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Modernizing Insulated Engines through Advanced Supercharging and Turbocharging

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ABSTRACT

Insulated engines offer a promising avenue for improving thermal efficiency, particularly when utilizing fuels like alcohols that have high latent heat of vaporization and low cetane numbers. The higher temperatures inherent in insulated engines can facilitate the vaporization of these fuels, enhancing combustion. However, one of the primary challenges associated with insulated engines is the reduction in volumetric efficiency. This decrease is attributed to the higher wall temperatures of the insulated components, which in turn reduce the density of the air entering the cylinder. Consequently, this leads to increased frictional losses due to the thinning of lubricants, potentially offsetting some of the efficiency gains. To counteract the drop in volumetric efficiency, supercharging emerges as a viable solution. By forcing more air into the cylinder, supercharging can compensate for the losses incurred due to insulation. In our experimental setup, we employed an external blower driven by a motor to achieve supercharging. This approach allows for a controlled increase in intake pressure, thereby enhancing the air density and potentially improving combustion efficiency. In contrast, turbocharging utilizes the exhaust gases to drive a turbine coupled to the engine, offering another method to boost intake pressure without directly consuming engine power. Our experiments were conducted on a single-cylinder, water-cooled direct injection (DI) diesel engine that was modified with insulation. Specifically, the engine featured an air-gap insulated piston and liner, along with ceramic-coated cylinder head and valves. To mitigate the volumetric efficiency losses, a supercharger was integrated into the system. The results indicated that the insulated diesel engine, when equipped with supercharging to compensate for volumetric efficiency, demonstrated improved performance and a notable reduction in smoke emissions. Furthermore, we investigated the impact of varying intake boost pressures on engine performance under both supercharging and turbocharging conditions. These findings are crucial for optimizing the design and operation of insulated engines, particularly in applications where efficiency and emissions are critical considerations.

INTRODUCTION

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In a normal diesel engine about one third of total energy is rejected to the coolant. The insulated engine concept is based on reducing the heat rejection to the coolant and recovering energy in the form of useful work by expanding the exhaust gases in lower pressure turbines. Some important advantages of the insulated engines are improved fuel economy, reduced HC and CO emission, reduced noise due to lower rate of pressure rise and higher energy in the exhaust gases. Due to higher temperatures in the combustion chamber low cetane fuels can also be burnt. This is due to the higher temperature available at the time of fuel injection. The heat available due to insulation can be effectively used for vaporizing alcohols. However, one of the main problems in the insulated engines is the drop in volumetric efficiency. This decrease in the volumetric efficiency is attributed to the decrease in the density of air entering the cylinder because of high wall temperatures of the insulated engine. The degree of degradation of volumetric efficiency depends on the degree of insulation.

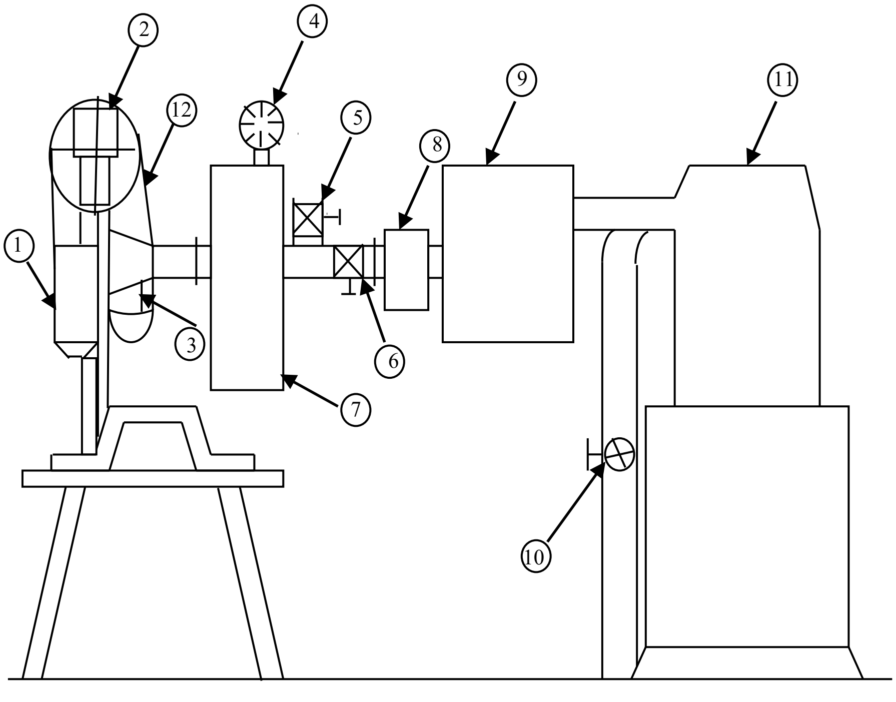
In the present work a single cylinder insulated diesel engine is supercharged to different inlet pressures depending upon the load, for compensating the decrease in volumetric efficiency. Performance of the insulated engine under supercharging condition is investigated.

EXPERIMENTAL DETAILS

The engine used for this experimental investigation is a 3.68 KW Kirloskar, single cylinder, water cooled DI diesel engine. Suppression of the heat rejection is achieved by using air gap insulated piston, air gap insulated liner and ceramic coated cylinder head and valve (BP9).

SUPERCHARGING EQUIPMENT

To pressurize the inlet air, externally powered supercharging equipment with closed loop lubrication is fabricated. This can supply air at the rate of 50 m^3/hr.The schematic diagram of the supercharging equipment is shown in Fig: 1. This consists of a two lobe roots blower, a gear pump for lubrication and a motor to drive the blower as well as the lube oil pump. In order to lubricate the blower, a closed loop lubrication system consisting of gear pump and an oil pump is fabricated. Blower and lubricating oil pump are driven by a motor on a V-belt. The pully ratios are selected such that blower and lubricating oil pump rotate at correct RPM to give the required discharge. The air outlet from the blower is connected to the engine with a receiver tank and two control valves in between. These valves are for bypassing and throttling. The required pressure in the surge tank is maintained by adjusting these valves.



1. **Roots blower**
2. **Motor**
3. **Lub. Oil pump**
4. **Pressure gauge**
5. **Bypass valve**
6. **Throttle valve**
7. **Receiver tank**
8. **Flow meter**
9. **Surge tank**
10. **Exhaust throttle valve**
11. **Engine**
12. **V- Belt**

Fig: 1 Block diagram of the Supercharging equipment

EXPERIMENTS

Initially the tests are performed at a constant speed of 1500 rpm in a normal diesel engine. At this speed for a constant injection timing (29^0 bTDC), the fuel flow rate and the load is varied. For all the operating conditions the cooling water and lubricating oil temperatures are maintained constant throughout the experiment. All the performance parameters and emissions are measured. For the insulated engine, due to higher operating temperatures and further lower ignition delays with insulation in the combustion chamber, the injection timing of 27 ^{0}bTDC is found to give the optimum performance. The above tests are repeated in the insulated engine with alcohol as fuel. For testing the engine under supercharging conditions the specially fabricated supercharging equipment is used.

RESULTS AND DISCUSSIONS

Effect of Insulation on the Volumetric Efficiency

The volumetric efficiency drop mainly depends on the cylinder temperatures in an insulated engine, which in turns depends upon the type and degree of insulation employed. In the present work air-gap insulation both for the piston and liner and PSZ coating for the cylinder head and valve have been incorporated. Fig: 2 shows the variation of the volumetric efficiency drop of the insulated alcohol engine compared with normal diesel engine (NE). The volumetric efficiency drop of an insulated engine is about 10% compared to normal engine at rated load

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Effect of Supercharging on the Insulated Engine

For the supercharging of the engine a separate external blower is used. While calculating the power calculation this power used by the blower is also added. The effect of supercharging on the volumetric efficiency, thermal efficiency, emissions and combustion parameters of the insulated engine are studied and the results are presented below. The supercharging pressures have been varied from 765 mm of Hg to 810 mm of Hg in order to find the optimum pressure at which the volumetric efficiency loss due to the insulation to the combustion chamber is compensated.

Volumetric Efficiency

The engine is supercharged at different inlet pressures for compensating the volumetric efficiency depending upon the load. The variation of volumetric efficiency with Power output for insulated engine at different inlet pressures is shown in Fig: 3. From the figure it is observed that the volumetric efficiency decreases with the increases of power output. However, the volumetric efficiency of the Insulated engine increases as the intake boost pressure increases due to higher amount of air is available for the combustion process. The volumetric efficiency for the insulted engine is higher than the normal engine at a pressure 790mm of Hg at all loads. At pressure more than 790 mm of Hg, excess air is available for the combustion process so supplying more air does not improve the efficiency. So it is concluded from the above figure that 790 mm of Hg is the optimum pressure for supercharging at which the volumetric efficiency losses is compensated.

The volumetric efficiency curves intersect the normal engine volumetric efficiency curve at different points. These intersection points, at different loads give the

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inlet boost pressures which could compensate for volumetric efficiency drop. The boost pressure requirement increases almost exponentially as the engine load increases.

The percentage of boost pressure required at each load is shown in Fig: 4. The maximum 10% volumetric efficiency drop at rated load is compensated nearly at 790mm of mercury (about 4% boost pressure). Relatively, higher boost pressures are required at higher engine loads.

Brake thermal efficiency

The compressor work is deducted from the engine output for the calculation of brake thermal efficiency, since a blower driven by a separate motor is used for supercharging the engine. Fig: 5 shows the variation of brake thermal efficiency with load with super charging at the pressure of 790 mm of mercury. At each pressure the improvement in the thermal efficiency is observed over a narrow load range. The increase in brake thermal efficiency is marginal at lower loads. The reason for the above mentioned trends are: (i) Even in naturally aspirated insulated alcohol engine excess air is available at lower loads and so supplying some more air does not improve the combustion efficiency enough to compensate for the losses involved in compressing the air in compressor and expanding it in engine. (ii) The peak pressures of insulated engine increased uniformly over peak pressures of naturally aspirated insulated alcohol engine. This further increases the frictional losses. Thermal efficiency gain of insulated engine with supercharger is maximum at rated load with the increase of boost pressure and is about 2.5% higher than insulated engine. The thermal efficiency curve of the insulted engine without supercharger lies in between these two extremes.

Combustion parameters

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The peak pressure developed in the combustion chamber depends on the amount of fuel taking part in the uncontrolled combustion process which is governed by the delay period, rate of heat release and spray envelope of the injected fuel. This further depends on the insulation and supercharging. Fig: 6 shows the effect of supercharging on the peak pressures at different power outputs. In the above figure, the peak pressure of normal engine, Insulated engine with and without supercharging are compared. As the load on the engine increases, peak pressure also increases. At the rated load, the peak pressure is maximum and is about 9.95% higher than normal engine at an inlet boost pressure of 790mm of mercury, where as it is 7.7% higher for the BP9 compared to normal engine.

Ignition delay variation with power output for supercharging conditions is shown in Fig: 7. It is observed from the figure that the ignition delay decreases with increase in inlet boost pressure in the low load range due to higher temperatures in the combustion chamber. At higher loads the variation of the ignition delay is low. This is because as the load on the engine increases the alcohol induction also increases. This further absorbs the heat from the combustion chamber and increases the ignition delay due to lower temperatures in the combustion chamber. It is concluded that the ignition delay is lowest at the intake boost pressure of 790 mm of Hg.

Exhaust emissions and temperatures

Due to the better combustion in the hotter environment in the insulated engines the smoke levels are considerably reduced. With supercharging more amount of air is available for the complete combustion. So the smoke emissions are further reduced with supercharged insulted engine. Fig: 8 shows the comparison of smoke number with power output for supercharged conditions. The reduction in the smoke level is found to

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maximum at inlet boost pressures of 790mm of mercury compared with the normal engine at the rated load.

With the increase in boost pressure, more amount of air is available for the complete combustion of alcohol. But with the higher latent heat of vaporization of alcohol it absorbs more heat from the combustion chamber and makes it cool. So the increase in exhaust temperature is only 15^0C to 20^0C compared to the normal engine and this is indicated in Fig: 9.

CONCLUSIONS

The following conclusions are drawn based on the experimental investigations on an insulated diesel engine under supercharging conditions.

1. The increase in the in take boost pressure improves the brake thermal efficiency of the engine.
2. For the compensation of drop in volumetric efficiency of the insulated engine 4% intake boost pressure is required with supercharging.
3. Brake thermal efficiency improves by 2.5% with supercharging when compared with insulated engine.

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4. Volumetric efficiency compensation with supercharging reduces smoke emission by 5% compared to insulated engine.

5. The peak pressures have gone up to 80 bar under supercharging condition at 790mm of Hg of intake boost pressure compared to 72.76 bar in the normal engine.

6. Though the higher temperatures are available in the combustion chamber due to insulation, the increase in exhaust gas temperature is marginal. This is attributed to the higher latent heat of vaporization of alcohol.

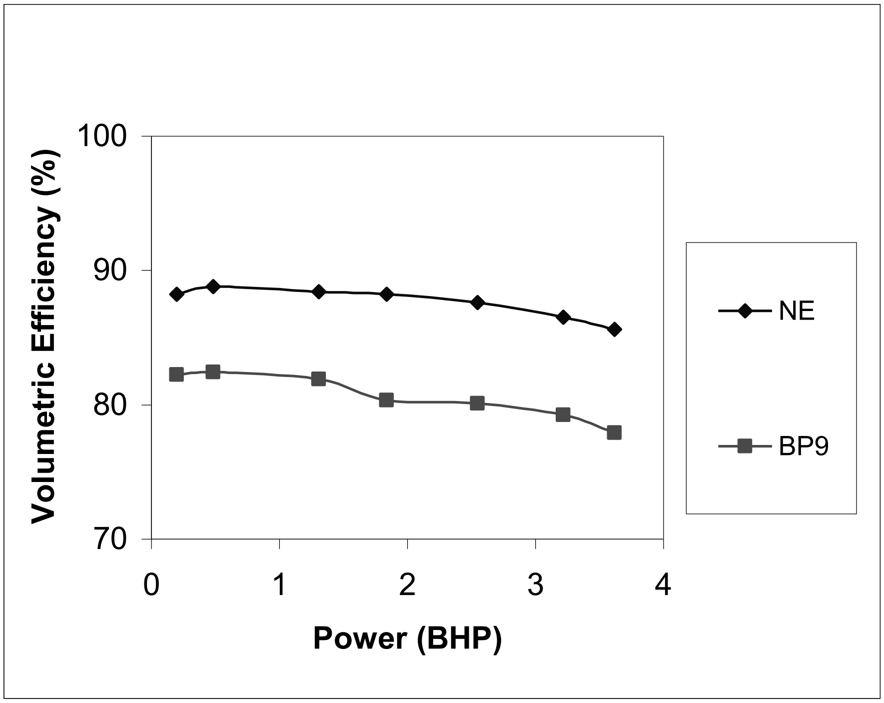

Fig: 2 Variation of Volumetric Efficiency with Power Output

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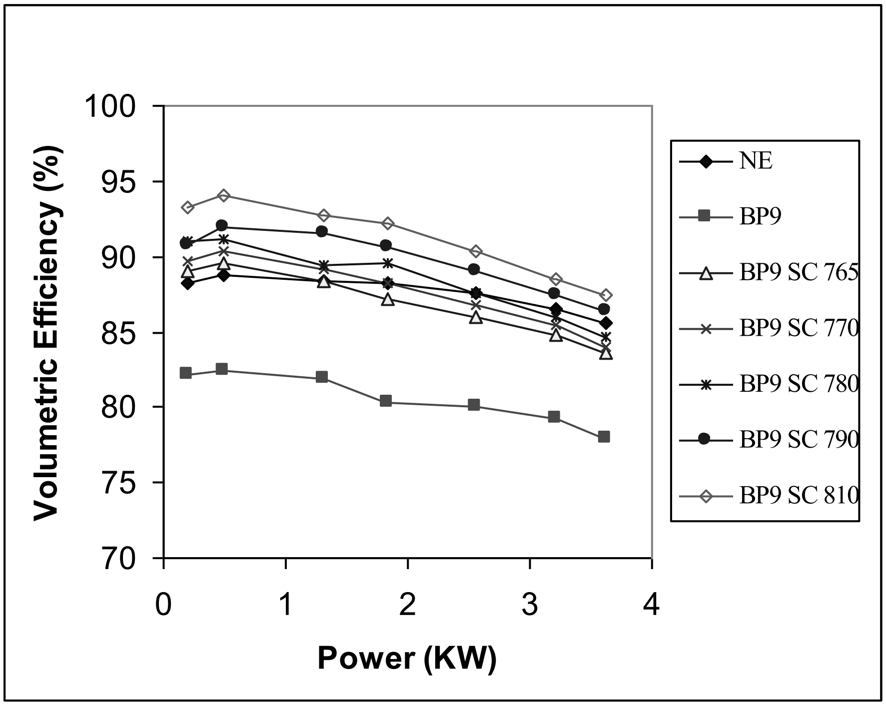

Fig: 3 Variation of Volumetric Efficiency with Power Output For Supercharging

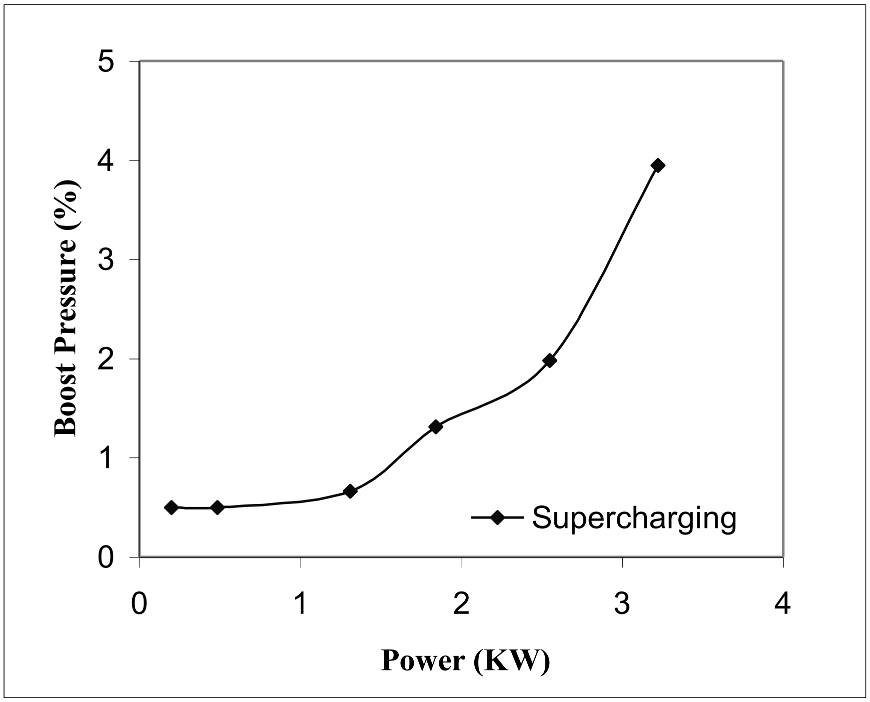

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Fig: 4 Comparison of Percentage of Boost Pressure Required for Volumetric Efficiency Compensation with Power Output in Supercharging

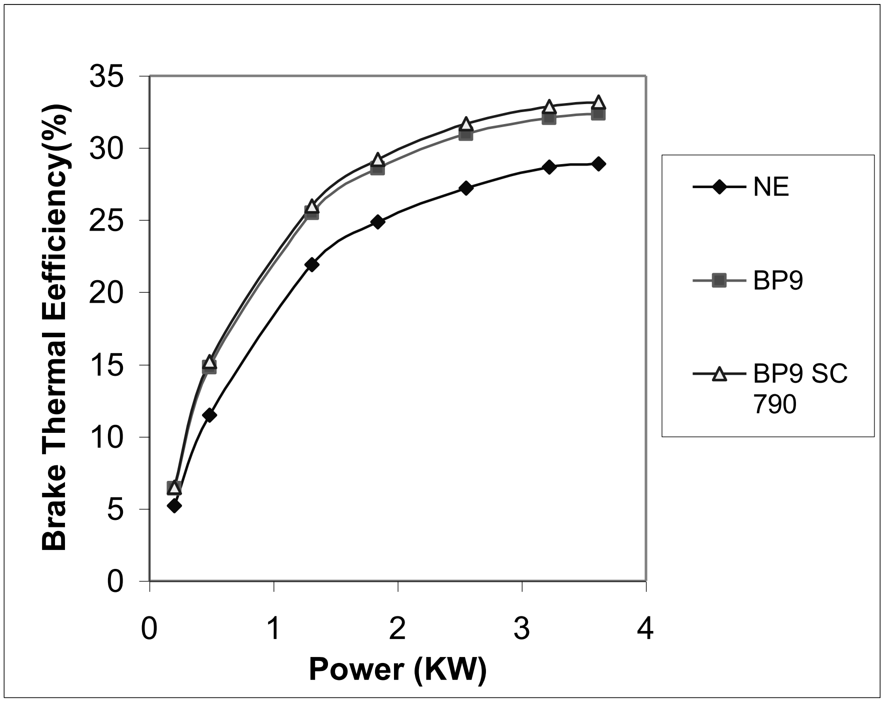

Fig: 5 Comparison of Brake thermal Efficiency with Power Output for Volumetric Efficiency Compensation with Supercharging

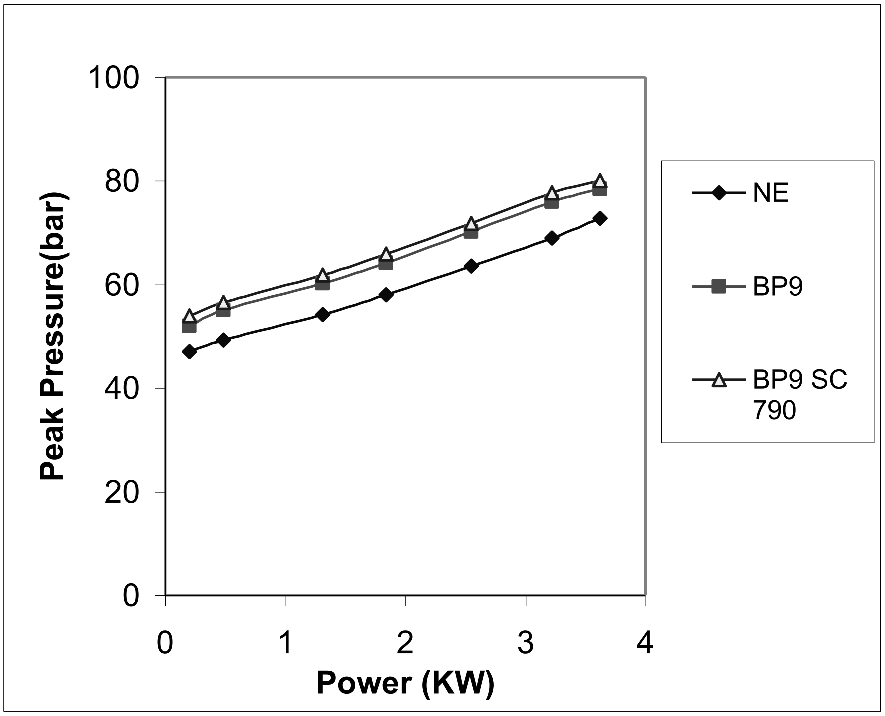

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Fig: 6 Comparison of Peak Pressure with Power Output for Volumetric Efficiency Compensation with Supercharging

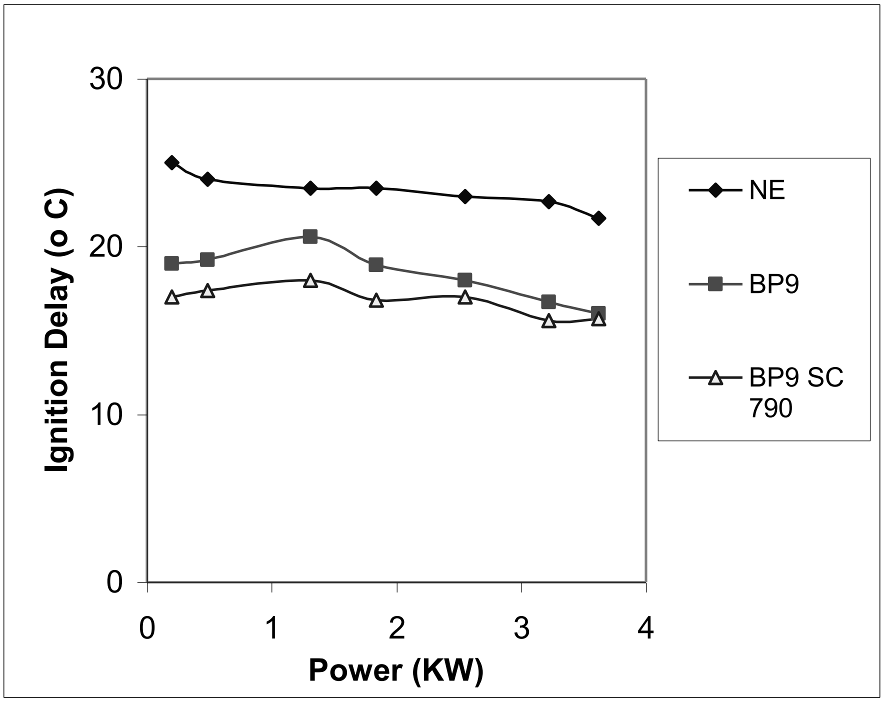

Fig: 7 Comparison of Ignition Delay with Power Output for Volumetric Efficiency Compensation with Supercharging

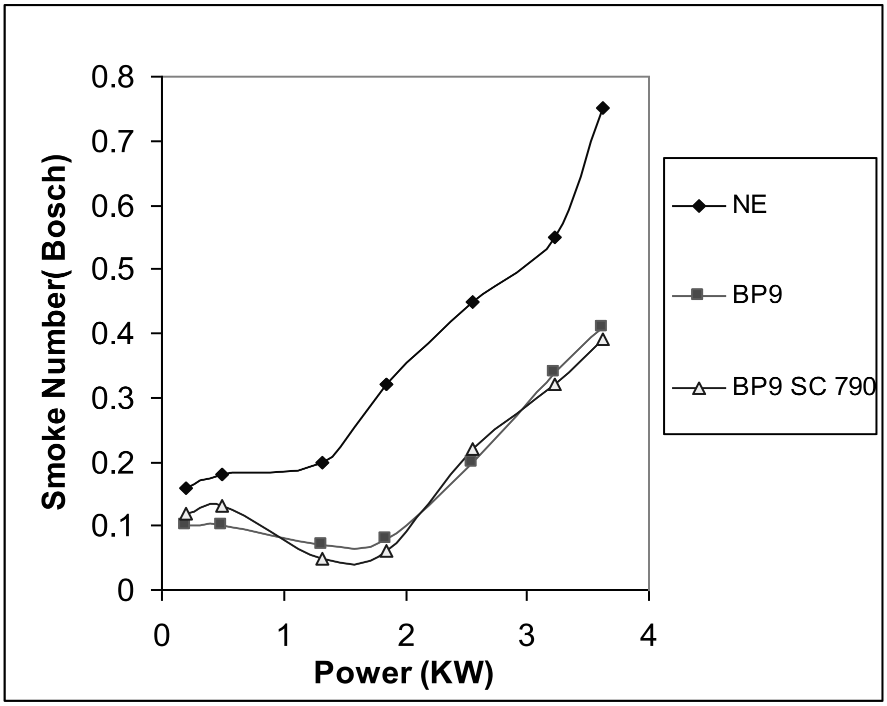

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Fig: 8 Comparison of Smoke Emissions with Power Output for Volumetric Efficiency Compensation with Supercharging

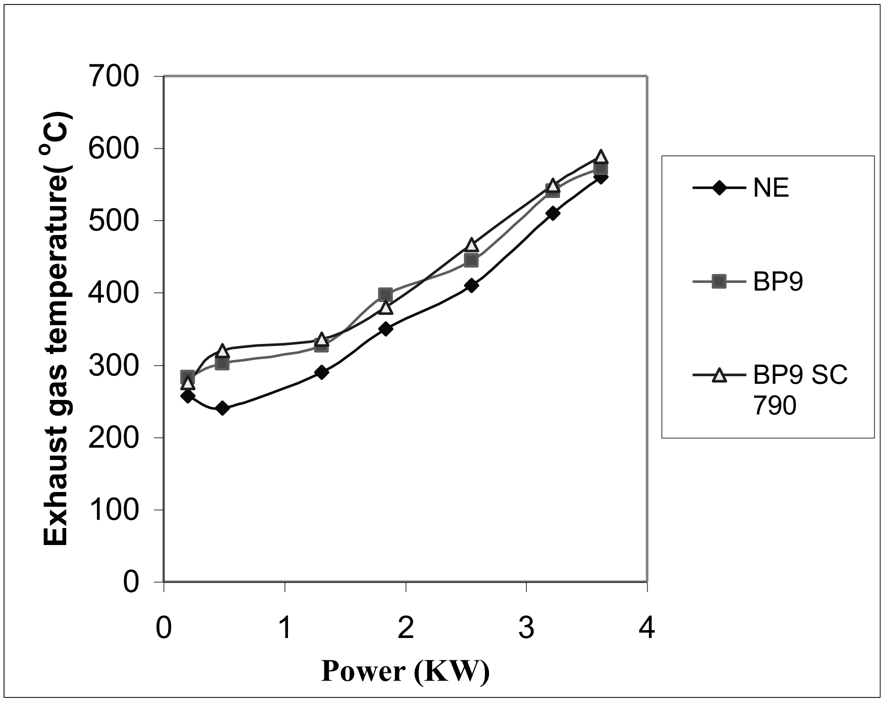

Fig: 9 Comparison of Exhaust gas Temperature with Power Output for Volumetric Efficiency Compensation with Supercharging

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