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Performance Evaluation of Multi-Fuel Spark Ignition Engines

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ABSTRACT

An experimental investigation was conducted on a spark ignition engine using Gasoline and CNG . The aim is to compare the effects of both fuels on the steady and transient performance of the engine as well as the exhaust emission characteristics .
A complete facility for the testing was constructed and operated. The test rig includes, besides the 1.301 litre spark ignition engine and the Heenan hydraulic type dynamometer, all instrumentation necessary for evaluating engine steady and transient performance, and exhaust pollution characteristics. The test rig was also furnished with computer controlled data acquisition systems.
It was concluded that using CNG increases the brake specific fuel consumption and decreases the volumetric efficiency, brake thermal efficiency, and exhaust gas temperature. It also increases CO concentration in the exhaust gases at full loads but slightly decreases it at part loads. The propane and methane hydrocarbon emissions are increased with CNG at all engine operating conditions . The mixture equivalence ratio studied has the greatest influence on engine performance and emission. The transient acceleration test results showed that using CNG decreases engine response to a sudden acceleration than using gasoline. The transient load acceptance test results showed that using CNG decreases the ability to overcome the sudden load than gasoline.

KEYWORDS : CNG as engine fuel – Spark Ignition – Natural gas .

NOMENCLATURE :

CNG	compressed natural gas
HC_{meth}	hydrocarbon methane
HC_{prop}	hydrocarbon propane
CO	carbon monoxide
CO_2	carbon dioxide
HC	hydrocarbon
NO_x	nitrogen oxides
BP	brake power

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INTRODUCTION

Over the years since the invention of the internal combustion engines, plenty of related researches have been carried out. The prime objective was mainly devoted towards improving the engine efficiency, specific power and reliability.
In addition to this, many researches and developments as the issue of air pollution, fuel cost and market competitiveness has become increasingly important [1-5].
The spark ignition engines are one of the major sources of air pollution [6]. Their exhaust gases contains oxides of nitrogen (nitric oxide NO, and small amount of nitrogen dioxide NO_2 – collectively known as NO_x), carbon monoxide (CO), and organic compounds which are unburned or partially burned hydrocarbons (HC). The relative amounts depend on engine design and operating conditions. These compounds affect our environment and human health in many ways. So many techniques have been developed to reduce these compounds such as controlling the air to fuel ratio in the mixture, or controlling the combustion process, or using alternative fuels, and treating the exhaust gases.
The fuel cost is an important factor in spark ignition engines. So alternative fuels such as natural gas was used due to its favorable cost advantage over gasoline. The popularity of engine conversion to natural gas has increased recently. However, fuel cost rather than energy efficiency has been the primary motovation behind these engine conversions, and little emphasis has been placed on the anti-nock, wide flamability, and emission characteristics of natural gas. Some researchers have made theoretical analyses of natural gas as a fuel. Others have worked on improved fuel systems and/or engine performance improvements using natural gas as a fuel.
So the second objective of the present work is to experimentally evaluate not only performance and fuel efficiency but also a comprehensive evaluation of exhaust emissions and transient response characteristics of multi-fuel spark ignition engines.

EXPERIMENTAL WORK

The first stage of this work was devoted to the preparation and operation of a complete test rig for Spark Ignition Engines [7]. The test rig includes the engine, all the instrumentation necessary for measuring and recording macro as well as micro operating parameters . An On-line / Off-line data acquisition system was furnished to improve the speed and accuracy of data collection and recording.
A four-stroke, four-cylinder, water-cooled gasoline FIAT engine rated 50 kW at 5700 rpm. was used. The compression ratio is 9.1: 1 while piston bore and stroke are 86.4 and 55.5 mm respectively. The engine is equipped with a compressed natural gas (CNG) and gasoline fuelling systems. The exhaust tube is modified to allow the fixation of gas analyzer probe and exhaust gas oxygen sensor.
The load is applied by an ELZE/Heenan hydraulic dynamometer (type AN5f). The fluid used is water with which the maximum braking power could reach 50 kW at 5700 rpm.
The test rig is fully instrumented in order to get the experimental data as well as to monitor the engine operating conditions. The measured parameters are :
Engine speed, engine load, fuel consumption, airflow rate, crank angle, ambient conditions , real time. cylinder pressure, inlet air and exhaust gas temperature, lubricating oil pressure and temperature, and cooling water temperature.

Pressure signals were fed to a conventional multi-channel oscilloscope to display their variation with time. This was mainly used for monitoring and manual control purposes.

Brake Power

The angular position of the dynamometer pointer is transferred to a proportional voltage signal. Such a voltage signal being proportional to the dynamometer resisting torque is fed to the data acquisition system. The following equation was used to calculate the engine power.

$BP = (DY * N * 0.001) / (2 * 1.36)$. (kW)

where: DY: Dynamometer reading
N: Engine speed (rpm)

Pressure Measurement

A water cooled piezoelectric transducer of the type Kistler (601A SN283692) along with a charge amplifier type Kistler 5007 which has the capability of statically holding the output charge for calibration purposes were used for measuring the cylinder pressure. The transducer, amplifier and cabling arrangement were calibrated together using a dead weight tester.

Linear and Angular Displacements

a-Engine Speed

Engine speed was measured using an electric tachometer , which produces 20 volt signal every 1000-rpm. which could be fed to the on-line data acquisition card.

b-Crank Angle

The crank shaft angular position is detected by means of two magnetic sensors fixed opposite to the rim of a specially manufactured disk with 180 identical slots.

c-Top Dead Center Marker

The top dead center (TDC) of the first cylinder is sensed by means of magnetic pick up supported opposite to an 8 mm thickness aluminum disk with a magnetic insert glued inside a special slot at the disk periphery. The pickup is mounted on a stand adjustable steel frame fixed to the test bed concrete base.

Mass Flow Rate Measurement

a-Air Flow Rate

A standard orifice of 32-mm diameter is mounted on the air surge tank entrance with U tube manometer to measure the pressure drop across the orifice.

b-Fuel Flow Rate

(1) Gasoline Flow Rate

The engine fuel consumption at a steady state operation is evaluated by recording the time of consumption of a certain volume of fuel. This old method remains particularly valuable today because of the high accuracy achieved. The measuring device consists of a glass flask of 1000-c.c volume, an auxiliary fuel tank, control cock and a stopwatch.

(2) CNG Flow Rate
A standard orifice of 8-mm diameter is mounted at the inlet of the natural gas to the engine and a U tube manometer between the inlet and outlet of the orifice.

Exhaust Gas Content Measurement
One of the objectives of this work is to study the exhaust gas content variation with the air-to-fuel ratio and engine performance parameters. For this purpose , a HERMANN exhaust gas analyzer type MHC 222 was used to measure the concentration of CO, CO_2, O_2, (HC),and air equivalence ratio(λ).

Data Acquisition Systems
The employment of microprocessor and electronic data acquisition systems in fast measurement applications shaped the modern sophisticated measuring techniques. The separate data acquisition system used in the present work is a 16 input channels on line system for recording the slow varying parameters. The second system is an off-line 4-channel fast recorder that is separately adjusted and then signaled to start data recording. After finishing, the recorded data are transferred to a permanent storage for future analysis. This off-line system is used for measuring the very fast changing parameters.

The Computer
IBM compatible personal computers are used with the two data logging systems. Peripherals include data storage, visual display, data communication and hard copy devices.
Programming the test sequence and communication commands was made in "quick basic version 4.5" and later in "c" language.
Plotting and analysis of the collected experimental data was made by a complete package of software especially written for these purposes.

The On-Line Data Acquisition System
This is an industrial input output data acquisition card that is used from within personal computers. The card offers 16 input A/D channels and a single output D/A channel. The sampling rate of the A/D converter is software adjustable within a maximum of 1 kHz. The physical interpretation of the obtained data is handled by the software. For this purpose, signal offsets and calibration constants for each input channel must be known.

The Off-Line Data Acquisition System
A 4 channel YokoGawa 3655E recorder analyzer is used as the off-line system. This is a wave form measuring instrument having an operational function analyzer and a plotter. Simultaneous measurement of high speed and resolution is available by an A/D converter of 4 channels each capable of converting 14 bits of data each 20 s. The memory capacity available is up to 8 Kbytes of data per channel. The instrument could be used for momentary to long time measurement.
A general purpose interface bus (GPIB) with an IEEE standard port is used for establishing communication between the off-line data record and the computer mother board. The interface handles analogue and digital signals and performs all necessary conversions and information transfer for experimental input/output data. This is achieved by careful programming based on the soft ware provided by the manufacturer of the GPIB card.

ANALYSIS OF EXPERIMENTAL RESULTS

This part presents detailed analysis of the measured engine performance and emission characteristics at different operating conditions. The effect of air equivalence ratio on engine performance and emissions at different operating conditions, in addition to transient response characteristics were also presented and discussed for engine fueled with gasoline and CNG. All results were taken at the same brake power.

Engine Performance

Figures (1-5) compare the overall engine speed characteristics which were obtained for the two types of fuels.

-The measured specific fuel consumption (BSFC), figure (1) ,was shown to increase for engine fueled with CNG than for gasoline because the engine fueled with CNG operates in the rich zone to obtain the same power compared to engine fueled with gasoline besides the relatively lower heating value of CNG .

-The air equivalence ratio, figure (2), was shown to decrease for engine operating with CNG at all operating conditions because as mentioned above the engine fueled with CNG operates in a richer zone to compensate for the lower flame speed experienced .

-The volumetric efficiency of the engine, figure (3), is shown to increase for engine fueled with gasoline because the volume which CNG fuel occupies in the inlet manifold is slightly more than the volume occupied by gasoline droplets in the inlet manifold so the amount of actual air entering the engine cylinders is slightly increased for engine fueled with gasoline than for engine fueled with CNG.

-The brake thermal efficiency, figure (4), was observed to behave in an inverse manner to that of the BSFC shown above.

-In figure (5), the exhaust temperatures when using gasoline are higher than those for CNG specially at high loads. This attributes to the higher heating value of gasoline .

Exhaust Emission

Figures (6 - 9) compare the different emission characteristics of the engine for both gasoline and CNG.

-As shown in figure (6) ,the percentage of CO in the exhaust gases for CNG was shown to increase compared to gasoline at low engine speed , because of the lower flame speed of CNG and decreases at high engine speed which is mainly due to the increased level of turbulence that leads to faster flame speed .

-The presence of carbon dioxide (CO_2) in the exhaust, figure (7), is seen to decrease for engine fueled with CNG than gasoline.

-The oxygen concentration in the exhaust gases, figure (8) ,is found to increase for engine fueled with gasoline than CNG fuel.

-The hydrocarbons (HC), figure (9), are found to increase for engine fueled with CNG specially for HC Propane which is very high compared to HC Methane and HC for gasoline which is very low, this is also due to the lower flame speed of CNG .

Air Equivalence Ratio and Engine Performance

Figures (10 - 14) compare the effect of air equivalence ratio on engine performance

-The engine brake power, figure (10), is shown to decrease for engine fueled with CNG than gasoline at the same air equivalence ratio.

-The BSFC, figure (11), is shown to increase for engine fueled with CNG than with gasoline at lower air equivalence ratio but decreases as air equivalence ratio increases.

-The volumetric efficiency, figure (12), is slightly increased for engine fueled with gasoline than CNG.

-The brake thermal efficiency, figure (13), is observed to behave in an inverse manner to that of the BSFC.

-The exhaust gas temperature, figure (14), is shown to increase for gasoline fuel than CNG fuel as the engine load increases.

Air Equivalence Ratio and Pollutants in the Exhaust Gases

Figures (15 - 18) compare the effect of air equivalence ratio on engine pollutants.

-Figure (15) shows that the percentage of CO for engine fueled with gasoline is lower than that fueled with CNG.

-The percentage of CO_2 ,figure (16), is found to increase for gasoline than CNG .

-The oxygen concentration, figure (17), is shown to increase for engine fueled with CNG than with gasoline at low loads but decreases at high loads.

-In figure (18), It is clear that the hydrocarbons for engines fueled with CNG is higher than with gasoline.

Transient Performance Results

The acceleration and load acceptance tests were carried out to investigate the transient performance of the spark ignition engine fueled with gasoline and CNG .

Acceleration Test Results

The engine speed was set to 1500 rpm at the chosen brake load. After a short warm up period, a sudden turning of throttle valve to the maximum position is applied to increase the engine speed to its maximum possible value. The measured corresponding dynamometer readings during the acceleration period are plotted in figure (19). The data presented were measured for both gasoline and CNG.

The results showed that using CNG decreases engine response to a sudden acceleration than using gasoline.

Load Acceptance Test Results

Before each test of this kind, the engine speed was set to a chosen value under a constant brake load. After a short warm up period, the dynamometer water control tap was suddenly opened to increase the water flow rate and hence the brake torque. Instantaneous engine speed and dynamometer reading were recorded for a period of 10 seconds. Figure (20) displays the results of the load acceptance test.

The results showed that using CNG decreases the ability to overcome the sudden load than using gasoline.

CONCLUSIONS

The results showed that using CNG:

-Increases the brake specific fuel consumption and decreases the volumetric efficiency, brake thermal efficiency, and exhaust gas temperature.

-Increases CO in the exhaust gases at full loads but slightly decreases it at part loads, increases HC_{prop}, and HC_{meth} at all engine operating conditions.

The mixture equivalence ratio has the greatest influence on engine performance and emission. So the results showed that using CNG:

-Decreasing air to-fuel-ratio thus increases brake specific fuel consumption , decreases the volumetric efficiency and exhaust gas temperature, and also increases exhaust gas emissions.

The transient acceleration test results showed that using CNG decreases engine response to a sudden acceleration than using gasoline. The transient load acceptance test results showed a less ability to overcome the sudden load when using CNG.

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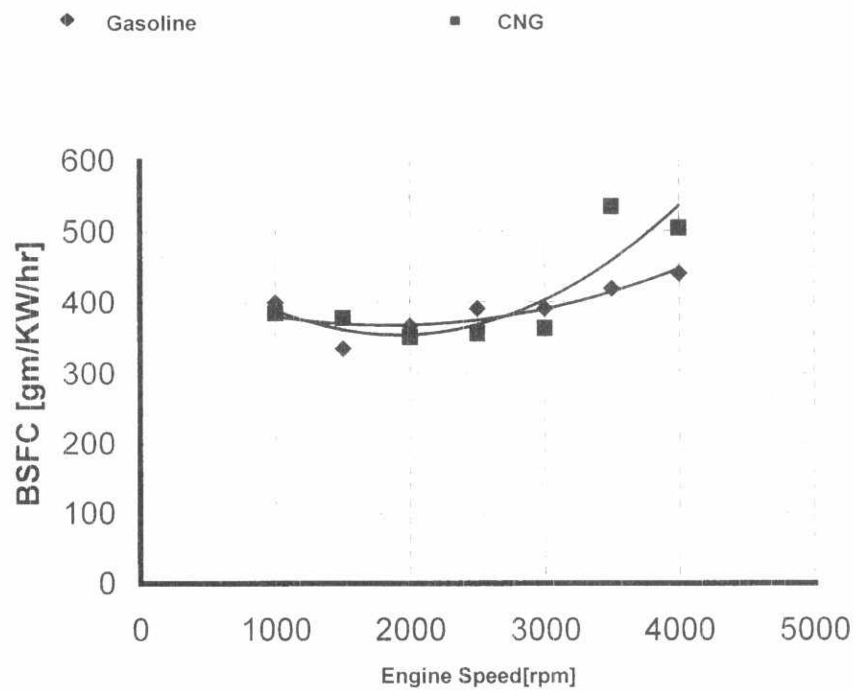

Fig.(1) Engine BSFC at Different speeds

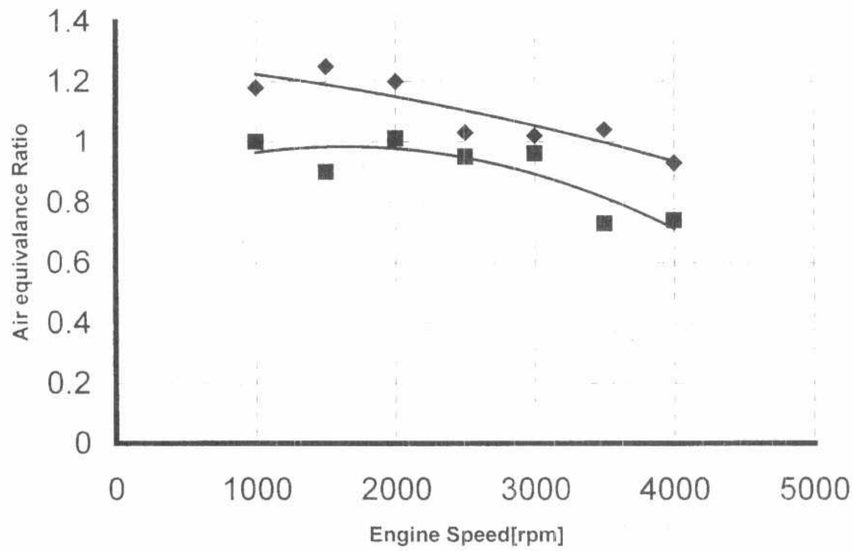

Fig.(2) Engine Air Equivalence Ratio at Different speeds

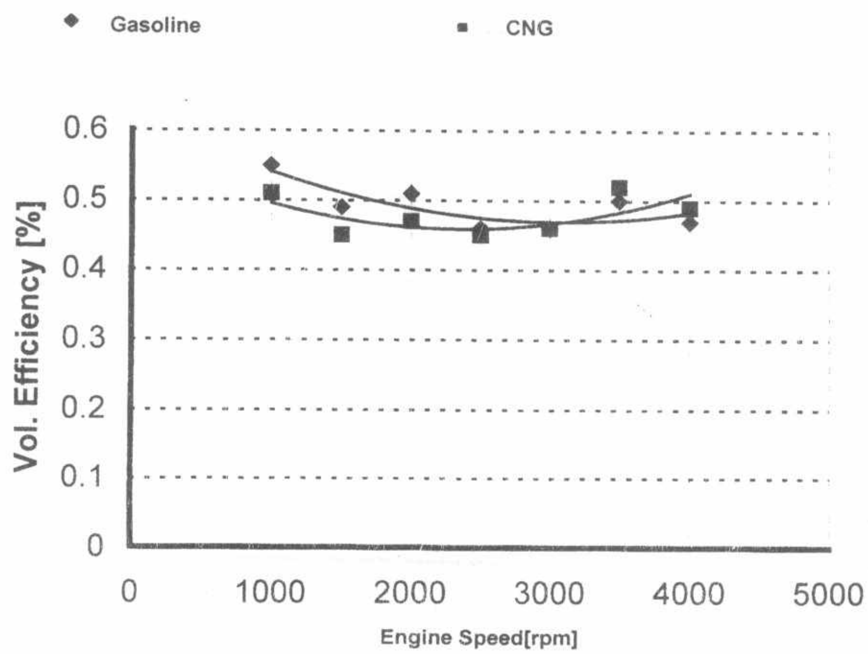

Fig.(3) Engine Volumetric Efficiency at Different speeds

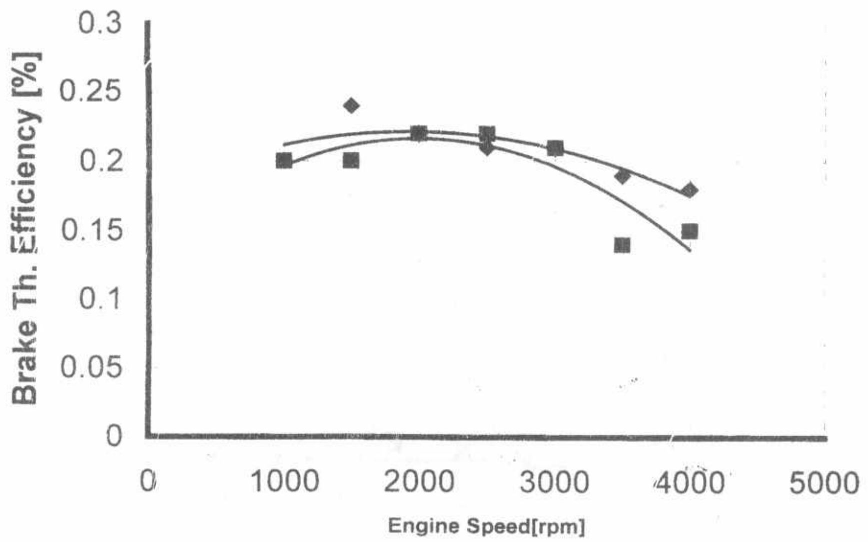

Fig.(4) Engine Brake Thermal Efficiency at Different speeds

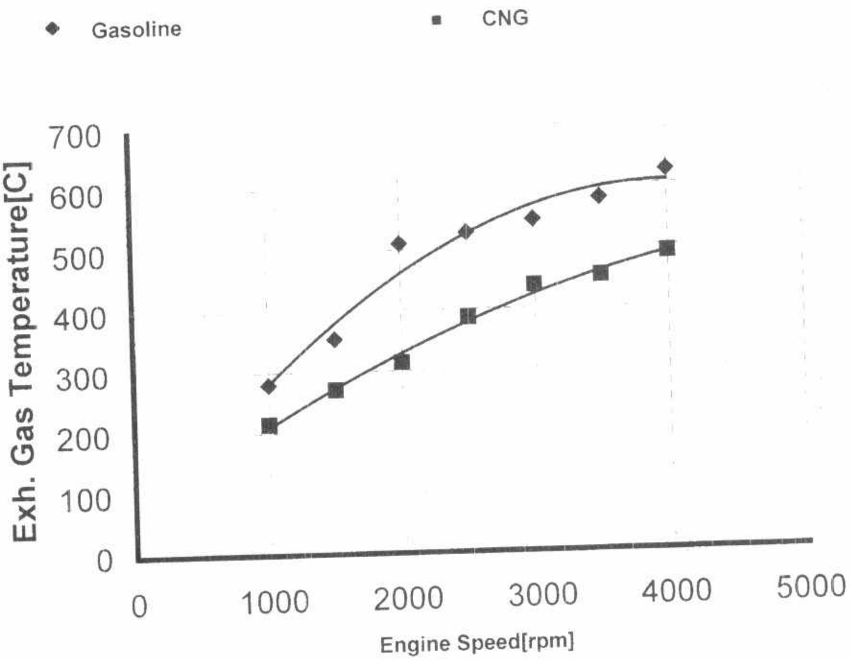

Fig.(5) Engine Exhaust Temperature at Different speeds

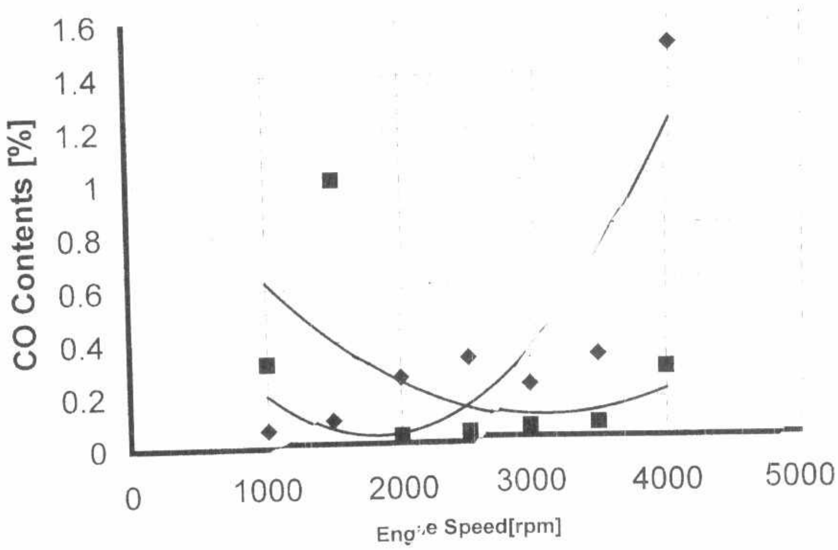

Fig.(6) CO% in Exhaust Gases at Different speeds

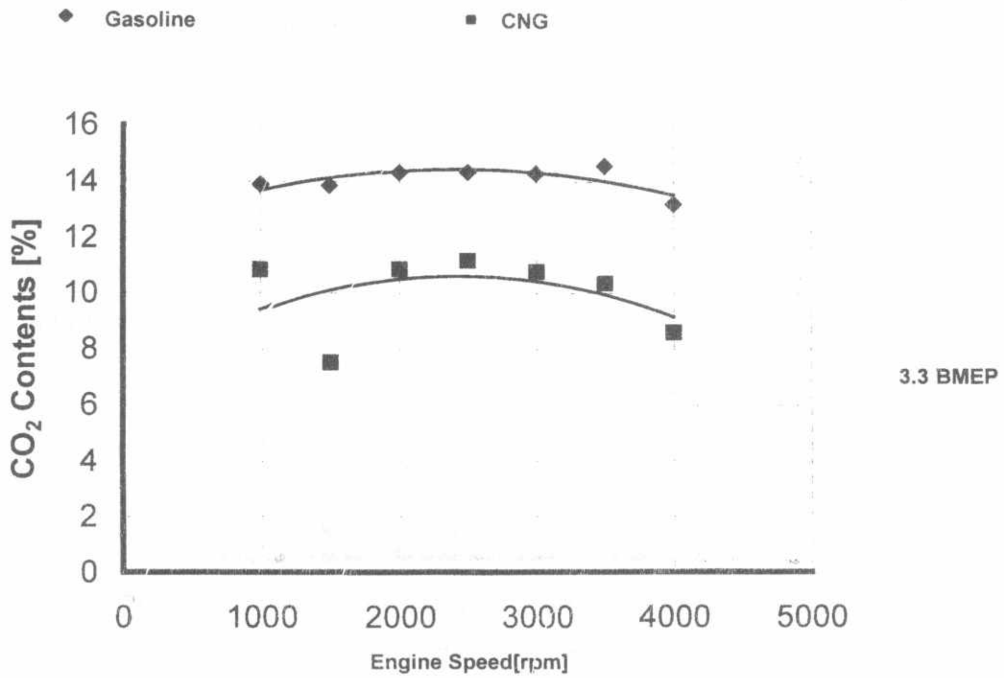

Fig.(7) CO_2% in Exhaust Gases at Different Speeds

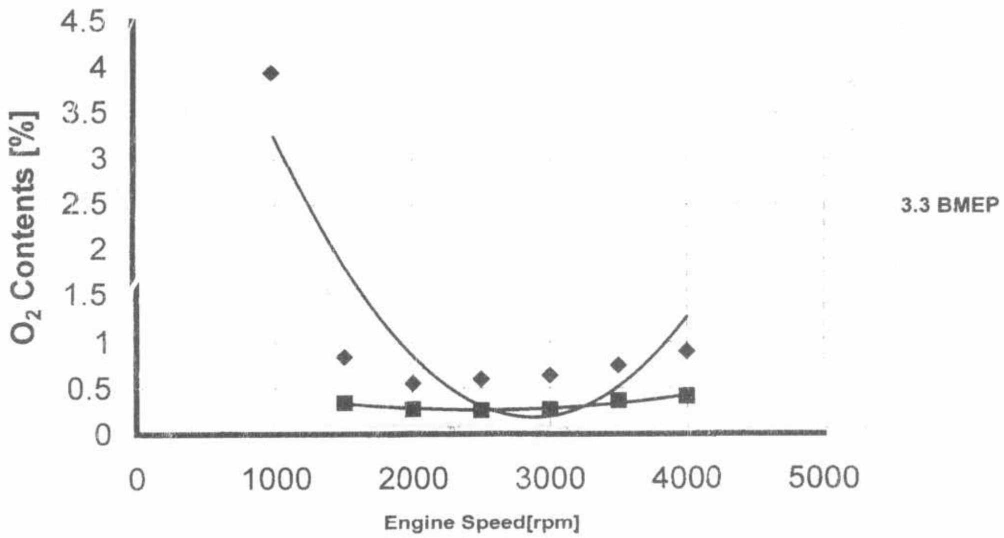

Fig.(8) O_2 % in Exhaust Gases at Different Speeds

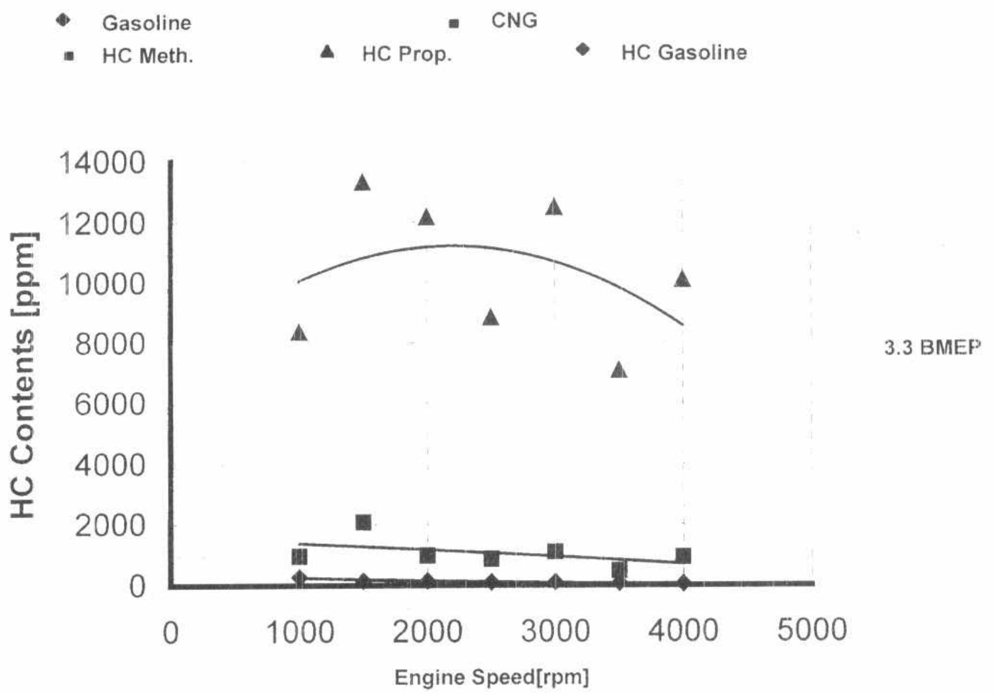

Fig.(9) HC [ppm] in Exhaust Gases at Different speedss

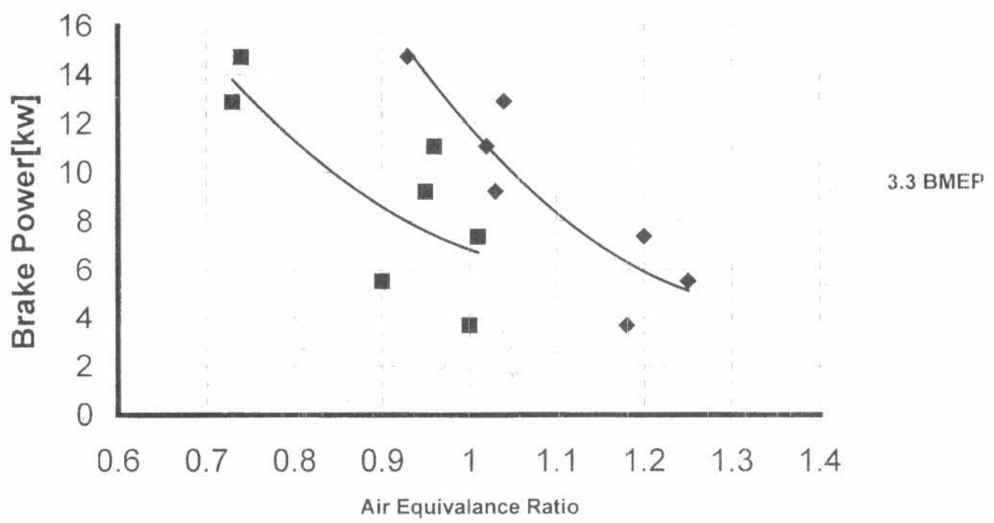

Fig. (10) Engine Brake Power at Differenr Air Equivalence Ratio

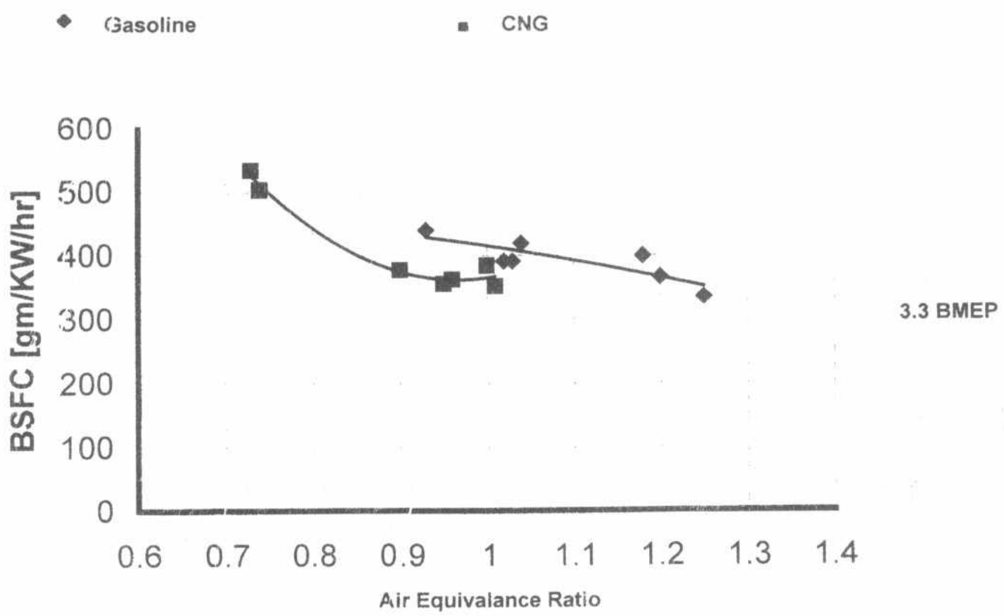

Fig. (11) Engine BSFC at Differenr Air Equivalence Ratio

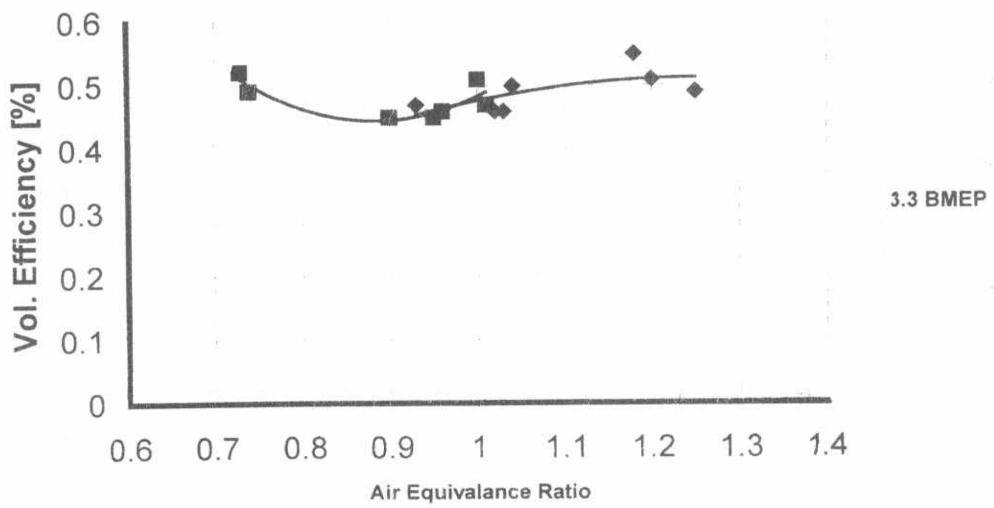

Fig. (12) Engine Volumeteric Efficiency at Differenr Air Equivalence Ratio

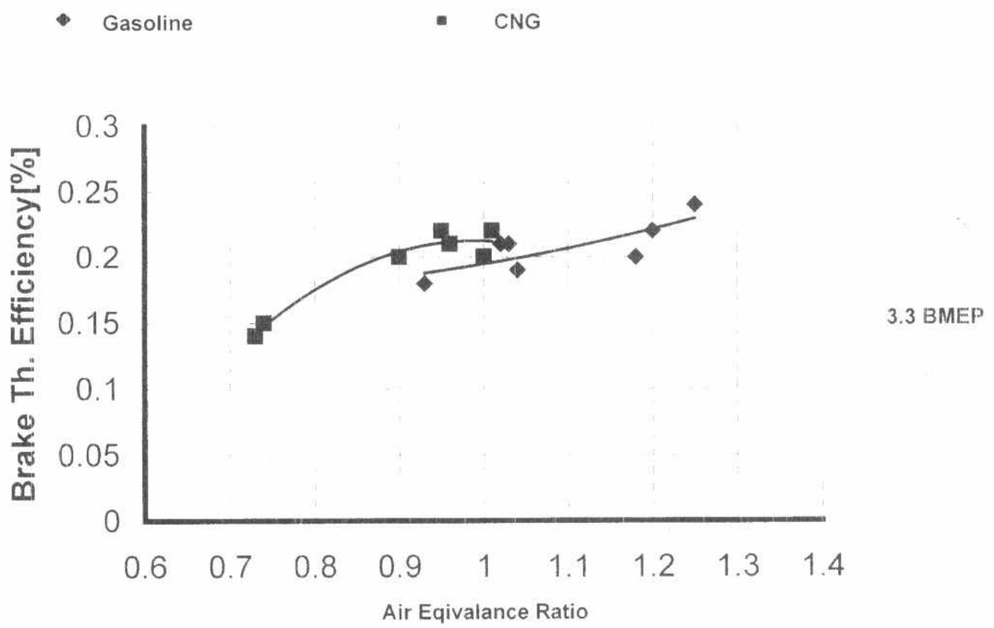

Fig. (13) Engine Brake Thermal Efficiency at Differenr Air Equivalence Ratio

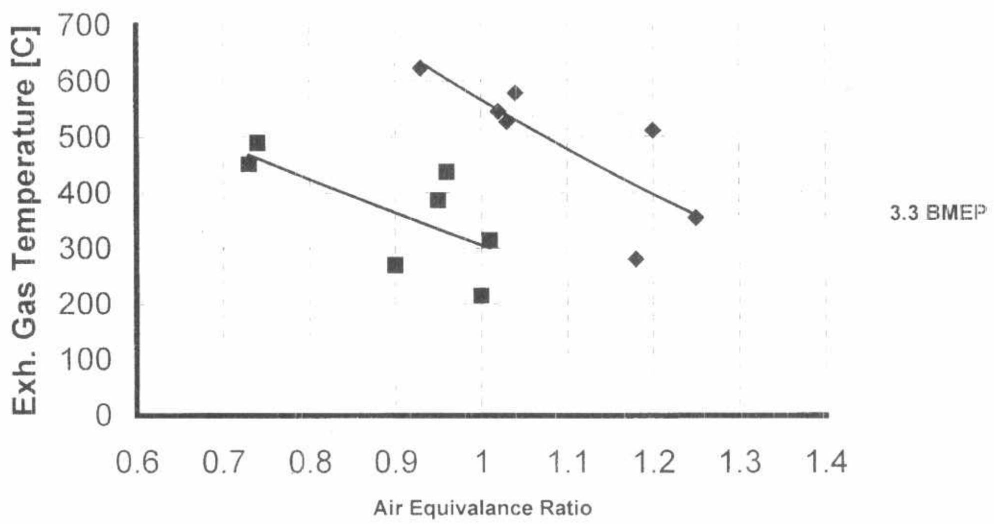

Fig. (14) Engine Exhaust Gas Temperature at Differenr Air Equivalence Ratio

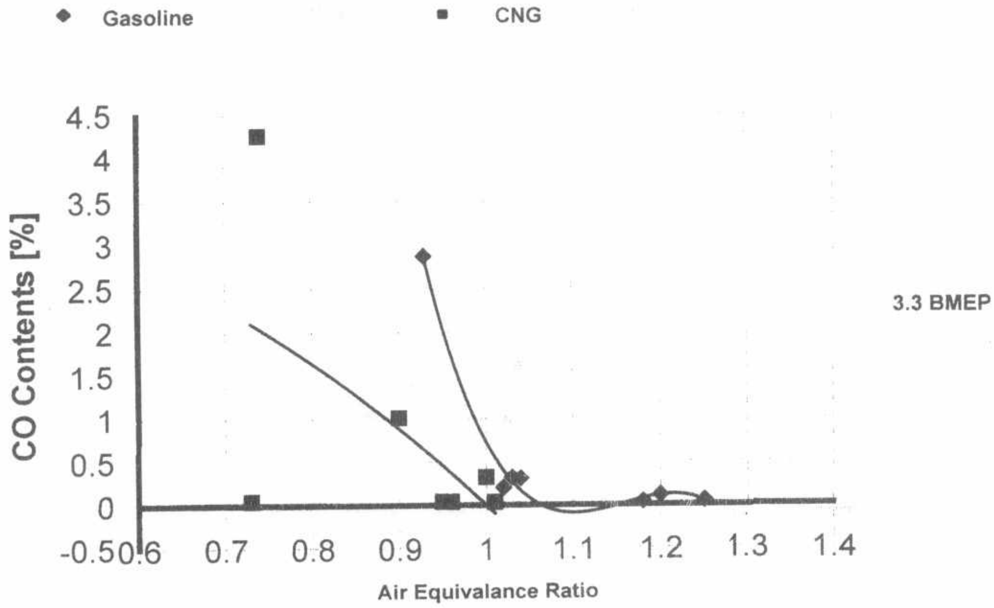

Fig. (15) CO% in Exhaust Gases at Differenr Air Equivalence Ratio

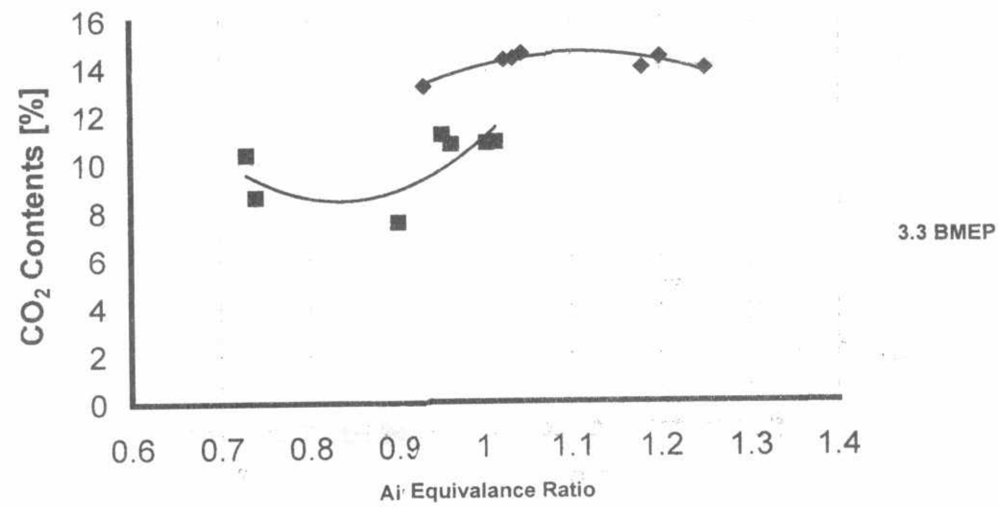

Fig. (16) CO_2% in Exhaust Gases at Differenr Air Equivalence Ratio

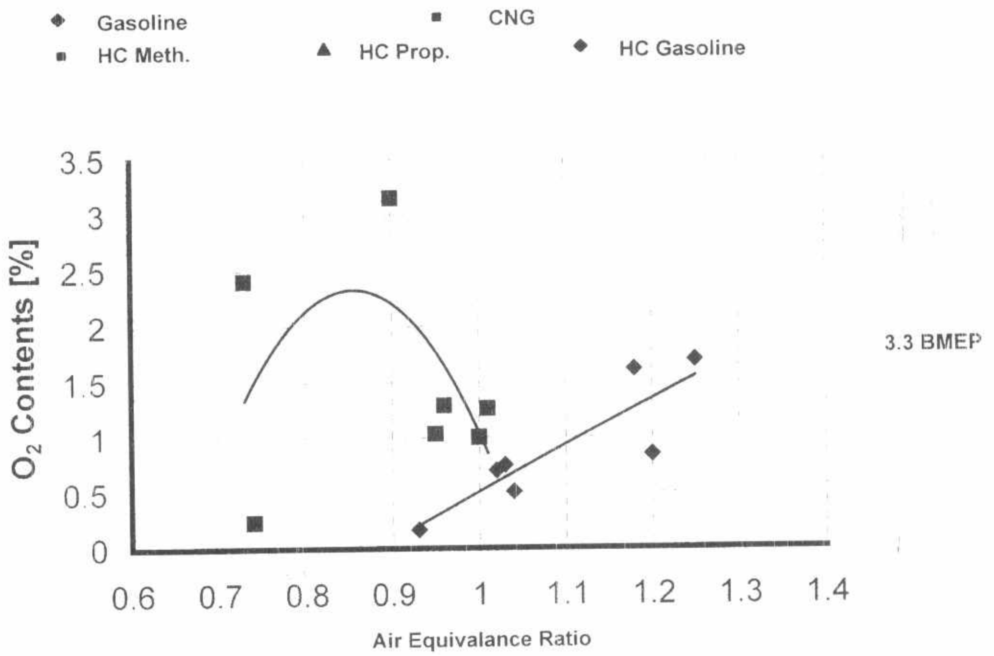

Fig. (17) O_2% in Exhaust Gases at Differenr Air Equivalence Ratio

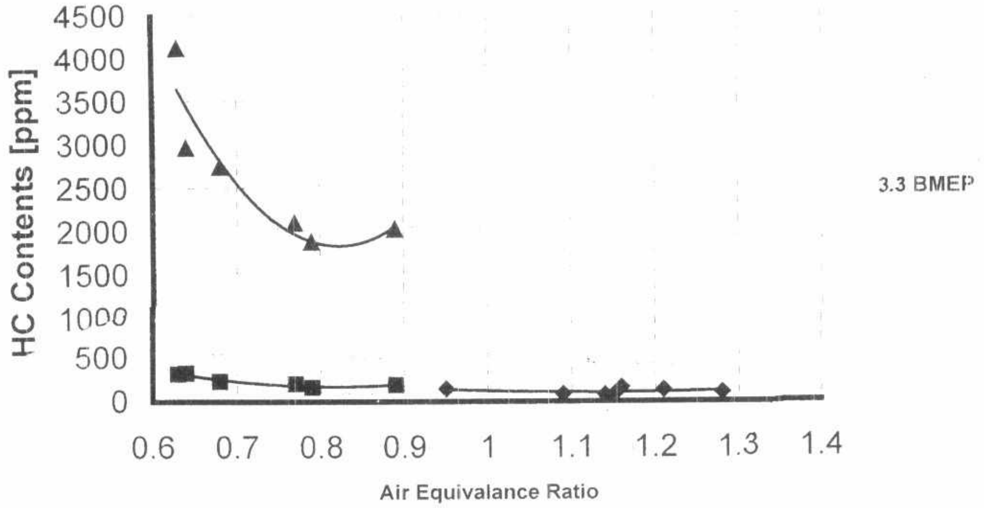

Fig. (18) HC [ppm] in Exhaust Gases at Differenr Air Equivalence Ratio

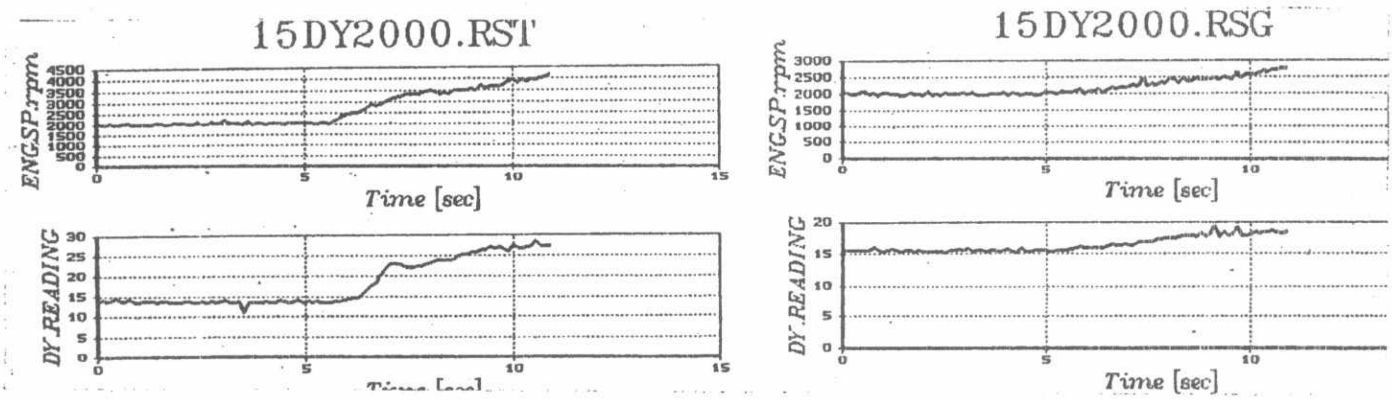

Fig. (19) Acceleration Test

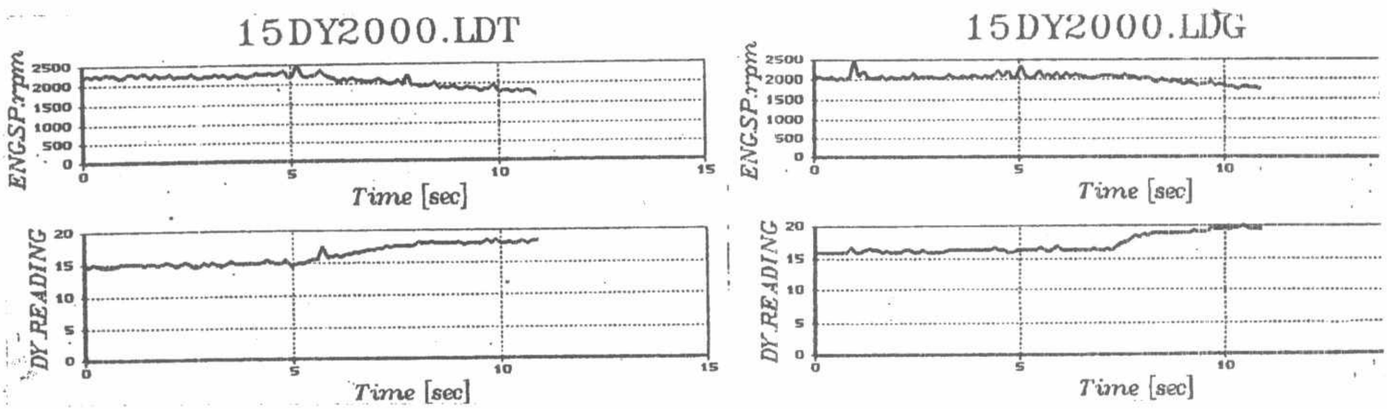

Fig.(20) Load Acceptance Test