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PERFORMANCE OF A GASOLINE ENGINE FUELLED WITH NATURAL GAS: EFFECT OF SPEED AND IGNITION TIMING

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ABSTRACT
This research work is aimed at investigating the effect of variation of speed and spark advance settings on the performance of a spark ignited gasoline engine fuelled with natural gas without any design and operational modification. Study is carried out for two modes of operation-one with gasoline fuelling for baseline data generation and another one with natural gas for four different engine speeds at different engine loading conditions at three different spark advance settings and then various engine performance parameters (maximum brake power, brake specific fuel consumption, exhaust temperature, peak cylinder pressure, rate of pressure rise etc) are analyzed and reported. Finally the effect of speed and spark advance setting on the performance parameters are compared for the two fuels. Results show that for the same speed and spark setting, the conventional gasoline engine has lower power, higher bsfc, and higher engine operating temperature with NG fuelling and more sensitive to change in speed and spark settings than with gasoline. For gasoline at higher speed, the change of spark setting has no significant effect on the engine performance. While for NG, the change of spark setting leads to considerable improvement in performance over the entire speed range. Moreover, NG fuelling causes moderate pressure rise, so high speed operation can be carried out smoothly compared to gasoline fuelling.

Keywords: Gasoline, Natural Gas, Speed, Ignition Timing.

1. INTRODUCTION

Use of natural gas has widely been initiated for three wheelers, cars and buses in Bangladesh due to its huge reserve and consequent low price and low emission characteristics. Bi-fuel type SI engines are used mainly which can run both with gasoline and natural gas with very minor modification in the conventional gasoline engine design. This paper examines the effect of using various speed and spark settings on the performance of a bi-fuel type SI engine run with gasoline and natural gas.

The properties of fuel used may have considerable influence on the design, output power, efficiency, fuel consumption and in many cases the reliability and durability of the engine [1]. The several factors affecting the low performance of a modified SI engine run by natural gas are loses in volumetric efficiency, low flame speed, low compression ratio, absence of fuel evaporation, change in stiochiometric air/fuel ratio [2].

On gaseous fuel operation [3], spark timing influences all the major operating parameters such as specific fuel consumption, thermal load, power output and the tendency to knock. Optimum ignition timing depends on engine load, speed, excess air ratio, type of fuel used, pressure and temperature. So spark timing requires adjustment towards optimum to achieve maximum indicated power output with smooth running and high efficiency and lower exhaust emissions.

It is an established fact that the burning speed and heat release rate for natural gas-air mixture is usually lower than that of a gasoline-air mixture, so that the spark timing may need to be advanced [4]. The ignition timing influences the peak flame temperature and exhaust temperature through the influence of the timing on the peak heat release and combustion duration, which is also influenced by the air-fuel ratio.

There exists a particular spark timing which gives maximum engine torque at a fixed speed and mixture composition. It is referred to as maximum brake torque, MBT timing which also gives maximum brake power and minimum bsfc [5]. The MBT timing depends on speed, as speed increases the spark must be advanced to maintain optimum timing because the duration of the combustion process in crank angle degrees increases.

The present paper reports the effect of various speed and ignition timings on the maximum brake power, brake specific fuel consumption, exhaust temperature, lubricating oil temperature and ignition plug seat temperature in a conventional gasoline engine fueled with gasoline and natural gas. Cylinder pressure variation with crank angle (P-θ diagram) and rate of pressure rise with crank angle (dP/dθ) are also investigated with the variation of speed and spark setting.

2. EXPERIMENTAL SET-UP AND METHODOLOGY

The standard engine test bed was equipped with necessary instrumentation for measurement of engine performance. Detailed specification of the typical automotive SI engine mounted on the test bed is given below.

Engine Specification

Engine Model : A12
Engine Manufacturer : Nissan Motor Co. Ltd., Tokyo, Japan
Type : water cooled, in line 4 cylinder, 4 stroke, gasoline engine
Bore x stroke (piston displacement) :73 x 70 (1171 cc)
Compression ratio : 9 to 1
Firing order : 1-3-4-2
Ignition timing at idle speed (B. T. D. C degree/rpm) : 12^0/650
Power at specific rpm : 30 hp / 3200 rpm (max)

A water brake dynamometer equipped with load changing facilities using water flow control and adjusting the impeller angles was coupled with the engine using a universal joint. A calibrated load cell with digital display was used to measure the torque. A magnetic pick-up transducer with digital display was used for engine speed measurement. A graduated measuring flask was used to measure the gasoline consumed volumetrically in a time period measured using a stopwatch. RTD were provided to measure the temperatures of cooling water at engine inlet and outlet, intake air and exhaust gases, lubricating oil and engine body (spark plug seat).

For operating with natural gas, a manually operated valve was installed in the natural gas supply hose to control the flow-rate of NG with the variation of engine loads and speeds. A rotameter was fitted after the valve in order to measure the volume flow-rate of NG as a percentage of maximum flow-rate through it. The NG supply hose was connected with the air inlet line through a metal tube which had many small holes on its periphery to inject gas, in the form of jets, for proper mixing of air with NG. So air-fuel mixing took place before the carburetor unlike gasoline fuelling. Gasoline supply line to the carburetor was kept closed by means of a valve during NG fuelling. The throttle position was controlled manually with the variation of flow-rate of NG.

A strain gage type pressure measuring transducer was used for recording instantaneous cylinder pressure. An inductive type TDC detector (proximity switch) was provided to send a trigger signal, whenever the cylinder, in which the pressure transducer has been attached, reaches the TDC. From the time series of TDC signals recorded, the corresponding crank angle was calculated using a linear relationship between total cycle time and total crank angle (720^o).

For baseline data generation, the engine was run with gasoline at four different speeds (2000, 2300, 2600 and 2900 rpm) and at factory specified spark advance setting (15^0 btdc) varying the load from 50% to full load. The engine parameters like air flow, fuel flow, temperature of exhaust gas, lubricating oil and ignition plug seat etc were recorded for each speed and load. At each setting, maximum available power and minimum bsfc was obtained as operating point. The instantaneous pressure diagram was recorded at this point. The tests were then repeated for the same engine loads and speeds, varying the spark settings (10^o and 20^o btdc). The entire procedure as described was repeated for NG fuelling.

The data recorded were then processed for analyzing the effect of different operating conditions of speed and SA settings on the performance parameters like output power, bsfc, exhaust gas temperature, lubricating oil temperature, engine body temperature etc for both gasoline and NG fuelling. The effect on peak pressure and its occurrence and rate of pressure rise with crank angle (dP/dθ) at MBT were also investigated for the two fuels.

3. RESULTS AND DISCUSSION

The results are presented below for the steady state performance obtained with the fuels, gasoline and natural gas, operated at various operating conditions.

Maximum Brake Power

Investigations revealed that for gasoline (figure 1) at comparatively lower speed (2000 rpm), output power is similar for 15^0 and 20^0 SA setting and much higher than that for 10^0 SA. At higher speeds (2300, 2600, 2900 rpm) as the spark setting is gradually increased from 10 to 20 deg btdc, the effect of spark setting on the maximum output power is found to diminish.

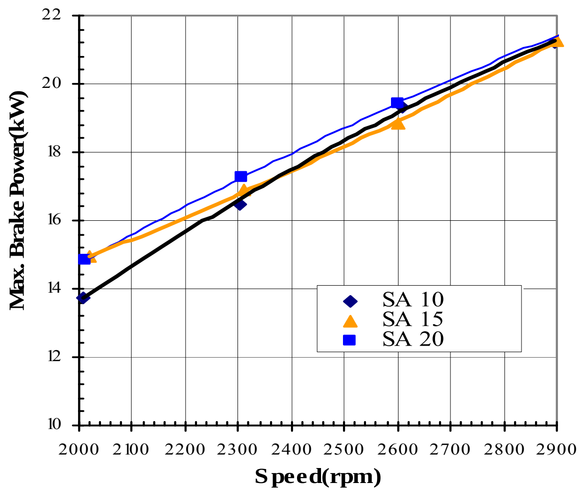

Fig 1. Maximum Brake power for Gasoline

In case of natural gas (figure 2) gradually increasing spark setting from 10^0 to 20^0 results in gradual improvement of maximum brake power at all speeds and therefore the spark setting of 20 deg btdc gives highest output power at all investigated speed levels compared to other spark settings. It indicates that as speed increases, the duration of the combustion process in crank angle degrees increases slightly and unless the spark is advanced the combustion would continue too late in the expansion stroke causing a loss of power.

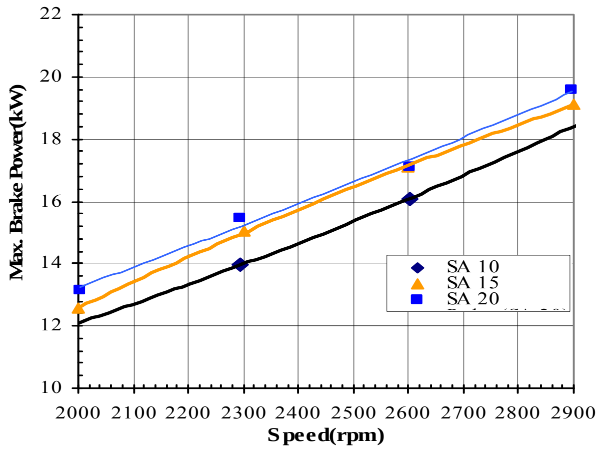

Fig 2. Maximum Brake power for NG

In all cases, the maximum available power is approximately 10-20% lower for natural gas compared to that with gasoline. This finding conforms to the fact that burning velocity and energy density per unit volume of NG in the stoichiometric mixture are lower than those of gasoline.

Specific Fuel Consumption

Plot of bsfc vs. speed at different spark settings for gasoline (figure 3) shows that, bsfc is lowest for 15^0 SA setting at 2000 rpm. At higher speeds, gradually advancing spark setting from 10^0 to 20^0 results in gradual improvement of bsfc. So 20^0 SA setting gives lowest bsfc at high speed operation. At each spark setting the bsfc

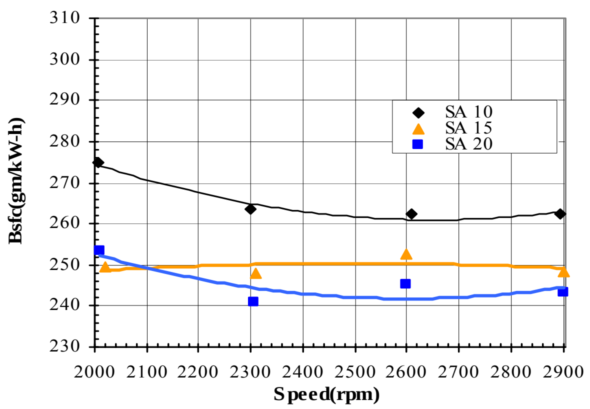

Fig 3. Minimum Bsfc vs. Speed for Gasoline

remains more or less constant within the range of speed 2300-2900 rpm for gasoline. Similar plot for NG (figure 4) shows that the bsfc gradually reduces at all speeds with advancing spark setting giving lowest value at 20^0 btdc. Moreover, at each spark setting the bsfc reduces with increase in speed. So, operation of the engine with NG will be more economic if the engine is operated at higher speed and the spark setting is advanced further.

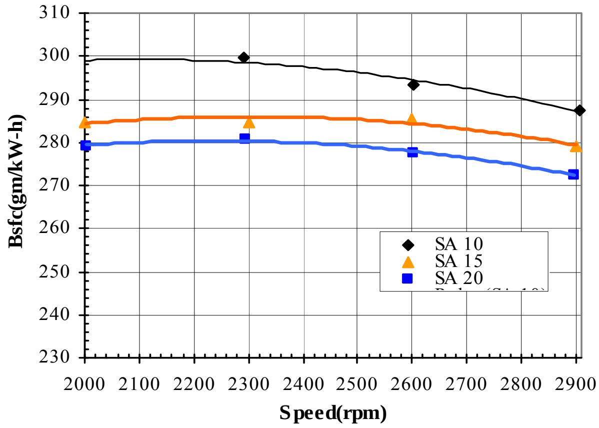

Fig 4. Minimum Bsfc vs. Speed for NG

The specific fuel consumption is always higher with NG operation compared to gasoline operation at all speeds and spark settings. Depending on the speed and the spark setting, the difference in bsfc varies between 8-16%. Due to longer ignition delay, major portion of NG is burnt in expansion stroke which cannot be converted into work thus resulting in higher bsfc.

Exhaust Gas Temperature

For both gasoline and NG operation, the 10^0 SA setting gives the highest temperature of exhaust gases at all speeds. For gasoline (figure 5), the exhaust gas temperatures are almost similar for 15^0 and 20^0 SA. For NG (figure 6), the exhaust temperature is the lowest in all

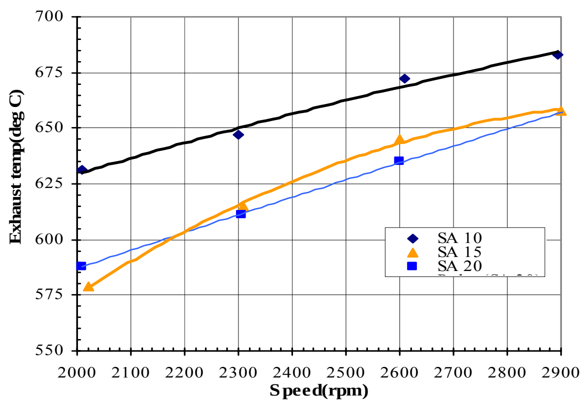

Fig 5. Exhaust Temperature variation for Gasoline

cases when the spark setting is 20^0 btdc. On full load, the exhaust temperatures with NG are higher (maximum difference 30^0C) than that with gasoline for all operating conditions. However, at very low loads the exhaust temperatures for NG are lower than that for gasoline at all investigated speeds and spark advance settings. So low load performance of the engine with NG is better than with gasoline regarding exhaust gas temperature.

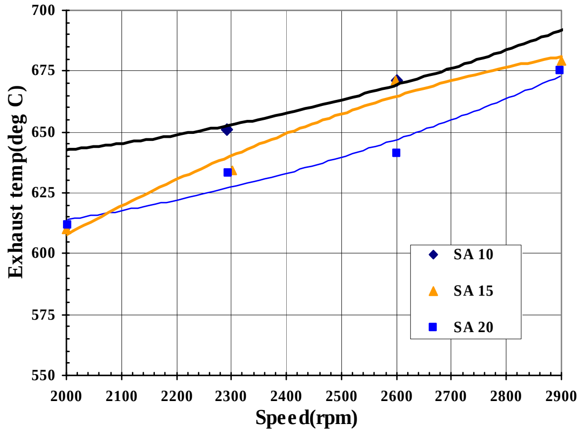

Fig 6. Exhaust Temperature variation for NG

Advanced spark timing increases ignition delay but decreases burn time, therefore the combined effect is a decrease in total combustion time [6]. The decrease in total combustion time increases the burned gas temperature. A major portion of that heat is converted into work during expansion. Again, as the residence time is higher in combustion chamber for advanced spark timing, lower exhaust gas temperature will be obtained due to heat loss during the expansion and exhaust strokes.

Ignition Plug Seat Temperature

For gasoline (figure 7), the ignition plug seat temperatures on full load are more or less similar at all spark settings for the entire speed range. In case of NG,

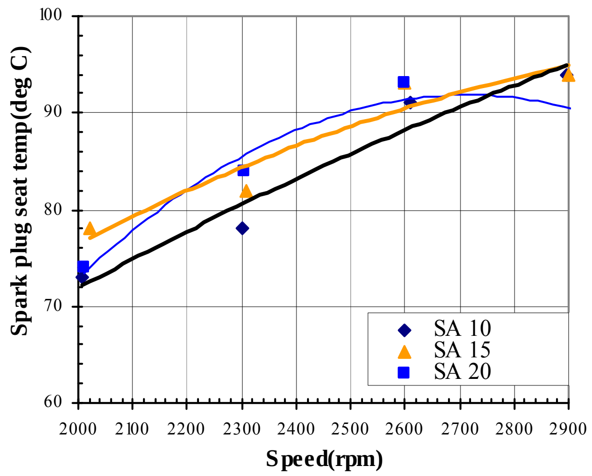

Fig 7. Spark plug seat Temperature for Gasoline

20^0 SA setting gives lowest seat temperatures at all speeds. The seat temperature at 2000 and 2300 rpm shows no significant variation with spark timing for 15^0 and 20^0 SA. At 2600 and 2900 rpm, 10^0 and 15^0 settings give similar seat temperatures. The variation of seat temperature with output power at 2900 rpm for NG is shown in figure 8.

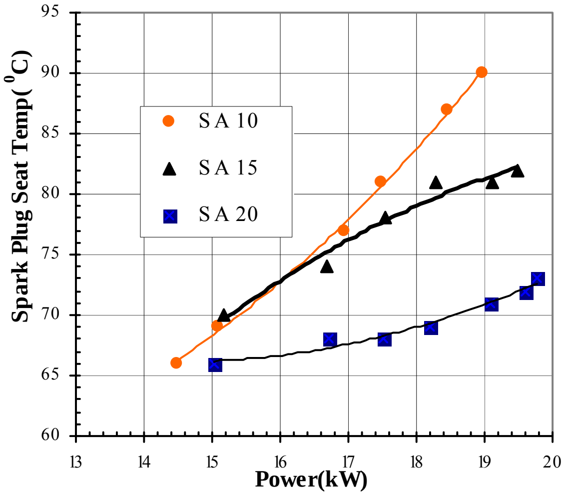

Fig 8. Spark plug seat Temperature at 2900rpm For NG

On full load operation, NG fuelling gives higher seat temperature than gasoline fuelling at lower speed and lower temperature at higher speed. It indicates that the heat loss to cylinder wall is lower for NG fuelling compared to gasoline fuelling at high speed. So high speed operation with NG is favorable.

Due to lower heat release rate, major portion of NG is burnt in expansion stroke. So the time available for heat transfer is less than that with gasoline fuelling which results in a corresponding decrease in the ignition plug seat temperature for NG at high speed.

Lubricating Oil Temperature

The plot of lubricating oil temperature variation for gasoline (figure 9) shows that oil temperature is the

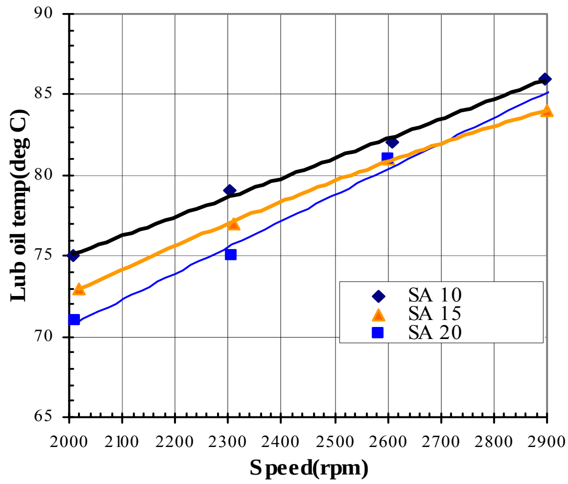

Fig 9. Lube oil Temperature for Gasoline

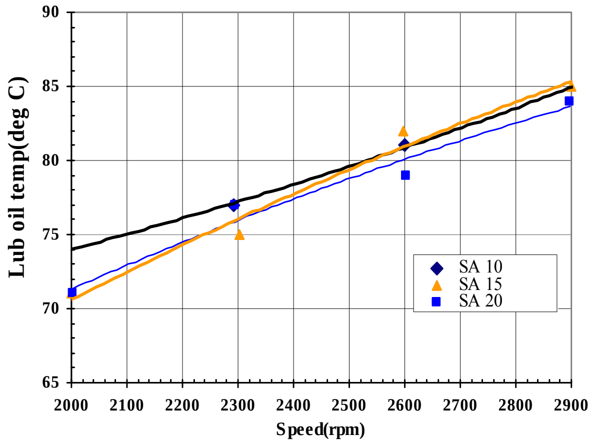

Fig 10. Lube oil Temperature for NG

highest at 10^0 SA at all speeds. At 15^0 and 20^0 SA, oil temperatures are very close in value particularly for higher speed. Similar thing is observed for NG (figure 10) at 2000 and 2300 rpm, while at 2600 and 2900 rpm no appreciable change in temperature is observed with spark settings. For NG, 20^0 SA gives slightly (2^0C) lower temperature at higher speeds. In general the lubricating oil temperature is higher for operation with NG at entire load range.

P-θ Diagram

At all speeds, the minimum peak pressure is obtained at 10^0 btdc for both gasoline and NG (figures 11 & 12).

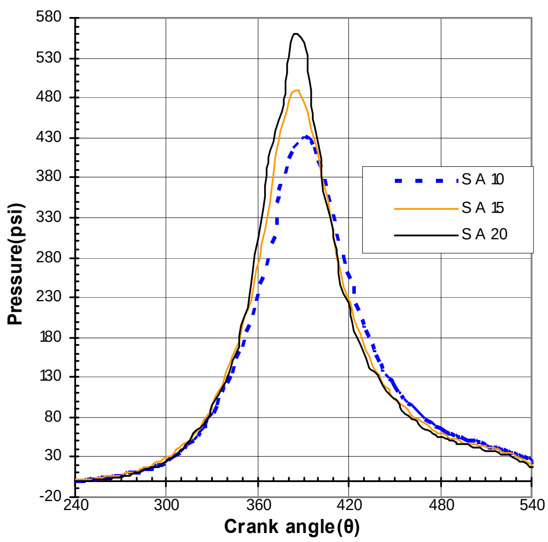

Fig 11. Cylinder Pressure variation for gasoline

For NG, the peak pressures at $20^0$and 15^0 btdc settings are very close in value at all investigated speeds. The peak pressure at 20^0 btdc SA is found comparatively earlier than that at 15^0 btdc SA. For all operating conditions peak pressure is noticeably lower for NG than that for gasoline which justifies lower amount of power production with NG compared to that with gasoline fueling.

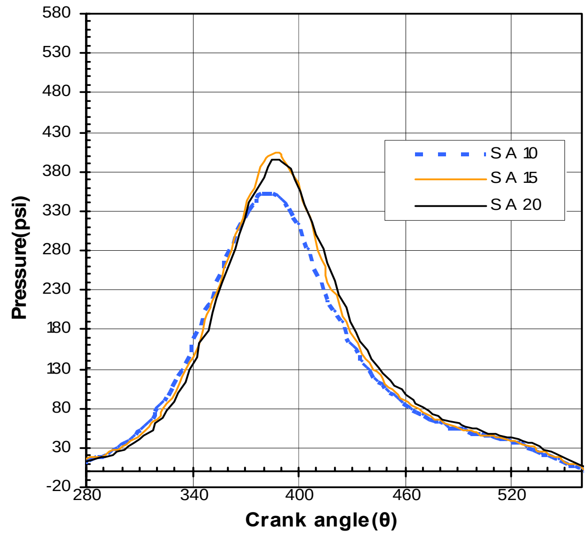

Fig 12. Cylinder Pressure variation for NG

Rate of Pressure Rise and Knocking Tendency

The rate of pressure rise (dP/dθ) vs. crank angle diagram is shown in figure 13 and 14. For same speed

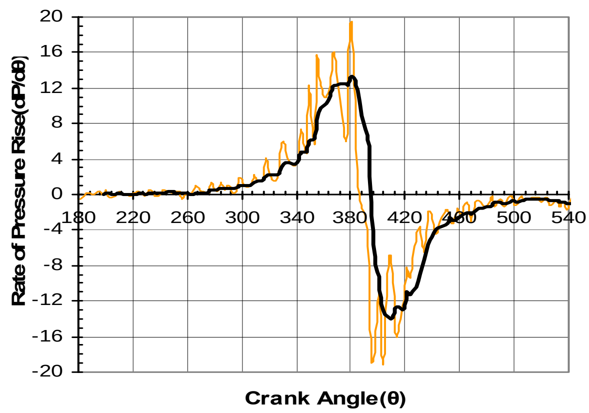

Fig 13. Pressure rise rate at 2600 rpm for gasoline at SA=20

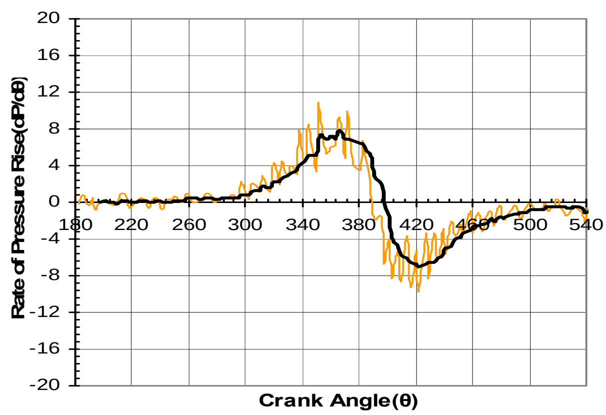

Fig 14. Pressure rise rate for NG at 2600 rpm, SA 20

and spark setting, the curve for gasoline rises and falls sharply and pressure rise rate is much higher than that for NG. So gasoline creates sudden pressure rise which may cause heavy knock. For NG fuelling knocking tendency will be much less which indicates relatively smooth running of engine compared to gasoline fuelling.

4. CONCLUSIONS

Gasoline Engine performance characteristics are found to be inferior in some respect with natural gas which justifies the requirement of design and operational modification of SI engine before shifting from gasoline. With NG, the conventional gasoline engine has lower power, higher bsfc, operating temperature is also higher and more sensitive to change in speed and spark settings than with gasoline. Appreciable improvement of maximum brake power and bsfc are obtained by carefully selecting spark setting for NG over the entire speed range. Operation of the engine with NG will be advantageous if the engine is operated at higher speed and the spark setting is advanced further. As NG fuelling causes moderate pressure rise compared to gasoline fuelling, high speed operation can be carried out smoothly.

5. REFERENCES

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6. NOMENCLATURE

Symbol	Meaning	Unit
Bsfc	brake specific fuel consumption	(gm/kW-hr)
Btdc	before top dead centre	(-)
IC	internal combustion	(-)
MBT	maximum brake torque	(-)
NG	natural gas	(-)
P	pressure in the cylinder	(psi)
RTD	resistance temperature detector	(-)
SA	spark advance	(-)
SI	spark ignition	(-)
TDC	top dead centre	(-)
θ	crank angle	(Degree)