Mansoura Engineering Journal, (MEJ), Vol. 31, No. 2, June 2006.

EMISSION CHARACTERISTICS FROM VEHICLES AT IDLING CONDITION

خصائص إنبعاثات المركبات عند السرعة الخاملة

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ملخص

في هذه الدراسة تم توضيح العلاقة بين بعض العوامل المرتبطة بصيانة المحرك وبين الانبعاثات الصادرة عنه وفيها تم إجراء التجارب العملية عند السرعة الخاملة.

وقد وجهت الدراسة إلى بحث تأثير منظومة الحريق وجودة الخليط على مكونات العادم.

- فبالنسبة لمنظومة الحريق تم اختبار تأثير الآتي على مكونات العادم

(أ) تم تغيير فتحة مصدر الشرارة من 3. إلى 1.9 مم

(ب) تم تغيير توقيت الشرارة من 1- 19 درجة قبل النهاية الميتة العليا.

- وبالنسبة لجودة الخليط تم أختباره في مدى الحريق الممكن من خلال التحكم في صمامي الهواء والوقود.

تم إجراء الاختبارات على مركبة واحد وذلك لتلافي الإختلاف الحادث من مركبة إلى أخرى. وتم قياس نسب مكونات اعادم (CO, HC, CO_2.) وقد خلصت النتائج إلى التأثير الكبير لتلك العوامل التي تم دراستها على مكونات العادم وكذا أفضل وضعية لها في الضبط وبالتالي أهمية ضبطها طبقاً لتلك الوضعية .

ABSTRACT

The present study aims to evaluate the emission characteristics for gasoline-fueled vehicles at idling condition. Factors influencing the formation of emissions at different operating conditions are examined. The study is focused on the ignition parameters as well as the mixture quality which are the most important factors affecting the engine performance and emission. A wide range of spark plug gap(0.3- 1.9) mm and ignition timing (1^0- 19^0 BTDC)were employed in the present study. The mixture quality at idling is varied along the flammability limit to clarify its effect on the combustion products concentration. The measurements were carried out on a specified vehicle. Both the engine speed and combustion products concentration were recorded simultaneously. The results indicate the importance of adjusting the idling condition to optimize the exhaust products.

Accepted April 23, 2006

1 INTRODUCTION

The emission from vehicles equipped with spark ignition engines contributes in raising the pollutants level of atmosphere and consequently the global environment [1]. This pushes the scientific society and authorized institutions to review the current legislations to reduce the emission [2-3]. The remarkable increase in the pollutants comes from the fast growing in the vehicles production [4]. The other important sources are the fuel factor, operating condition and performance and finally the engine mechanical condition [5-6]. The later factor was found to be responsible about considerable emission part. It is believed that, the engine performance is subjected to decay due to several factors. The rate of depreciation and maintenance processes plays the important role for governing the engine performance and emission. So, the present study is planed to cover this aspect. It is focused on emission evaluation at idling condition. Idling speed is the condition at which the engine runs at no load. The engine in such case consumes the lowest rate of fuel consumption and produce indicated power enough to overcome the mechanical losses. However, the mixture is rich to ensure adequate fuel vapor around the spark plug, which contributes to reduce the probability of miss-fire occurrence. According to these conditions, incomplete combustion is expected and the percentage of CO and UBHC concentration in the exhaust becomes high. Any misalignment in the ignition configuration or mixture formation leads to great variation in exhaust constituents.

2 LAY OUT OF THE EXPERMINTAL WORK

The experimental work is carried out on specified vehicle to avoid vehicle-to-vehicle variation comes from different designs, operating conditions and maintenance processes. According to the previously mentioned plan of research, the idling condition is submitted to study to clear the governing factors. In idling mode, the ignition system as well as the mixture quality is examined according to the following sequence. The spark plugs gap is stretched from 0.3 mm up to 1.9 mm. Ignition timing is varied from 1 to 19 degree before TDC. Idling mixture valve is adjusted at different positions in order to control the excess air factor. Each of the previous factors is varied separately at the constancy of the other parameters. The emissions and engine rotational speed are recorded during the test. The measurements are taken at steady state condition.

2.1 The Used Vehicle in the Present Experimental Work

The vehicle used in the present study is selected to represent statistically the average of manufacturing year for most vehicles in Egypt during the period of study. The vehicle is Peugeot 305 SR model 1983. The engine is spark ignited four strokes, four cylinder in-line and water cooled. It is transversally mounted with front wheel drive technique.

The engine is equipped with manually operated gear box mounted transversally and sharing the same oil sump of the engine. The gear box offers 4 forward speeds and single reversal speed. The technical data of the engine are represented in table [1].

Table 1 Technical data of the engine used in the present study

No. of cylinders	4 inline
Type	S-4 SOHC 8 valves total 2 valves per cylinder
Main bearings	5
Bore × stroke	78 mm × 77 mm
Bore / stroke ratio	1.01
Displacement	1472 cc
Compression ratio	9.2
Fuel system	1 Solex carbureotr
Aspiration	Normal
Catalytic Converter	Not installed
Max. output	75 PS (74.0 bhp) (55.2 kW) @6000 rpm
Max. torque	116.0 Nm @3000 rpm
Coolant	Water

2.2 Instrumentation

The measurements program is focused on evaluating the emission characteristics at different operating conditions. For this reason, measuring the concentration of exhaust constituents is essential as well as the engine speed. For this purpose, portable version of infrared gas analyzer is used during the experimental work. The gas analyzer is equipped with gas sampling probe to collect the exhaust gas from the muffler. The gas is then filtered and dried before entering the analyzer. Magnetic inductive pickup transducer is used also to measure the engine speed in rpm. It clipped to any of spark plugs cable in order to capture the spark signal. The sparking rate is then considered as linear proportion to the engine speed.

3 TEST PROCEDURES

Studying the emission characteristics from the vehicles require intensive measurements program at different operating condition. The selected vehicle is equipped with previously mentioned measuring instruments. The gas analyzer and its accessories are mounted in the rear seat of the passenger cabinet. Rechargeable power supply and printer are the most important attachment to the analyzer. Gas sampling probe with 3 m long is inserted inside the muffler, where its other terminal is connected to the gas analyzer through the window of the rear door. Magnetic inductive transducer is clipped also to the spark plug cable to measure the engine rotational speed. Before starting measurements, the following precautions are taken into account.

- The engine is warm enough before starting measurements and runs steadily at standard idling configuration.
- All electric accessories like electric fan, lights and radio-cassette are switched off.

4 RESULTS AND DICUSSION

In the present work, the following standard configuration for idling condition is as follows.

Table 2 Standard idling configuration

Item	value
Spark timing	10^0 BTDC
Spark gap	0.8 mm
Fuel adjusting valve position	30 % from valve stroke
λ at idling	0.96
N	764 rpm
Fuel octane No.	90

These values represent the recommended optimized configuration from the manufacturer. During the experimental work, these values are varied individually to examine their effect on the engine emission and performance. The results are presented and discussed in the following sections.

4.1 Effect Of Ignition Properties

Ignition process for the fresh reactant mixture is essential for initiating the combustion process in the proper time and rate. The energy of spark transferred directly to the combustible mixture. Most of this energy consumes for raising the kinetic energy of the reactant molecules. If the energy is high enough, the collision of activated molecules break the chemical bonds of the reactants and exothermic reaction begins. As result a self-sustained and propagating flame kernel is produced. In case of low spark energy, the collision between reactant molecules becomes too weak to break the bond energy in order to start the reaction. This leads to miss fire or partially burned mixture and highly concentration of unburned hydrocarbon exists in the exhaust products. It is obvious from previous researches [7-13] that, the ignition quality plays an important role for governing the engine emission and performance. The potential difference, instantaneous currant, spark timing and duration and the gap between the electrodes represent the most important factors affecting the ignition phenomenon. The potential difference across the electrodes and spark duration depend mainly on the design of the ignition system and the properties of the elements used. So the main variation in ignition system performance comes from the change in spark electrode gap which is affected directly by the operation and maintenance processes. The other governing factor is the ignition timing, which plays an important role for optimizing the combustion process. These two parameters and their effects on the emission level are studied in this work.

4.1.1 Effect Of Spark Plug Gap

Effect of spark plug electrode gap is studied in the present work. The gap is stretched from 0.3 mm up to 1.9 mm. Figure 1 represents the measured results showing the effect of spark plug gap on the engine speed and emission at idling condition. In case of narrow gap between the spark plug electrodes, the resistance of the gap media is reduced. The electric current breaks the gap insulation rapidly before the inductive currant attained its peak value. The electric current is then flows through the gap at relatively low potential difference representing a condition that leads to reduce the energy of the resultant spark. Consequently the energy transferred to the combustible mixture becomes less than or equal to the minimum ignition energy required to start reaction. For this reason, the probability of miss fire occurrence increases constituting a condition, which reflects on reducing the engine speed and causing highly increase in unburned hydrocarbon as shown in the figure. On the other hand, the resultant flame kernel (if exist) has relatively low temperature so it quenched rapidly, and leaving the most of fresh mixture unburned. The little part of burned mixture produces lower concentration of carbon oxides represented in CO and CO_2 decrease as shown in Figs.(1) and (2), respectively . As spark plug gap increased, higher energy spark is obtained. The size and energy of the resultant flame kernel becomes suitable for producing self-sustained and propagating flame front. So, the combustion quality is improved and great reduction in unburned HC is obtained. The slight increase in CO indicates the increase in carbon oxidization rate. At wide gap the power density of the spark along the resultant plasma cylinder becomes too low. The repetition rate of ignition loses its uniformity and the cyclic variation tends to increase. Corresponding reduction in rotational speed is obtained as shown in the figure. Further increase in spark gap leads to increase the insulation of the gap beyond the capability of the potential difference to break it and the ignition cannot be occurred in such case.

It is obvious from the results that the optimum gap lies between 0.7 mm and 1 mm. At that gap, the engine speed reaches its peak value which means lower cycle-to-cycle variation and emissions of both unburned HC and CO are in the acceptable level.

It is noticed from the experiments that when the spark gap becomes below 0.3 mm the ignition is off and the engine fall to run. When stretching the gap beyond 1.9 mm the engine runs very rough and the cyclic variation especially in rotational speed and products concentration becomes very high. This condition is not acceptable within the standard configurations.

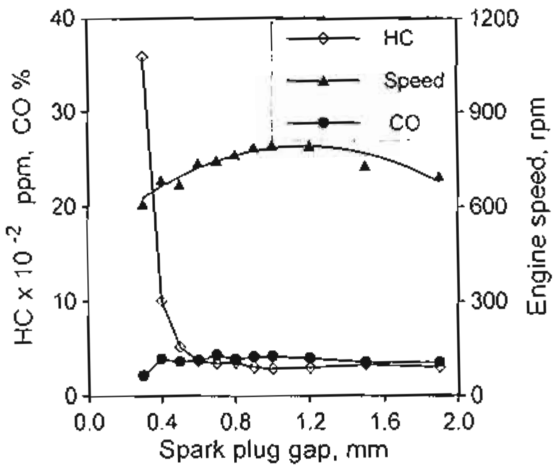

Fig. 1 Effect of spark plug gap on HC and CO concentration.

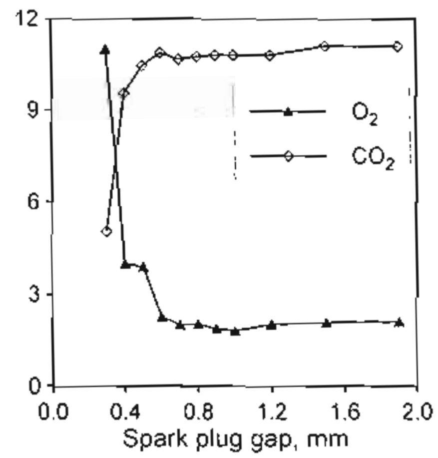

Fig. 2 Emission of CO_2 and O_2 at at different spark gap.

4.1.2 Effect Of Spark Timing

Spark timing is one of the most important parameters affecting the emission formation. It controls the beginning of combustion and consequently the reaction kinetics, which in turn governs the rate of pressure and temperature rise inside the cylinder during that period. At idling condition, the mixture tends to be rich and its kinetic energy inside the combustion chamber is low. These conditions lead to reduce the flame speed during its propagation. Beside, the combustion delay for rich mixture is longer. These reasons give the adjustment of firing angle an exceptional importance. The angle at the end of combustion depends on several parameters such as sparking angle, delay period, flame speed and spark location which govern the flame travel distance. The angle at the end of combustion is expressed mathematically as follows.

$$\theta_{eoc} = \theta_i + \left(\varpi \int \frac{ds}{u_f} + \Delta\theta_d \right) \ldots(1)$$

It is obvious from the engine performance that combustion must be completed within narrow range after TDC. In other word, this angle must be fixed as much as possible at idling condition. Any shift of such angle from its optimum value leads to reduce effective work done of the thermal cycle and consequently reduce the thermal efficiency. Equation (1) shows the ability for controlling the time of combustion termination by the proper selection of firing angle.

Figure 3 shows the effect of spark timing on the idling speed. When advancing the spark timing, combustion starts earlier and the rate of pressure rise increases. The result is increasing in the work done per cycle and consequently engine power. As the external torque remains unchanged, the increase in engine power leads to a corresponding increase in idling speed as shown in Fig. (3). On the other hand, retarding the spark timing leads to reduce the peak temperature of the cycle, which in turn contributes the reduction of dissociation rate of CO_2 to form CO as follows.

$$CO_2 \rightleftharpoons CO + \frac{1}{2} O_2 \quad \ldots(2)$$

When advancing the spark timing, both the combustion temperature and the engine speed increase leading to a remarkable enhancement in the turbulent mixing process for the reactants. The homogeneity degree of the combustible mixture is then increased and the rate of oxygen consumption during the reaction increases leaving lower concentration of O_2 in the exhaust products as shown in Fig (4). The figure shows also the relation between the low concentration of oxygen and the appearance of HC in the exhaust gases. In spite of the multiple sources of unburned hydrocarbon, the excess air factor and distribution of oxygen inside the combustion chamber stay the important player which assigns the rate of formation, specially at idling condition. The lower the concentration of oxygen the greater the concentration of HC as shown in Fig(4). It is clear from the figure that, the over advance in ignition timing exhibits considerable HC level.

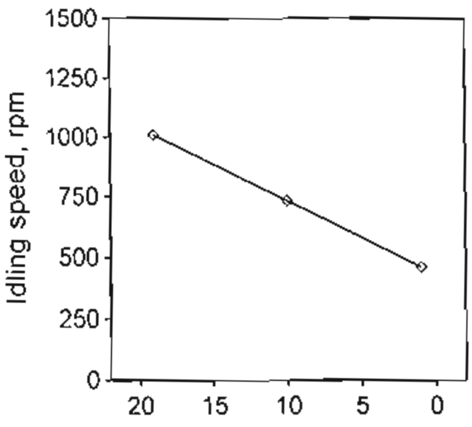

Fig. 3 Variation in idling speed with respect to spark timing

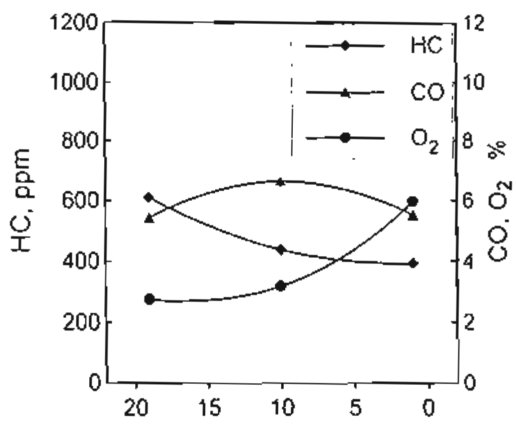

Fig. 4 Effect of spark timing on exhaust species concentration at idling

4.2 Effect Of Mixture Quality

At the idling condition, the mixture is rich enough to enable fast starting, reduce warm-up period and to ensure stable operation during the no load running. The fuel system in the present test engine contains Solex carburetor. It contains two valves to adjust the mixture quality at idling. The first valve (air valve) is used to control the upstream pressure of the fuel behind the idling orifice. The valve consists of threaded pin and bush with bypass air vent. When turning the threaded pin counterclockwise, it increases the area of air vent allowing the atmospheric air stream to flow and break the fuel flow through the orifice. The adjustment of this valve depends on assigning the number of turns of the treaded pin relative to the maximum effective number of turns as follows.

$$Air\ valve\ position = \frac{Nav}{Nav_{max}} \times 100\ \% \quad ..(3)$$

Where Nav represents the number of thread turns CCW for opening and CW for closing the air vent. While Nav_{max} represents the maximum effective number of thread turns. The second is the fuel valve, which used to throttle the area of fuel discharge. The fuel valve is a threaded pin with tapered end. When turning the valve CCW, the tapered end moves a distance from the tapered valve seat allowing wide area for fuel to flow through the orifice. The fuel valve position is assigned as the same procedure as in air valve position. This is represented mathematically as follows.

$$Fuel\ valve\ position = \frac{Nfv}{Nfv_{max}} \times 100\ \% \quad (4)$$

Where Nfv is the number of thread turns of the valve pin from the closing position to the current position. Nfv_{max} is the maximum number of thread turns available in the pin. The function of each valve differs from the other. Increasing the air valve position breaks the flow of the fuel. The same action on the fuel valve position leads to increase the flow of fuel. In the present work, three air valve positions were selected to study its effect on the mixture formation and consequently the resultant emission. These are 10, 30 and 50% respectively. The effect of fuel valve position is examined along its entire range (from 0 to 100%). At each position for air and fuel valves, the engine idling speed is measured and the concentration of exhaust emission is recorded also. The air gap of the spark plug and the spark timing remains unchanged according the basic standard configuration as in table [4]. It is noticed from the results that, the effective fuel valve position lies between 30 and 60% as shown in Figs.(5-9). It was found that, when the fuel valve position being less than 30%, the flow of fuel is highly throttled and the resultant mixture becomes less than the flammability limits. When the fuel valve position is extended more than 60% the discharge area of the fuel flow attains its maximum value and it becomes constant. Through the effective range of the fuel valve, gradual increase in fuel valve position leads to enrich the mixture and enhance the combustion stability. This reflects on reducing the unburned hydrocarbon and the oxygen concentrations. On the other hand the rich mixture is responsible to increase both CO_2 and CO level. The air valve position offers slight effect on the emission as shown in the figures. Decreasing the air valve position leads to corresponding increase in the fuel flow rate and consequently enriches the mixture. This mixture quality is responsible to the partial burning of the fuel inside the combustion chamber and consequently increases HC and CO level as shown in the figures. It is obvious from the results that, the idling speed responds to the fuel flow rate represented by the fuel valve position as shown in Fig (10). When the excess air factor goes down to rich zone, the engine speed comes to its peak value. Further decrease in excess air factor contributes for slowing the flame speed. The pressure and temperature inside the cylinder are then decreased and the final work done and engine speed are also decreased. Figures (11-17) represent the correlations of exhaust constituents and excess air factor. It is clear from these figures that, the lowest HC and CO emissions are obtained at $\lambda = 1.2$. The highest CO_2 concentration was found to be at the same excess air ratio, which is analogous to the maximum combustion efficiency. However, it is not convenient to start the engines at such ratio especially at cold environment. So it is recommended to run the engine at rich mixture, but not so far from the stoichiometric condition, whereas the λ value can be selected according to the desired CO and HC levels.

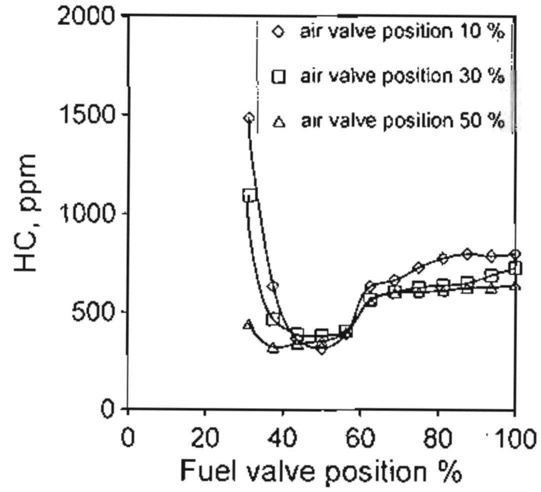

Fig 5 Effect of idling fuel valve position on HC emission.

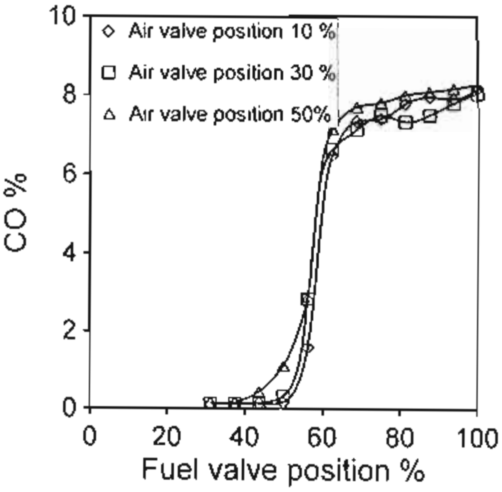

Fig. 6 Effect of idling fuel valve position on CO emission.

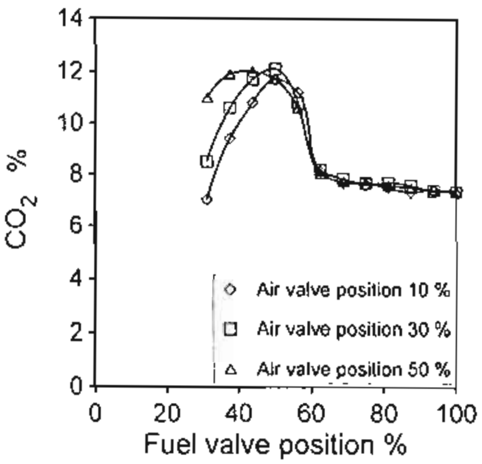

Fig. 7 Effect of idling fuel valve position on CO_2 emission

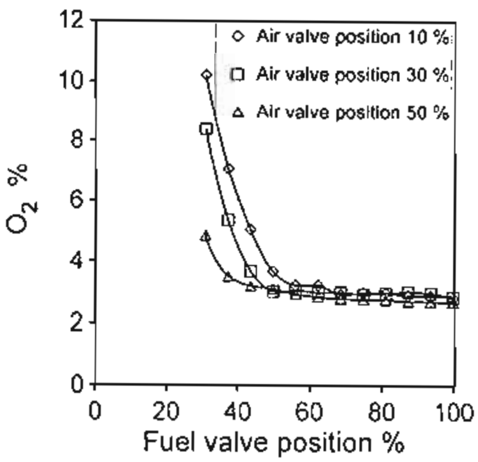

Fig. 8 Effect of idling fuel valve position on O_2 emission

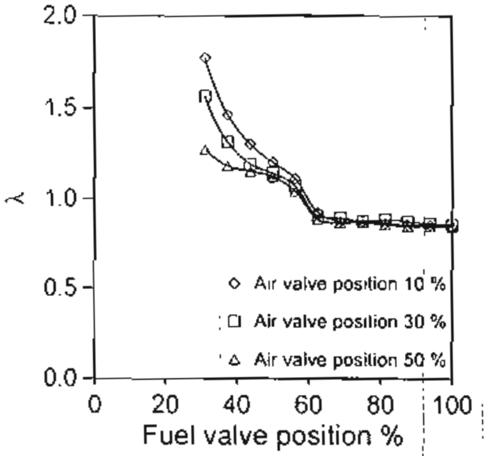

Fig. 9 Effect of idling fuel valve position on excess air factor

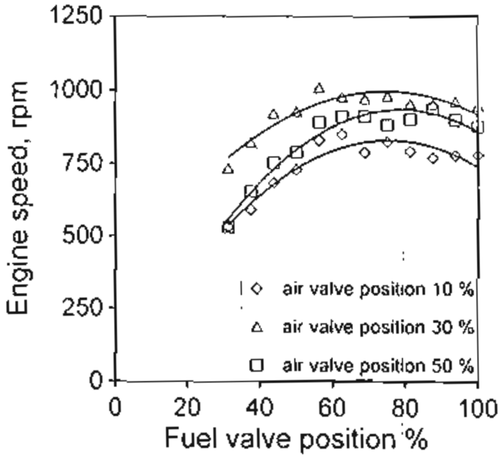

Fig. 10 Effect of idling fuel valve position on idling speed

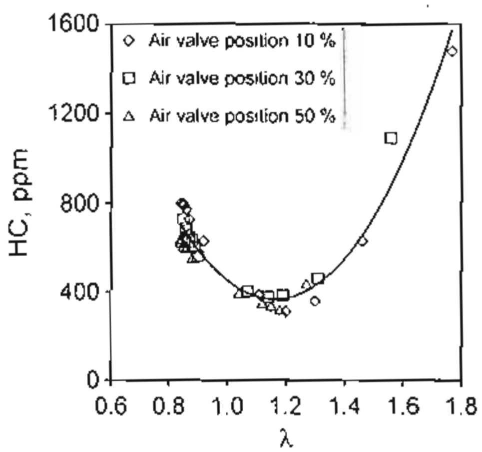

Fig. 11 Variation of HC concentration with excess air factor at different air valve position

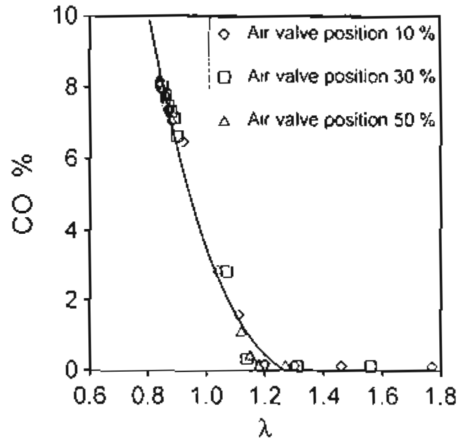

Fig. 12 Variation of CO emission with excess air factor at different air valve position

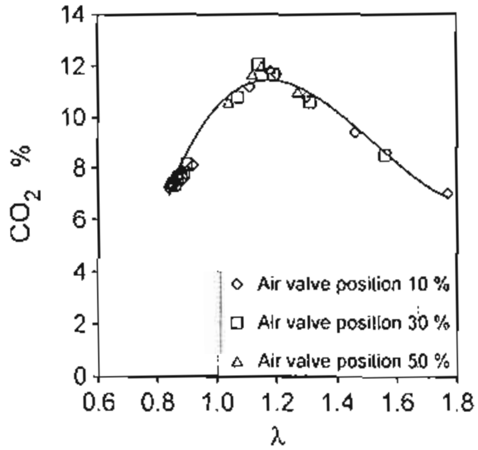

Fig. 13 Variation of CO_2 emission with excess air factor at different air – valve position

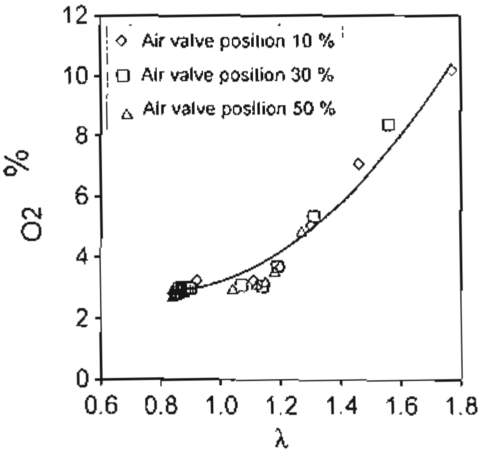

Fig. 14 Variation of O_2 emission with excess air factor at different air-valve position

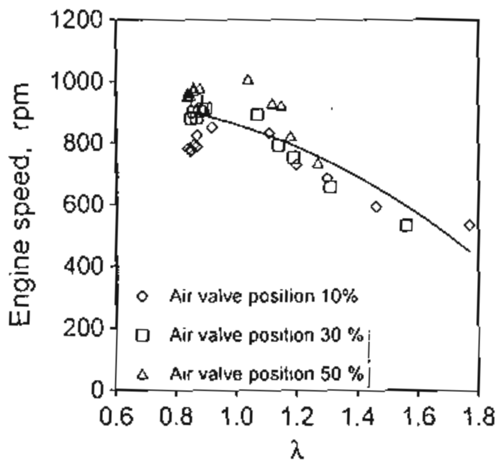

Fig. 15 Variation of idling speed with Excess air factor at different fuel and air valve positions .

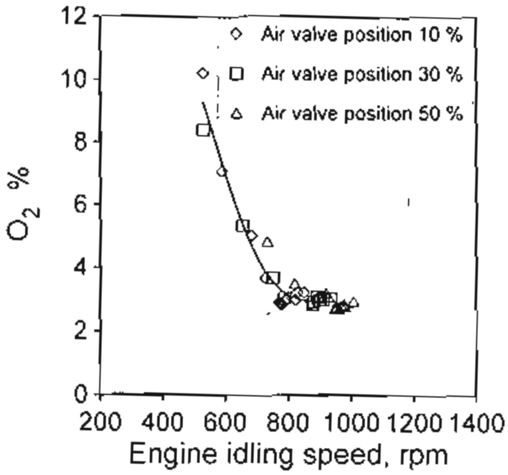

Fig. 16 Relation between O_2 emission and idling speed at different fuel and air valve position.

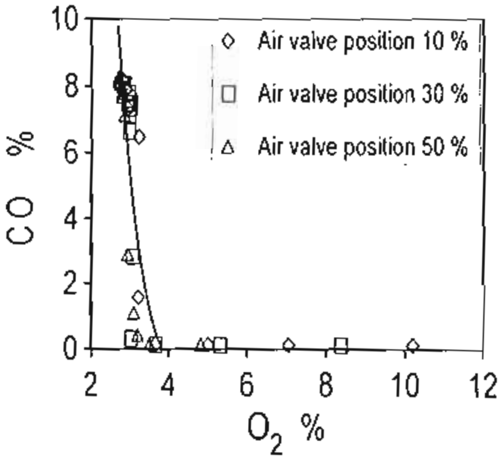

Fig. 17 Relation between CO emissions with oxygen concentration at exhaust at different fuel and air valve positions.

The results of emission characteristics represented in Figs.(11-17) are used to correlate both HC and CO as function of excess air factor λ in form of 2nd order polynomial equations, given as follows.

HC Concentration:

$$HC\ (ppm) = 4802 - 7623\ \lambda + 3277\ \lambda^2 \quad (5)$$

CO Concentration:

For $\lambda \leq 1.25$

$$CO\ \% = 50 - 71\ \lambda + 24.3\ \lambda^2 \quad (6)$$

for $\lambda > 1.25$

$$CO\ \% \approx 0$$

These correlations can be used to adjust the excess air factor required to obtain desired level of emission.

5 COCLUSION

In the present work series of experiments were conducted to clarify the effect of ignition parameters and mixture quality on the emission characteristics from gasoline-fueled engine. The engine runs at idling condition, whereas both the engine speed and species concentration of exhaust gases were recorded. The results indicate the following

- The optimum spark gap lies between 0.8 and 1.0 mm. No significant change in emission has been obtained beyond this limit, furthermore; a reduction in spark igniter life time is expected due to the corresponding increase in the spark potential. At narrow gap, the spark becomes too week to establish complete combustion, so a great emission of unburned HC is recorded.

- The results show the significant increase in HC emission when advancing the spark timing. On the other hand delaying the spark leads to reduce the idling speed and rough running is observed.
- The mixture quality at idling condition exhibits a great influence in controlling the exhaust emission. In spite of low emission were recorded at the stoichiometric condition, the idling condition needs rich mixture for fast starting and stable operation. The results enable assigning the excess air factor according to the allowable emission level.

NOMENCLATURE

symbol	definition	unit
N	Engine speed	rpm
s	Flame travel distance	m
u_f	Flame speed	m/s
θ_{eoc}	End of combustion angle	rad
θ_i	Ignition angle	rad
$\Delta\theta_d$	Delay period	rad
ϖ	Engine angular speed, $= 2\pi N/60$	rad/s
λ	Excess air factor $(A/F)/(A/F)_{ST}$	

ABBRIVIATIONS

CW	Clock wise
CCW	Counter clock wise
TDC	Top dead center
HC	Hydrocarbons
UBHC	Unburned hydrocarbons

REFERENCES

[1] Mage, D. and Zali, O. "Motor vehicle Air Pollution : Public Health Impact and Control Measures" WHO report, Geneva, 1992.

[2] Favre C. and Zidat S. " Emission Systems Optimization to Meet Future European Legislation" SAE Technical paper series No. 2004-01-0138, pp. 1-7, 2004.

[3] Lawson, D. R., Gurevich, M. "The DOE/NREL Environmental Science Program" SAE Technical paper series No. 2001-01-2069, pp.1-8, 2001.

[4] Faiz, A. , Weaver, C. S., Walsh, M. P. "Air Pollution from Motor Vehicles
Standards and Technologies for Controlling Emissions" The World Bank -
Washington, D.C. , 1996.

[5] Hien, L. "Effect of Natural Gas Composition Variations on the Operation, Performance and Exhaust Emission of Natural Gas-

Powered Vehicles" IANGV report, Sydney, August 2002.

[6] Sharma, S. P. and Mohan, C. "Fuels and Combustion"Tata McGraw-Hill Pub. Co., New Delhi, 1984.

[7] Heywood J. B. "Internal Combustion Engine Fundamentals" McGraw Hill Book Co. 1988.

[8] Sloane T. M. "Ignition and Flame Propagation Modeling With an Improved Methane Oxidation Mechanism" Combustion Sci. and Tech., Vol. 63, pp 287-313, 1989

[9] Sloane T. M. "Energy Requirements for Spherical Ignitions in Methane-Air Mixtures at Different Equivalence Ratios" Combustion Sci. and Tech., Vol. 73, pp 351-365, 1990

[10] Sloane T. M. "Numerical Simulation of Electric Spark Ignition in Atmospheric Pressure Methane-Air Mixture" Combustion Sci. and Tech., Vol.

[11] Frendi A. and Sibulkin M. " Dependence of Minimum Ignition Energy on Ignition Parameters" Combustion Sci. and Tech., Vol. 73, pp 395-413, 1990

[12] Kravchik T., Sher E. and Heywood J. B. "From Spark Ignition to Flame initiation" Combustion Sci. and Tech., Vol. 108, pp 1-30, 1995

[13] Laghai A., Nabavi S. H., Servati H. B., and Syed F. " IR-Laser Initiated Combustion – A Step Toward Complete Combustion" SAE Technical paper series, No. 960464, pp. 89-93, 1996.