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Effects of Pressure Boost on the Performance Characteristics of the Direct Injection Spark Ignition Engine Fuelled by Gasoline at Various Throttle Positions

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Abstract

The main objective of this study is to investigate the effect of boost boost and various throttle positions on performance characteristics of direct injection spark ignition (DISI) engine fuelled by gasoline at various throttle positions. The performance characteristics in this experimental study were measured in terms of brake torque (BT), brake specific fuel consumption (BSFC) at various engine speeds (1000 rpm, 2000 rpm, 3000 rpm, 4000 rpm and 5000 rpm), various throttle positions (TP) (25%, 50%, 75% and 100%) and various pressure boosts (10 kPa, 20 kPa, 30 kPa and 40 kPa). The tests have been performed on a 2.0 LITER MIVEC DOHC 16-valve inline, 4cylinder turbocharged direct injection spark ignition (DISI) engine. The results showed that with increase in TP from 50% to 100%, the brake torque (BT) is increase for natural aspirated (Unboosted Engine) engine. For boosted pressure engine, increase pressure boost from 0 kPa to 40 kPa; the BT also increases. The lowest BSFC result occurred at 50% to 100% TP with increasing engine speed. BSFC results at boosted pressure showed the BSFC decrease with increasing in pressure boost up to 10 kPa. Thus it can be concluded that by boosting the intake pressure (turbocharged) is one of effective ways to enhance the performance characteristics of the engine.

Keywords: Pressure Boosts, Throttle Positions, Performance Characteristics, Engine Speeds, Direct Injection Spark Ignition Engine (DISI) and Gasoline.

INTRODUCTION

The ultimate aim of every combustion engine manufacturer is to produce a vehicle that can deliver on high performance, very good fuel consumption and low engine out emissions. The air intake to the ignition chamber is an importance process in internal combustion engine and it can affect the performance of the engine. Most often that none, the reduction in performance experienced by most of the naturally aspirated engine occurred as a result of reduction in volumetric efficiency of the engine which is occasioned by losses that occur during the induction process (i.e., inducting pressure is less than atmospheric pressure) [1]. In view of the above constraint, the engine researchers have been working extensively on the various techniques to counteract these effects in order to produce a high performance engine. Among these are boosting the pressure of the air intake into the system. There is mechanical part in this spark-ignition engine that is use to boost the air intake and is call turbocharger. Figure 1 show the turbocharger cross-section.

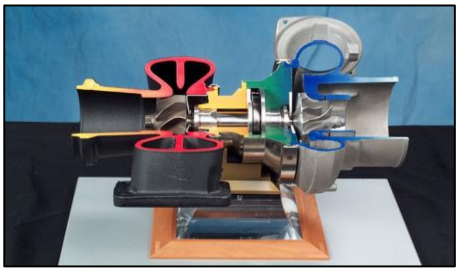

Figure 1: The Turbocharger cross-section with turbine and compressor connected with shaft [2]

The turbocharger is the device that is use in internal combustion engine to force induction to increase the output power and indirectly increase the efficiency of the engine by forcing more air into the combustion chamber. The turbocharger is commonly use on truck, car, aircraft and train. A turbocharger consists of a turbine and a compressor connected by a shaft. The outlet is routed to the engine air intake [1-2]. There are many published literatures regarding the performance and combustion characteristics of the gasoline engine. Ghadikolaei, 2014 [3] study the effect of fuel injection pressure and cylinder air pressure on combustion characteristics of DI gasoline engine. The results revealed that by increase in cylinder air pressure, the ignition delay reduces due to the reduction in the physical delay for diesel. The fuel injection duration of gasoline and ignition delay are longer than diesel and combustion duration decreases as the cylinder air pressure increases. This is because of the gain in the end of compression temperature and pressure and decrease in the fraction of residual gases. Ergenc, Koca, & Abacioglu, 2012, [4] investigate the effect of the various fuel injection advance angles on the combustion quality of bio-diesel blends. At the light of obtained values, no negative impact observed on performance with the addition 20% of ester. It is seen that ester blended fuels capture the peak pressure value in lesser time at relevant injection advance for engine as given in the literature. Bio-diesel addition to diesel fuel at premixed combustion phase raises heat output, reduces the combustion at diffusion phase. Jahagidar, Deore, Patil, & Desale, 2011 [5], investigated the specific fuel consumption of various blends of ethanol and diesel at varying brake loads and compression ratio. From this experimental, the results showed that at 2.138kW and 57% break thermal efficiency of pure diesel and blended with ethanol was almost same. Also observed that 20% ethanol blend is having higher volumetric efficiency and exhaust gas temperature is not showing any substantial increase. Reddy, Pandurangadu, & Hussain, 2013 [6] conducted an investigation on effect of turbocharging on volumetric efficiency of a diesel engine. The results showed that, increasing the boost pressure in diesel engine will increase more air and thermal efficiency for the engine. Till date, none of these researchers have ever examined the impact of pressure boosts on the performance characteristics of the direct injection spark ignition engine fuelled by gasoline at various throttle positions. Therefore study will aimed at study the effect of pressure boosts at various throttle positions on the direct injection spark ignition engine fuelled by gasoline and quantatively analyses the performance characteristics of the engine.

EXPERIMENTAL PROCEDURE

An experiment were conducted with MIVEC DOHC 2.0L, turbocharged, air cooled, four cylinder, 4-valve per cylinder direct injection (DI), spark ignition engine. The test engine specification is presented in Table-1 below.

Table 1: Engine specification

Engine specification	Value/description
Engine model	MIVEC DOHC (4B11 T/C)
Bore x stroke	86.0 mm x 86.0 mm
Cylinder number	4
Displacement volume	2.0L
Compression ratio	9.0:1
Torque	4000 RPM
Max power	291 kW @ 6500 RPM
Fuel injection system	MPI
Aspiration	Turbocharged

The experimental system consist of an engine, eddy current dynamometer, controller, combustion analysis instrumentation, and emission analyzers. The engine was fitted with an electronic control Unit (ECU) that monitors engine performance and control different events automatically. Figure 2 shows the experimental setup. The engine use multi point injection as the fuel system. The experimental works started by directly injecting the gasoline fuel into the cylinder. The amount of the fuel injected into the engine is controlled by the ECU. Also control by the E.C.U is the injection timing. The turbocharger was used to increase the air intake pressure in the inlet manifold with the aid of pressure regulator to regulate the level of the boost; while digital manometer was used to record the level of the boosted pressure in the system. Figure 2. Shows the schematic of the experiment set up.

Combustion Equation Representing Gasoline Combustion

The combustion equation representing the gasoline combustion where the air-fuel ratio utilized for this experiment was determined is given below:

$$C_8H_{18} + Z(O_2 + 3.67\,N_2) \rightarrow A\,CO_2 + B\,H_2O + C\,O_2 \times D\,N_2 \quad (1)$$

0 % of excess air which no excess oxygen exist

100% theoretical air

$$C_8H_{18} + 17.75(O_2 + 3.67\,N_2) \rightarrow 12\,CO_2 + 11.5\,H_2O + 66.74\,N_2 \quad (2)$$

$$stoichiometry\ air : fuel\ ratio = \frac{(mass\ of\ air)}{(mass\ of\ fuel)} \quad (3)$$

Where:

C_8H_{18} represents Gasoline

O_2 + 3.76 N_2 represents Air

CO_2 represents Carbon dioxide

H_2O represents Water

N_2 represents Nitrogen gas

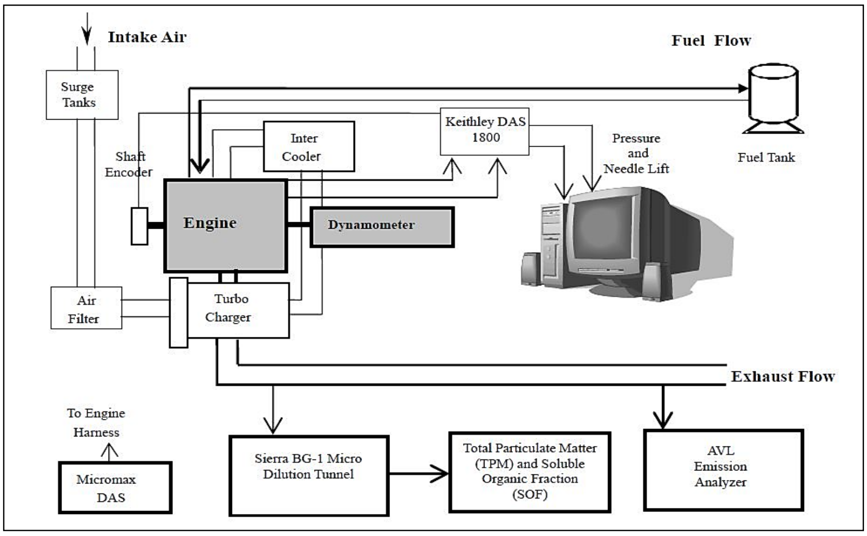

Figure 2: Schematic of the Experimental setup.

RESULTS AND DISCUSSION

This section is focused on the analysis of the results that are obtained from the experiment followed by the discussion.

Performance Characteristics

Brake Torque against Engine Speeds (Unboosted Engine)

The correlation between brake torque (BT) and engine speed of the SI engine subjected to four different throttle positions (TP) is presented in Figure 3. Generally, it can be seen that the BT has decreasing trend for various engine speeds under consideration. This is because, increase in engine speed increases the friction mean effective pressure consequence upon this BT will increases. Comparing the BT at various TP, it reveals that the highest BT occurred at 75% TP while the lowest BT occurs at 25% TP. The reason being that at 75% TP there is high volumetric efficiency of air and this will enhance more air-fuel mixture in the combustion chamber thus the BT will increases. At 25% TP, the BT extremely low compare to other TP and it has a decreasing trend while the engine speed is increased. This is because of low volumetric efficiency, less air/fuel (energy sources) in the combustion chamber. Thus it is plausible to say that 25% throttle position is not suitable for good engine performance at the high engine speed. Comparing the data points at 75% and 25% TP respectively, it reveals that at 1000 rpm, the BT is 104- Nm, while at 3000 rpm, the BT is 92 Nm. This shows that there is approximately 12% decrement in the BT at this operating condition of the engine. While at 25% TP, the BT respectively are 35 Nm and 10 Nm respectively. This shows approximately 70% reduction in BT. This might be due to deterioration in combustion quality occurring a 25% TP. Good agreement is achieve between this experimental results and [1,7 and 8].

Brake Torque (BT) against Pressure Boost

The relationship between brake torque (BT) and pressure boost of the SI engine subjected to four different engines speed is presented in Figure 4. Obviously, it can be seen that the brake torque has increasing trend for various engine speeds under attention. This largely due to the fact that increase in boosted pressure leads to increase in volumetric efficiency which promotes combustion process; consequence upon this BT will increase. Comparing the BT at various engine speeds, it reveals that the highest BT is occurring at 4000 rpm, while the lowest BT occurs at 5000 rpm engine speed. The reason why the highest the BT is occurring at 4000 rpm is largely due to the fact that increase in engine speed increases the burning velocity and combustion temperature during the combustion process and consequent upon this, the BT will increases. In addition, comparing the pressure boost against various engine speeds under consideration. It can be observed that 5000 rpm gives the highest pressure boost of 40 kPa while 2000 rpm gives the least pressure boost of 10 kPa. This is so, because high engine speed such as 5000 rpm will enhance greater turbulence within the engine cylinder and the greater turbulence requires more air pressure boost to increase the airflow velocity into the engine. Thus, we can conclude from the foregoing that in a direct injection spark ignition engine fuelled by gasoline, the maximum pressure obtainable that is best for engine performance is approximately 40 kPa. Good agreement is achieved between this experimental result and [1, 9].

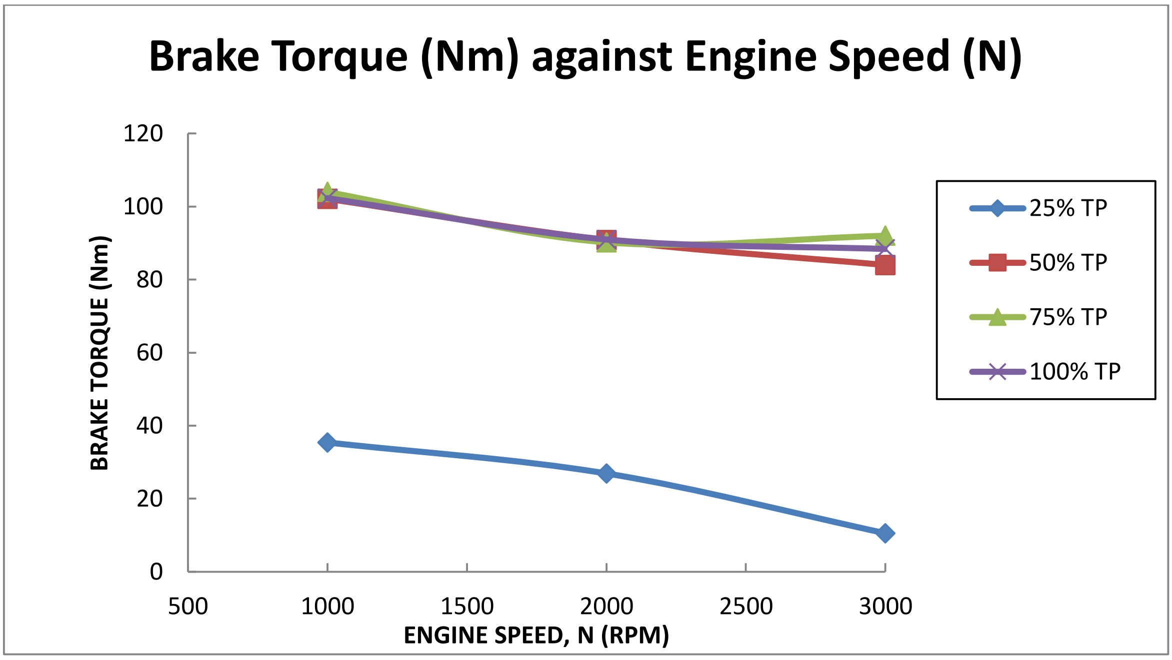

Figure 3: Brake torque against speed of engine at various throttle positions (TP)

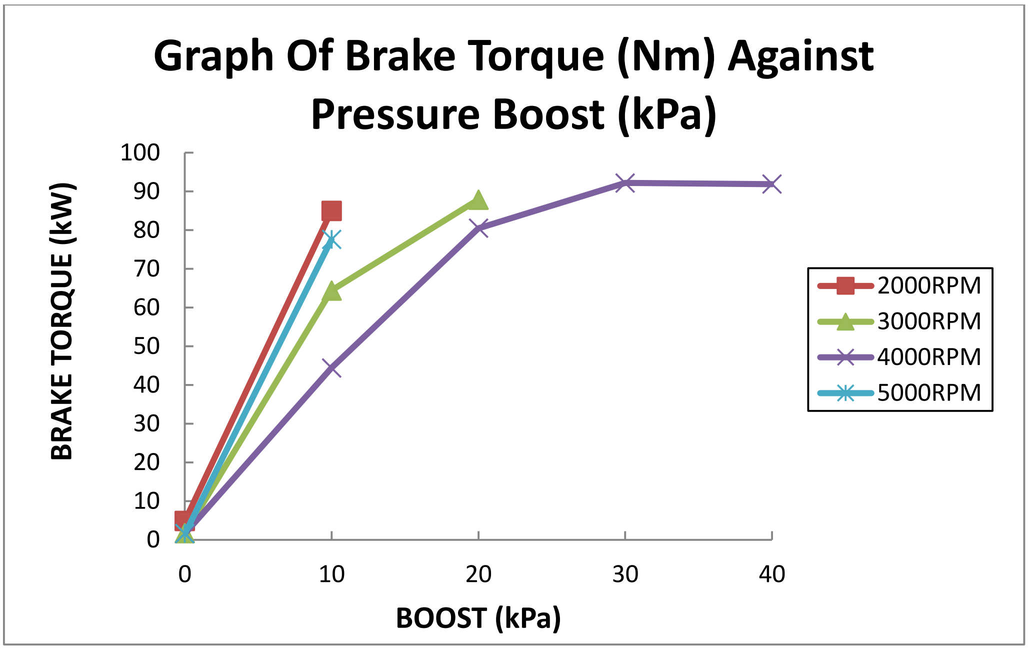

Figure 4: Brake Torque against Pressure Boost at various engine speeds

Brake Specific Fuel Consumption against Engine Speeds (Unboosted Engine)

The figure 5 shows relationship between brake specific fuel consumption (BSFC) and engine speed of the SI engine with four different throttle positions (TP) which are 25%, 50%, 75% and 100%. It can be seen that the BSFC has constant trend line for 50%, 75% and 100% TP while increasing the engine speed. This might be so because of decrease in combustion efficiency occurring at that operating condition of the engine. Exception to this observation occurs at 25% TP which shows increment in BSFC from 1000 rpm up to 3000 rpm before it starts to decrease. The reason might be due to cycle-cycle combustion variation occasioned by variation in mixture compositions. Comparing the BSFC at various TP, it reveals that the highest BSFC is occurring at 25% TP. The reason for this might be due to high coefficient of variation (COV) which leads to high cycle by cycle combustion variation in the engine cylinder. While at the other TP, BSFC remain constant. Good agreement is achieve between this experimental result and [10].

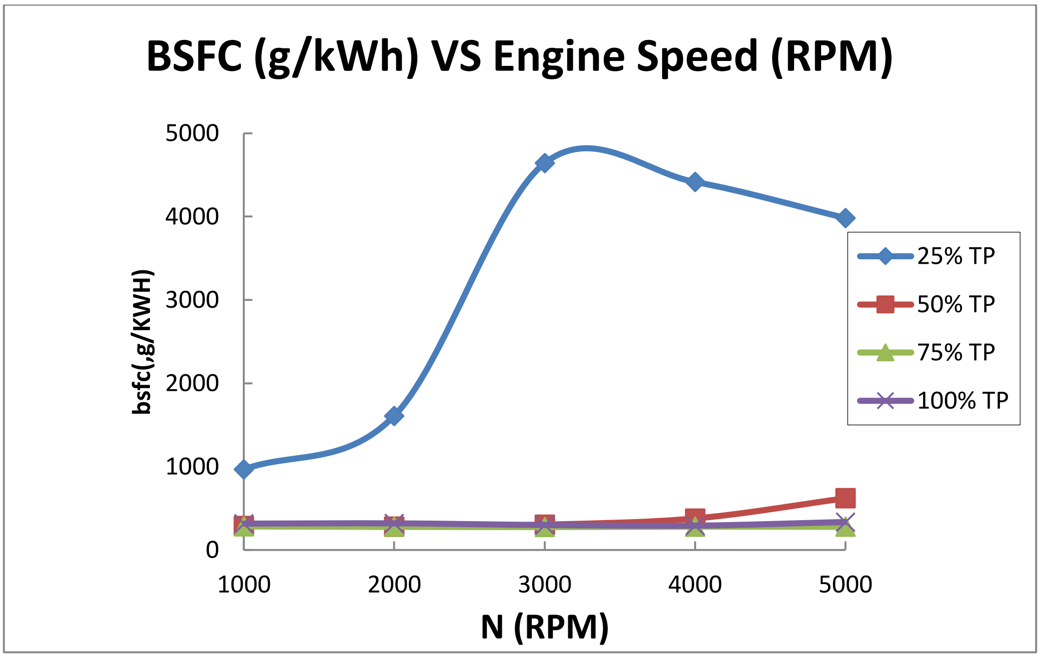

Figure 5: BSFC against Engine speed at various Throttle positions.

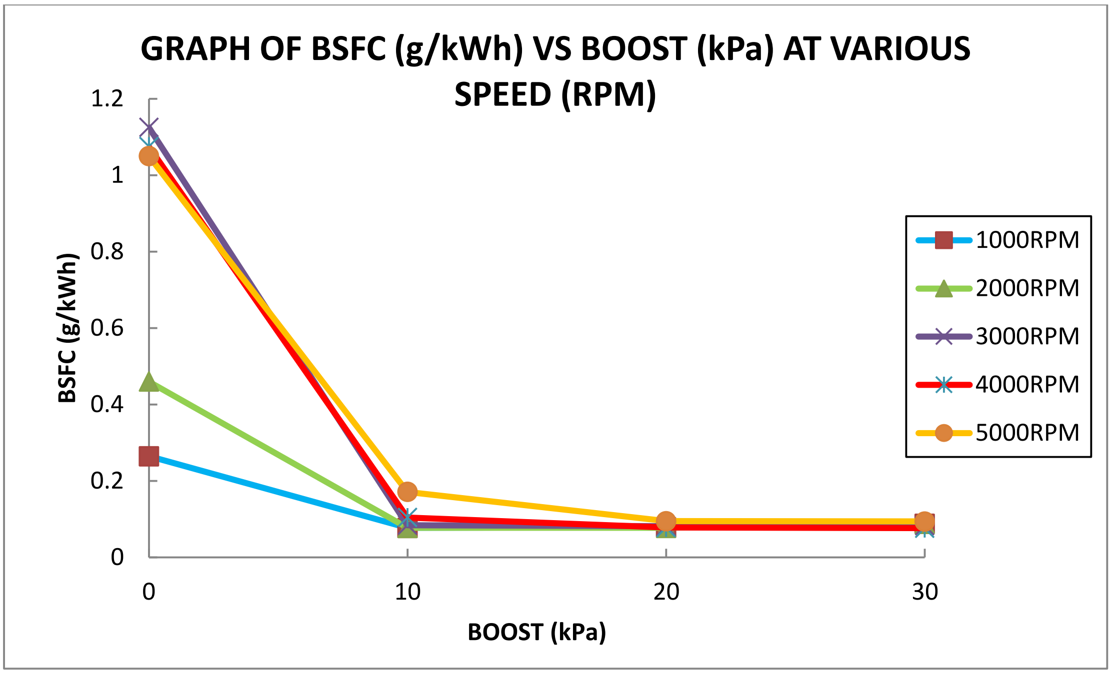

Figure 6: BSFC against Pressure Boost (boosted engine) at various Engine speeds

Brake Specific Fuel Consumption against Pressure Boost at Various Engine Speed (Boost Engine)

Figure 6 shows the relationship between BSFC against pressure boost with different engine speed. Generally, it can be seen that the BSFC has decreasing trend by increasing the boost up to 10 kPa at different speed of the engine (i.e. from 0 kPa to 10 kPa pressure boost, the BSFC for all engine speed is drastically decreased. This represents an improvement in fuel consumption at this operating condition of the engine. This is because higher pressure in the inlet causes higher volumetric efficiency in the engine which reduce the amount of fuel needed for the combustion process, hence the reason for the decrement in BSFC at this operating condition of the engine. While from 10 kPa to 30 kPa pressure boost; the BSFC is lowered and remain constant at all engine speed. This might be so because of increasing fuel conversion efficiency. Thus it is plausible to say that in a direct injection spark ignition engine fuelled by gasoline, a pressure boost of up 10 kPa is the best for fuel economy while from 20 kPa up to 30- kPa may be generally good for fuel economy. Good agreement is achieve between this experimental result and [11].

CONCLUSION

An experimental study has been performed on the effects of pressure boost and various throttle positions on the performance characteristics of the direct injection spark ignition engine fuelled by gasoline (petrol) at stoichiometric mixture and at different engine speed. The main results are summarized below:

- Brake torque for natural aspirated (Unboosted) engine is increased by increases the throttle positions. This is because increase in TP increases the acceleration of air into the engine and this enhances the mixture of air/fuel in the combustion process. For boosted pressure engine, brake torque increases with increase the boost pressure. This is due to the change in volumetric efficiency and increase friction force at the higher engine speed.
- Brake specific fuel consumption (BSFC) for natural (Unboosted) aspirated engine has approximately constant trend line for all the throttle positions under consideration with the exception being at 25% TP. For boosted pressure engine the BSFC showed a drastically reducing trend with the increasing in the pressure boost up to 10 kPa. This is because higher pressure in the inlet causes higher volumetric efficiency in the engine which reduces the amount of fuel needed for the combustion process.

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