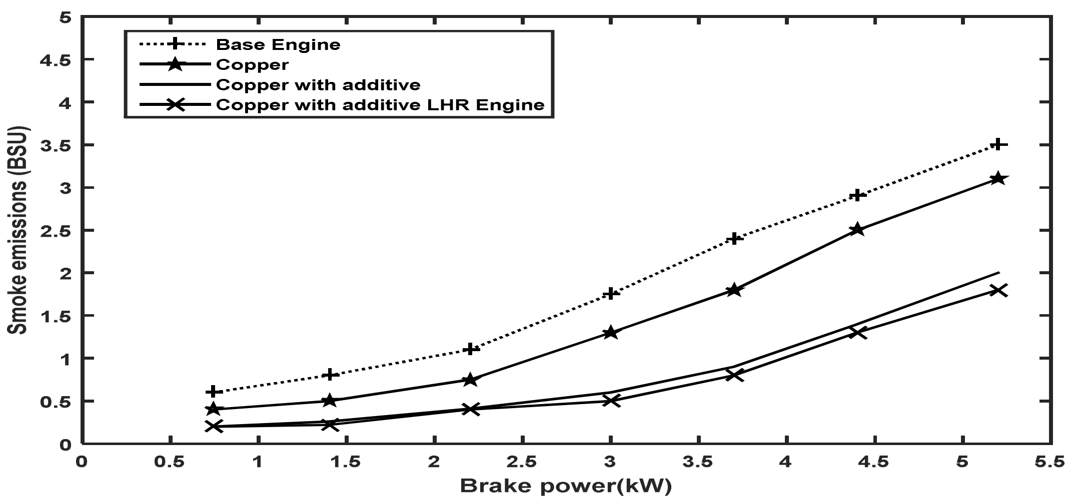

Figure 4.8: Variation of Smoke Emission with power output for copper piston crown GHI-LHR Engine with Iso-amyle Nitrate additive Ethanol as fuel.

Variation of smoke emission levels with brake power for different piston crown CHSI engine with LHR additive operations is shown in Figure 4.8. At lower loads fuel consumption is less after combustion quantity of smoke levels are also less and almost equal values for all the crown materials. By increasing the load fuel consumption also increases after combustion the smoke levels are significant variation for all piston crown materials. At higher load the maximum smoke emission is 3.5BSU for the normal base engine. And minimum smoke emission is 1.8 BSU for copper piston crown GHSI with LHR Ethanol as fuel with Iso-amylnitrate as additive.

The reason is Ethanol is containing oxygen therefore by this complete combustion takes place. The smoke value for copper without additive and copper piston crown with additive, are 3.1 BSU, 2.0 BSU respectively.

4.10 Exhaust Gas Temperature

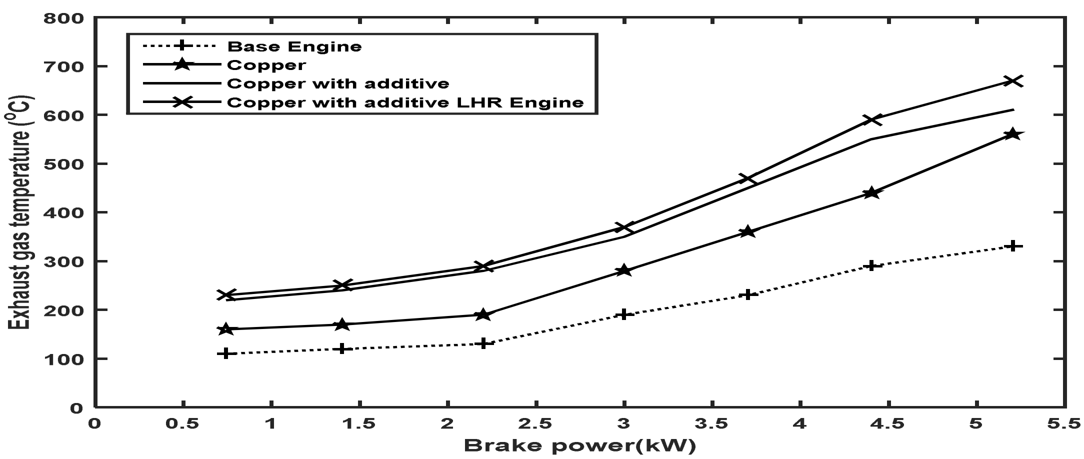

Figure 4.9: Variation of Exhaust gas temperature with power output for copper piston crown GHI-LHR Engine with Iso-amyle Nitrate additive Ethanol as fuel.

The variation of exhaust gas temperature with power output is illustrated in figure 4.9. It clearly indicates that with the degree of insulation increasing the exhaust gas temperature progressively increases. Exhaust temperatures increase with the engine load. Because of better insulation for the Copper GHSI with LHR gives the highest exhaust gas temperature that is about 670^0C. The exhaust gas temperature for normal base engine, copper piston crown without additive and copper piston crown with additive are 330^0C, 560^0C and 610^0C respectively.

4.11 Peak Pressure

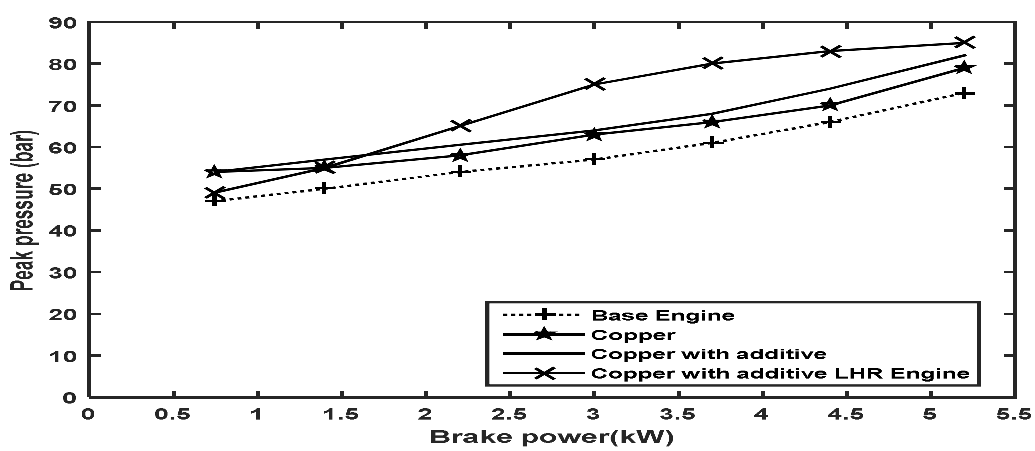

Figure 4.10: Variation of Peak Pressure with power output for copper piston crown GHI-LHR Engine with Iso-amyle Nitrate additive Ethanol as fuel.

Figure 4.10 shows the variation of peak pressure with brake power output. The peak pressure for normal GHSI engine is lower compared to the copper piston crown material GHSI with additive in LHR engine. The copper piston crown material GHSI engine with additive in LHR engine at rated load shows higher peak pressure and is about 85bar. The peak pressure for normal base engine, copper piston without additives and copper piston crown with additives are 73bar, 79bar and 82bar respectively.

4.12 Ignition Delay

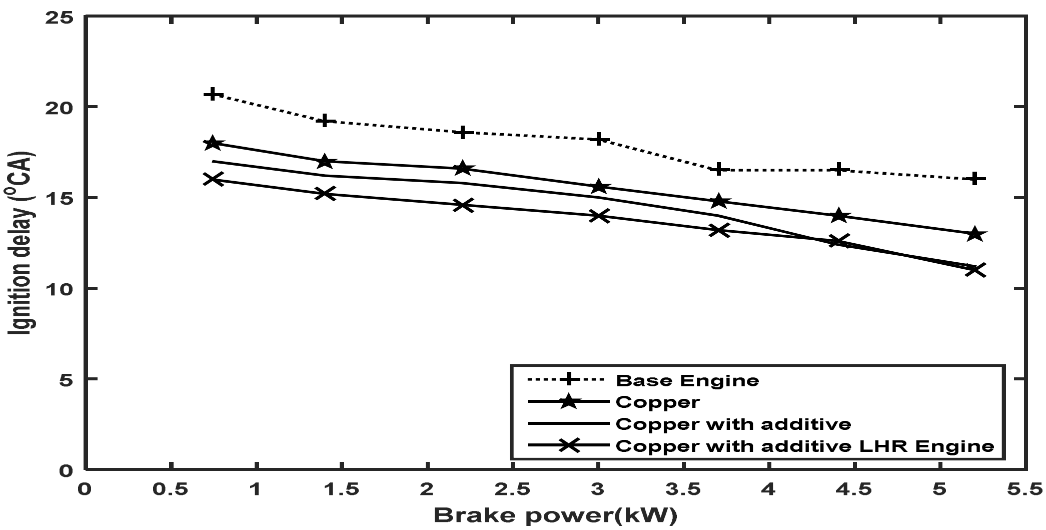

Figure 4.11: Variation of Ignition delay with power output for copper piston crown GHI-LHR Engine with Iso-amyle Nitrate additive Ethanol as fuel.

The variation of ignition delay with brake power output is illustrated in figure 4.11. The normal base engine has the highest ignition delay. The ignition delay for copper crown GHSI with additive LHR engine is about 13.1^{0}CA the reduction in ignition delay over normal GHSI engine for copper piston crown material GHSI engine with additive in LHR engine is 4.7^{0}CA, which is due to hotter combustion chamber of LHR engine. As compared to normal engine the operation of LHR engine is smoother.

4.13 **Indicated Mean Effective Pressures**

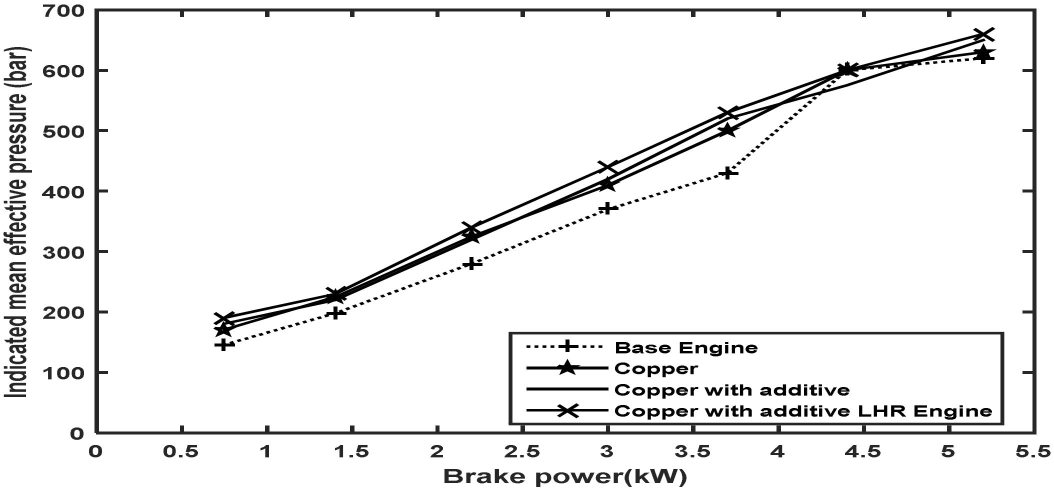

Figure 4.12: Variation of Indicated mean effective pressure with power output for copper piston crown GHI-LHR Engine with Iso-amyle Nitrate additive Ethanol as fuel.

The variation of indicated mean effective pressure with power output is illustrated in figure 4.12. The increase in the Indicated mean effective pressure is normally expected because of higher temperatures in these configurations. Highest Indicated mean effective pressure is obtained for the Copper GHSI with additive LHR Engine is about 660bar. For other normal engine, copper without additive and copper crown with additive are 620bar, 630bar and 650bar respectively.

4.14 Maximum Rate of Pressure Rise

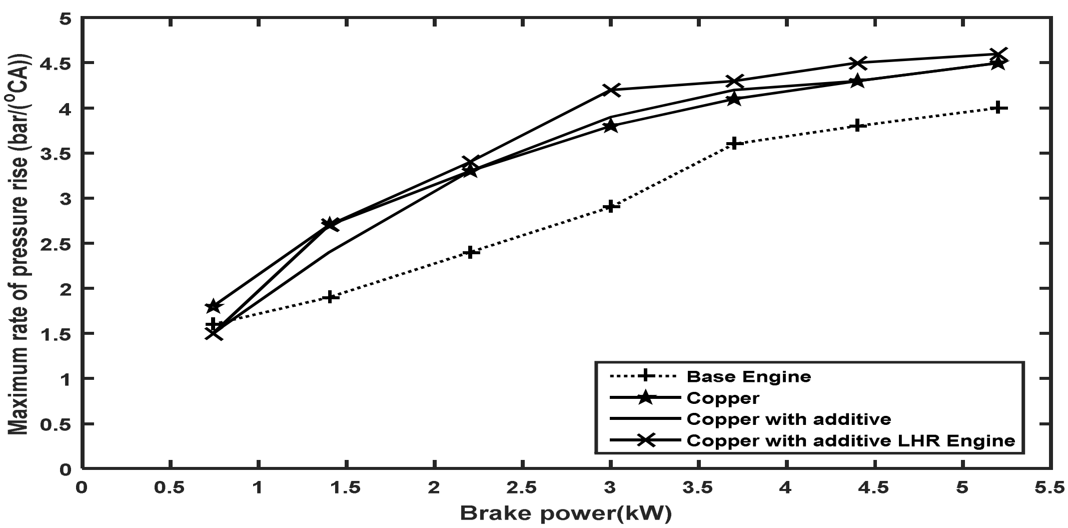

Figure 4.13: **Variation of maximum Rate of Pressure Rise with power output for copper piston crown GHI-LHR Engine with Iso-amyle Nitrate additive Ethanol as fuel.**

The variation of maximum rate of pressure rise with brake power output is shown in figure 4.13. The maximum rate of pressure rises for normal base engine is found to be lower than the copper piston crown material GHSI engine with additive in LHR engine. At rated speed, it is the highest for copper piston crown material CHSI engine with additive in LHR engine and is 4.6%.

Conclusions

- Over a wide range of operation, the brake thermal efficiency of copper piston crown material GHSI with additive LHR shows maximum thermal efficiency is about 31.5%. The copper piston crown material GHSI engine with and without additive has brake thermal efficiencies are 30.5%, 30% and the brake thermal efficiency for base engine is 26.5%. The copper piston crown material GHSI engine with additive in LHR engine has a percentage improvement of 5% at rated load over normal engine, which can be attributed to the positive ignition of the injected Ethanol spray by the ceramic Glow plug under all conditions.

- The copper crown piston GHSI Iso-amyl nitrate with LHR gives lower bsfc is about 0.21 kg/kW-hr at full load over wide range of operation, the value for the base engine is about 0.35 kg/kW-hr.

- The hydrocarbon emissions for the copper crown with additive LHR is gives the minimum HC emission is about 112ppm at full load, CO and CO_2 emissions are 0.13%,11.5% respectively.

- The smoke emissions are also lower it is about 1.8 BSU for copper piston crown material GHSI with additive (Iso amyl nitrate) in LHR engine Ethanol as fuel at rated load.

- At rated load, the copper coating GHSI engine with additive in LHR engine Ethanol as fuel shows higher peak pressure and is about 85bar, and shows higher maximum rate of pressure rise and is about 4.6%. And reduction in ignition delay is about 4.7^0CA.

- The increase in the Indicated mean effective pressure is normally expected because of higher temperatures in these configurations. Highest Indicated mean effective pressure is obtained for the Copper GHSI with additive LHR Engine is about 660bar. For other normal engine, copper without additive and copper crown with additive are 620bar, 630bar and 650bar respectively.

- The maximum rate of pressure rises for normal base engine is found to be lower than the copper piston crown material GHSI engine with additive in LHR engine. At rated speed, it is the highest for copper piston crown material CHSI engine with additive in LHR engine and is 4.6%.

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