PERFORMANCE OF A SPARK IGNITION ENGINE WORKING ON A GAS FUEL-AIR MIXTURE WITH A PARTIAL INJECTION OF LIQUID SPRAY.

عوامل الأداء لمحرك اشعال بالشرارة يعمل بخليط من الوقود الغازى والهواء مع حقن جزئى لرشة وقود سائل .

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الخلاصة – فى هذا البحث تم اجراء دراسة معملية لاختبار عوامل الأداء وخصائص انبعاثات محرك اشعال بالشرارة يعمل بخليط من الوقود الغازى والهواء مع حقن جزئى لرشة وقود سائل . أخذت قياسات لكل من خرج المحرك ومعدل استهلاك الوقود وكذلك نسب تركيز كل من غاز أول أكسيد الكربون والهيدروكربونات الغير محترقة وأول أكسيد النيتروجين فى غاز العادم وذلك مع تشغيل المحرك عند ظروف متعددة لكل من نسب خليط الوقود الغازى والهواء وأيضا تغيير كمية الوقود السائل المحقون وقد تم أيضا تسجيل التغير فى الضغط داخل غرفة احتراق المحرك . وتشير نتائج البحث والمقارنة أن الحقن الجزئى لرشة وقود سائل داخل غرفة احتراق محرك يعمل بخليط من الوقود الغازى والهواء يؤدى الى زيادة جودة الامتلاء وتحسن عملية الاحتراق من حيث زيادة سرعة انتشار اللهب عند زيادة درجة تخفيف الوقود للخليط الضعيف . وقد تمثل هذا التحسن فى زيادة الضغط الأقصى داخل غرفة احتراق المحرك . وقد أظهرت نتائج المقارنة التى تم التوصل اليها امكانية تشغيل المحرك مع زيادة درجة تخفيف الخليط الضعيف بنسبة تصل الى ٣٠٪ وتحسن عوامل أداء المحرك من حيث زيادة خرج المحرك بنسبة تصل الى ١٠٪ وخفض الاستهلاك النوعى للوقود بنسبة تصل الى ٨٪ وأيضا تقليل درجة تركيز أول أكسيد النيتروجين فى غازات العادم بنسبة تصل الى ٢٥٪ وذلك بحقن جزئى لرشة وقود سائل داخل غرفة احتراق المحرك عن الحالة الأخرى بدون حقن .

ABSTRACT

An experimental investigation to study the performance and the emission characteristics of a spark ignition engine operating on a natural gas-air mixture with a partial injection of liquid spray has been carried out. A light kerosine has been injected into the combustion chamber of the engine through an adopted injection system. Measurements of power output and fuel consumption as well as concentrations of CO, HC and NO in the exhaust gas have been made for a range of gas-air mixture ratios and different values of injected liquid spray mass fraction. The pressure variations in the combustion chamber have been detected and recorded by a piezo type transducer and a dual channel oscilloscope respectively.

The obtained results show that a partial injection of liquid kerosine into the spark ignition engine working on a natural gas-air mixture leads to improve engine performance for lean mixture ratios. The region of engine stable operation is extended by 20 ~ 30 percent, while the maximum power output is increased by 5 ~ 10 percent for constant operating conditions. This is due to the fact that the injected liquid particles will improve both volumetric efficiency and burning velocity for gas-air lean mixtures. Also, a significant reduction in the emission of the nitric oxide compared to the case without a partial injection of kerosine has been obtained.

INTRODUCTION

Performance, emission characteristics and economy of a spark ignition engine can be improved by applying various combustion techniques. Use of lean fuel-air mixtures have the potential advantage of improving the thermal efficiency for a certain compression ratio and decreasing the temperature of the burned gases in the combustion chamber. Thus NO formation rates are decreased. Lean combustion also leads to an increase of the oxygen concentration to the level that be needed to convert a large fraction of unburned fuel components and carbon monoxide to carbon dioxide and water.

Bernhardt [1] has reported that there is a potential for significant gains in both engine efficiency and emission levels by operating future engines on lean fuel-air mixtures. However, there are usually considerable difficulties in operating spark ignition engines on an extended lean fuel-air mixture ratios, since their performances and maneuverabilities are remarkably deteriorated, for lean mixture ratios. Quader [2] has indicated that under certain circumstances, incomplete combustion in the bulk gas may play an important role. As the lean flammability limit is approached, the typical automotive engine in use today exhibits an increase in unburned hydrocarbon emissons along with an increase in specific fuel consumption.

Use of gaseous fuel as a main or a supplimentary fuel in spark ignition engines can extend the boundaries of lean operating limit beyond those obtained with use of gasoline. The presence of the gas fuel in the mixture in the period of ignition and the initial phases of combustion provides a source of heat libration and active centers at an excess air ratio to which the gasoline-air mixture does not easily react. Gaseous fuel has the advantages of requiring only a simple carburation system, mixing throughly with air, burning more completely, quitly and smoothly than liquid fuel-air mixtures. Also, most gaseous fuel has higher octane ratings than gasoline, with resultant antiknock protection, thus greater compression ratios may be used without preignition or detonation. It also permits engines to be started and stopped easily.

There are some different types of gaseous fuel which can be used in operating spark ignition engines. Natural gas, which usually consists of nearly pure methane, forms an admirable engine fuel of high calorific value. A number of investigators have studied the natural gas operated internal combustion engines. Karim and Klat [3] have been early studied the knock and auto-ignition characteristics of some gaseous fuels and their mixtures. Also, Karim and Ali [4] have investigated the effects of low ambient temperature on the combustion of natural gas in a spark ignition engine.

A review on the combustion process in the dual fuel engine using natural gas has been reported by Karim [5]. It is interesting to note that in the dual-fuel engine, the combustion starts in a similar fashion to that of compression ignition engines and combustion continues by flame propagation, in a similar fashion to that of spark ignition engines. A study on the use of petroleum gases as fuel in diesel engines has been carried out by Bawadi [6]. An experimental study on the emission characteristics of a natural gas fuelled spark ignition engine has been carried out by Fleming and Allusp [7]. Also, Song and Hill [8] have carried out an experimental investigations on the combustion characteristics of the dual-fuelling diesel engine with natural gas.

A comparison study has been made on the performance of spark ignition engines fuelled with gasoline and natural gas by Evans et. al [9] and by Jones and Evans [10]. They have provided a considerable information concerning the relative power levels, efficiencies and exhaust emissions of the fuels. They showed that a power loss of an approximately 15% when changing from gasoline to natural gas was occured. They have concluded that this result may be due to low burning velocity of natural gas compared with that of gasoline.

Mizutani and Nakajima [11] have reported that an injection of a small quantity of liquid fuel spray accelerates the burning velocity and ensures the stabilization of lean mixture fuel vapour-air flames. An experimental investigation on the propagation velocity and structure of flames in droplet-vapour-air mixtures have been carried out by Hayashi et al. [12]. Kajitani [13] showed that the addition of droplets will increase the area of reacting zone of a lean gas fuel-air mixture flame and increase the burning velocity.

The objective of this work is to study the use of natural gas-air mixture for operating a spark ignition engine with a partial injection of liquid kerosine. The basic idea of the study is that use of lean natural gas-air mixture ratios leads to improve operating thermal efficiency and helps reducing the emissions of carbon monoxide, unburned hydrocarbons and oxides of nitrogen. The partial injection of liquid kerosine into the combustion chamber of the engine leads to improve volumetric efficiency, burning characteristics and engine performance.

EXPERIMENTAL APPARATUS

Experiments have been performed on a Farryman A 30 marine, water cooled, four stroke, single cylinder petrol engine. The cylinder bore of the engine is 95 mm, stroke is 82 mm, swept volume is 582 cc, the compression ratio can be ranged from 5:1 to 18:1 and the engine speed ranges from 1000 to 3000 rpm. Also, the engine can be equiped to run on diesel fuel or gaseous fuel. The engine is built in the TD43 test rig which has been developed by TeQuipment Corporation to incraese its versatility. The schematic diagram of the experimental apparatus is shown in Fig. 1.

A viscous flowmeter is used for measurements of air flow rate, $\dot{m}_a$, before being induced into the combustion chamber through a damping box and a gas-air mixing chamber. Natural gas of Abu-Madi gas fields Egypt, with the compositions shown in Table 1, is fed from the fuel bomb through a pressure reduction valve and a supply pipe to be injected and mixed with the air in the mixing chamber. The flow rate of the natural gas, $\dot{m}_g$, is measured using a gas flowmeter. The natural gas-air mixture strength, $(\dot{m}_g/\dot{m}_a)$, is controlled using a flow control valve in the natural gas supply pipe to the engine.

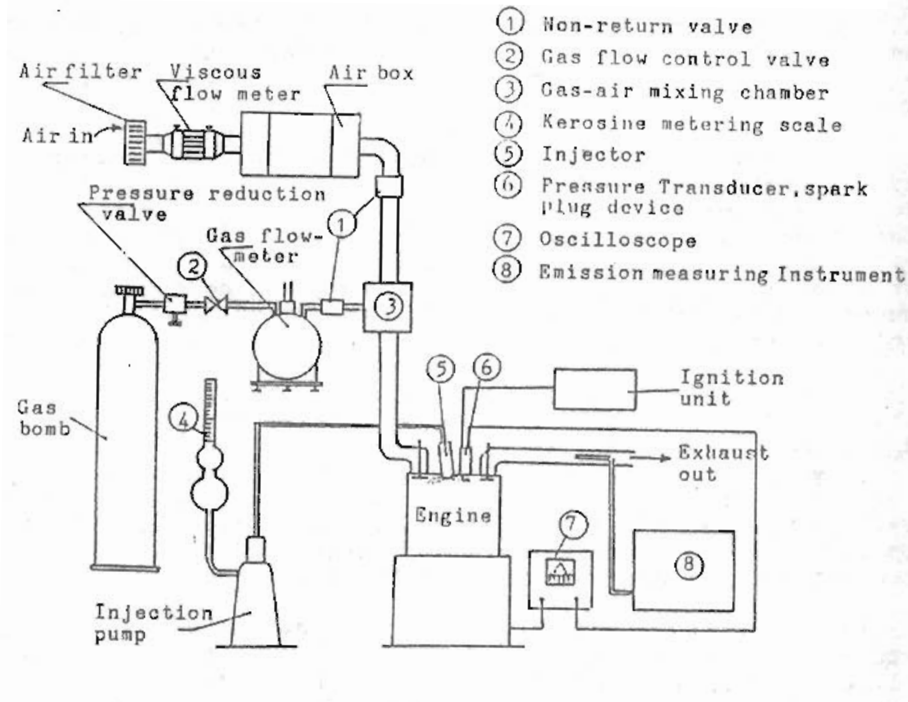


Fig. 1. Schematic diagram of the experimental apparatus.

Table 1. Compositions of the Abu-Madi Fields natural gas.

Compositions	Analysis, (%)	
	Volume	Weight
Methane, CH_4	92.51	85.10
Ethane, C_2H_6	4.40	6.76
Propane, C_3H_8	1.30	2.90
Butane, C_4H_{10}	0.55	1.30
Bentane, C_5H_{12}	0.16	0.44
Hexane, C_6H_{14}	0.15	0.45
Nitrogen, N_2	0.14	0.30
Carbon dioxide, CO_2	0.79	1.75

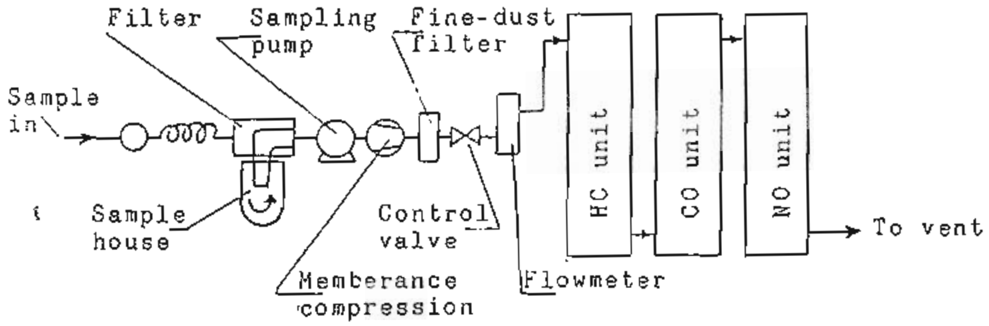


Fig. 2. Arrangement of exhaust gas emission measuring instruments.

A liquid kerosine of a specific gravity 0.7 at 15 °C is injected into the combustion chamber of the engine by an atomizing injector (type Bosh DLLA1SOS422). The injection flow rate as well as injection starting time into the combustion chamber have been controlled through a Bosh single cylinder fuel-injection pump. The atomization injector has six holes of 0.2 mm diameter and the angle of the injected spray is 150° . The injection flow rate of the liquid kerosine, $\dot{m}_{\ell}$, is measured using a metering scale. The pressure variations in the combustion chamber are detected and recorded by a piezo pressure transducer and a dual channel oscilloscope respectively.

Emission tests are carried out using gas analyzers and constant volume sampling techniques to provide an accurate mass emission measurements. A schematic diagram of the arrangement of the emission measuring instruments is shown in Fig. 2. A Beckman model 590 dual channel, is used for measuring concentrations of carbon monoxide, CO, and unburned hydrocarbons, HC. Also, a BIONS-IR analyzer is used for measuring nitric oxide, NO, concentrations in the exhaust gas. These are high selective, nondispersive infrared photometers for the quantitative and continuous determinations of measuring gas components with absorption bands in the short-wave and medium-wave infrared ranges.

RUNNING CONDITIONS AND PARAMETER CALCULATIONS

For the experimental comparisons to be considered, the engine was run until equilibrium conditions have been attained before readings. The cooling water temperature has been held constant at 70±3 °C. The intake pressure and temperature were in the range of 670 ~ 700 mmHg and 27 ~ 30 °C respectively. The compression ratio, CR, was remained constant at 10:1. The injection rate of the kerosine, $\dot{m}_{\ell}$, was varried in the range from 0 ~ 0.2 g/s, while the injection timing, θ_i , was varried in the range from 30° to 90° BTDC. Excepting the optimum ignition advance experiments, the spark advance, θ_s, was set at 18° BTDC in all other tests, which represent the maximum advance for maximum torque.

The coefficient of excess air, ε, was calculated from the following equation:

$$\varepsilon = \frac{\dot{m}_a}{(\dot{m}_g \cdot \alpha_g) + (\dot{m}_\ell \cdot \alpha_\ell)} \qquad \text{(1)}$$

where α_g is the stoichiometric air mass for combustion of the natural gas and α_ℓ is the stoichiometric air mass for combustion of kerosine.

The overall equivalence ratio, Φ, was estimated from the next equation:

$$\Phi = (\dot{m}_g / \dot{m}_a) \cdot \alpha_g + (\dot{m}_\ell / \dot{m}_a) \cdot \alpha_\ell \qquad \text{(2)}$$

The injected kerosine mass fraction, x, was estimated from the following equation:

$$x = \frac{\dot{m}_\ell}{\dot{m}_g + \dot{m}_\ell} \qquad \text{(3)}$$

The engine specific fuel consumption, SFC, was estimated from the following equation:

$$SFC = \frac{\dot{m}_g + \dot{m}_\ell \, (H_\ell / H_g)}{N_e} \qquad \text{(4)}$$

where H_ℓ and H_g are the lower heating values for the kerosine and gas respectively and N_e is the engine power output.

EXPERIMENTAL RESULTS AND DISCUSSIONS

Influece of a Partial Injection of Kerosine

Results of the influence of the partially injected liquid kerosine at different mass fractions and several injection timings are illustrated in Figs. 3 ~ 6. Values of the detected maximum pressure variation in the combustion chamber plotted against the overall equivalence ratio for different mass fractions of the injected kerosine are shown in Fig. 3. During these tests, the engine speed is set at 2000 rpm, the spark advance, θ_s, is 18°BTDC and the injection advance, θ_i, is 60°BTDC. Generally, it can be noted that the detected maximum pressure is higher with partial injection of kerosine than the counterpart without injection of kerosine for a certain overall equivalence ratio. The maximum pressure being remarkably increased for small fraction values of the injected kerosine over the whole range of the examined overall equivalence ratios.

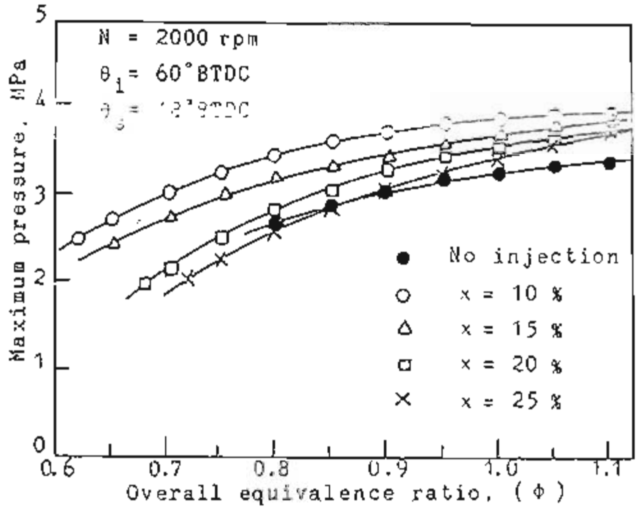


Fig. 3. Influence of injected kerosine mass fraction on the maximum pressure.

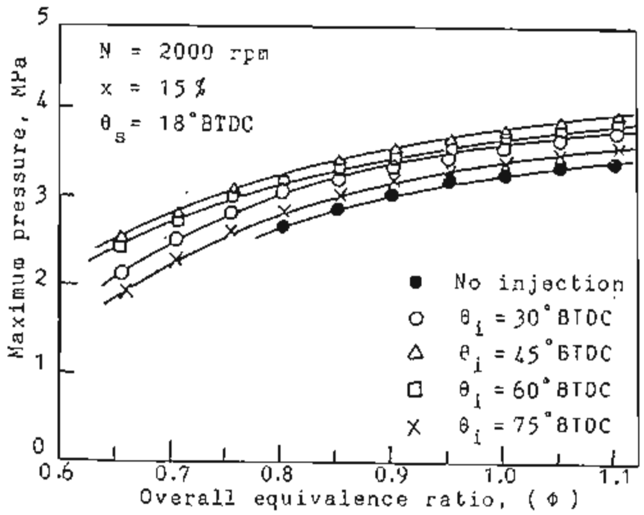


Fig. 4. Influence of injection timing of kerosine on the maximum pressure.

Figure 4 shows the detected maximum pressure in the combustion chamber plotted against the overall equivalence ratio for different injection timings. The mass fraction of the injected kerosine, x, is 15%. From the figure, it can be noted that the optimum value of the injection timing which gives the highest maximum pressure is $\theta_i = 45°$ BTDC and that the maximum pressure is lowered as the injection timing is either advanced or delayed from this value. This is may be because a too early injection causes an increased amount of injected particles to stick to the chamber walls and a too late injection causes an insufficient scattering of injected particles. The increase of the maximum pressure implies that a modification in the combustion process is occured by a partial injection of kerosine.

The influence of the injection of kerosune on the maximum pressure lag is shown in Fig. 5. The maximum pressure lags are defined as the periods from ignition to the maximum pressure. One can see that there is no noticeable difference observed in the maximum pressure lag for overall equivalence ratios greater than 0.9. The maximum pressure lag, however, becomes longer for overall equivalence reatios below 0.9 without a partial injection of kerosine, while the maximum pressure lag is kept roughly constant and a stable operation is continued down to the overall equivalence ratio of less than 0.7 with a partial injection of kerosine.

The influence of the partial injection of kerosine on the engine lean operating capability is shown in Fig. 6. The figure illustrates the relationship between the maximum coefficient of excess air and the mass fraction of the injected kerosine. The maximum coefficient of excess air, ε_{max} , is estimated from Eq. (1) as the engine running steadily yet for lean operating capability. From the figure, it can be shown that the maximum coefficient of excess air is increased with injection of kerosine. The maximum coefficient of excess air shows its highest values for a small values of the injected kerosine mass fraction, x = 10 or 15%. This means that the lean operating capability of the engine is increased with an injection of small mass fraction values of kerosine. This result may be due to the fact that the small quantity of the injected kerosine has significat effects on the combustion process inside the engine cylinder.

Engine Performances with Injection of Kerosine

The influence of the injection of kerosine on the engine performances are illustrated in Figs. 7 ~ 9. Comparisons of specific fuel consumption and thermal efficiency of the engine with and without injection of kerosine are shown in Fig. 7. It can be noted that an improvement in both specific fuel consumption and thermal efficiency of the engine for all examined overall equivalence ratios. Specific fuel consumption is decreased by about 5 ~ 8 percent while the thermal efficiency is increased by about 6 ~ 10 percent with injection of kerosine.

Results of the measured load characteristics of the engine with and without injection of kerosine are shown in Fig. 8. It can be noted that the specific fuel consumption is lowered for all engine loads and the maximum economy of the engine operation is improved with injection of kerosine.

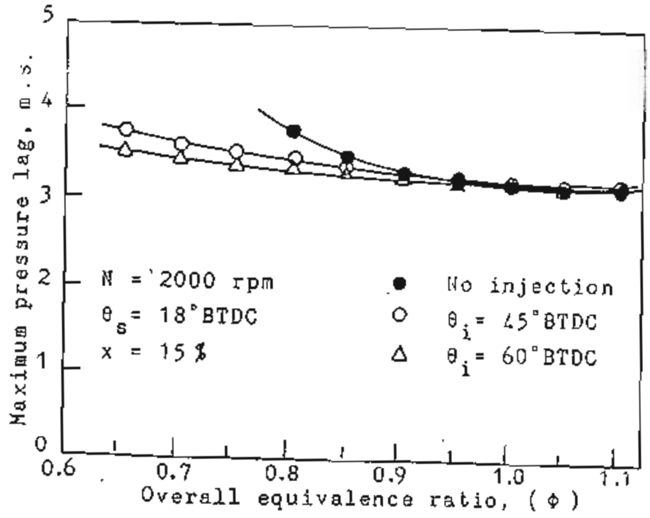


Fig. 5. Influence of injection of kerosine on maximum pressure lag.

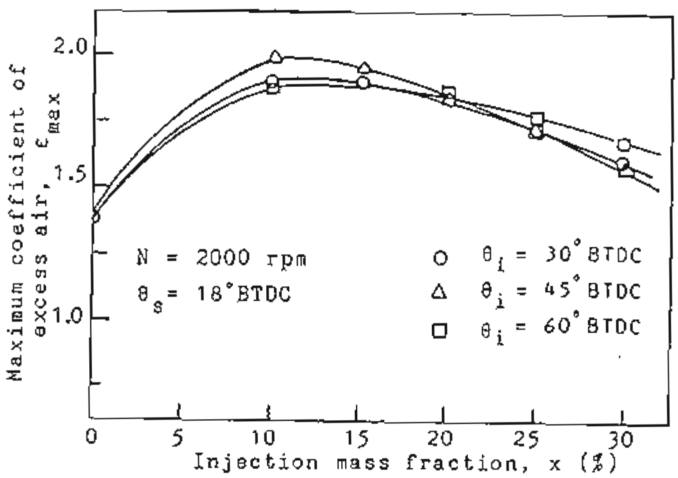


Fig. 6. Influence of injection of kerosine on lean operating capability of the engine.

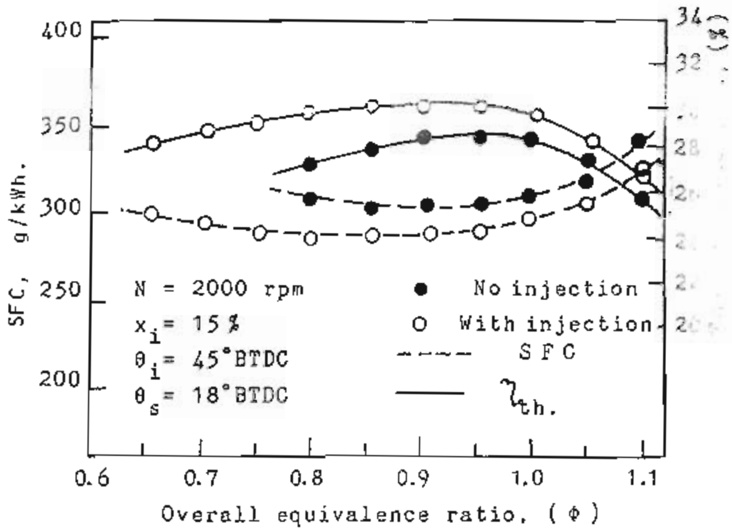


Fig. 7. Specific fuel consumption and thermal efficiency of the engine with and without injection of kerosine.

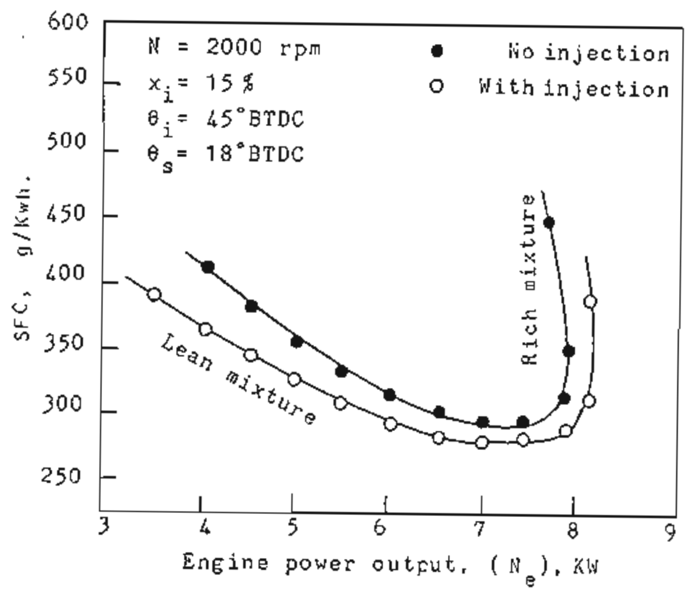


Fig. 8. Load characteristics of the engine with and without injection of kerosine.

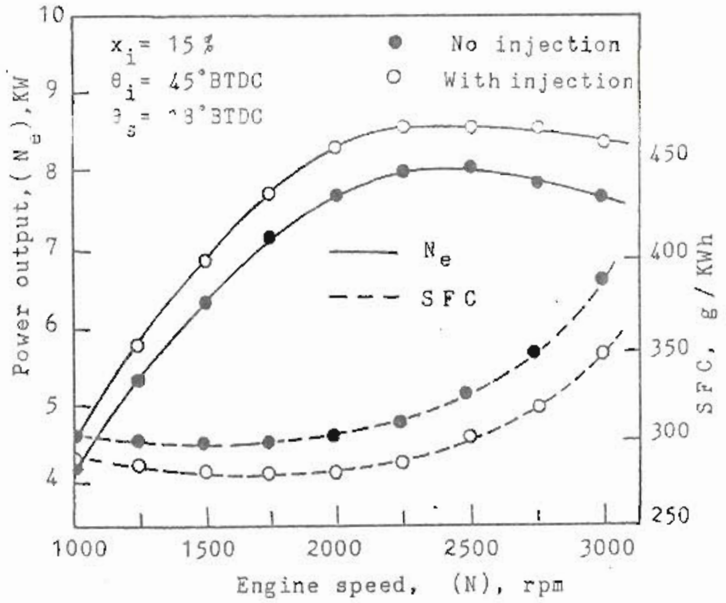


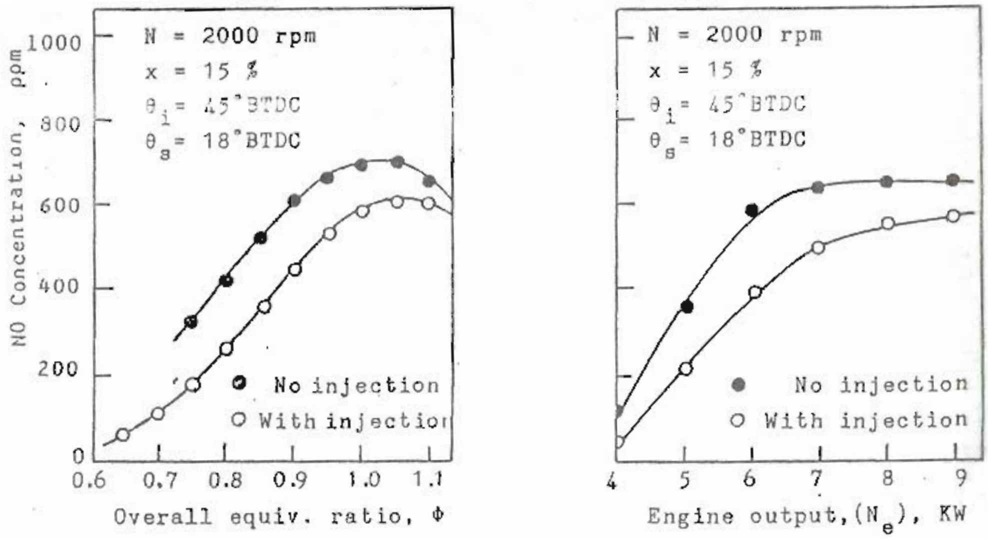
Fig. 9. Speed characteristics of the engine with and without injection of kerosine.

Speed characteristics of the engine with and without injection of kerosine are shown in Fig. 9. Generally, one can see that the engine power output is increased as the engine speed is increased. With injection of kerosine both engine power output and specific fuel consumption have been improved for all examined engine speeds. The engine power output is increased by 5 ~ 10 percent while the specific fuel consumption is lowered by 4 ~ 8 percent with injection of kerosine.

Exhaust Emissions with Injection of Kerosine

Comparisons have been made for the measured concentrations of the exhaust emissions with and without injection of kerosine for the optimum opertaing conditions of the engine. Results of the measured concentrations of nitric oxide, NO, unburned hydrocarbon, HC and carbon monoxide, CO, are shown in Figs. 10 and 11.

comparisons of the concentrations of nitric oxide, NO, against overall equivalence ratio and engine power output are shown in Fig. 10 (a) and Fig. 10 (b) respectively. The concentration of nitric oxide, NO, with partial injection of kerosine is remarkably lower than the case without injection of kerosine for a fixed overall equivalence ratio as well as for a certain power output. From the comparisons, it can be noted that concentrations of nitric oxide, NO, in the exhaust gas is reduced down by about 20 ~ 30 percent for constant operating conditions with injection of kerosine.



(a) NO versus Φ (b) NO versus N_e

Fig. 10. Concentrations of nitric oxide with and without injection of kerosine.

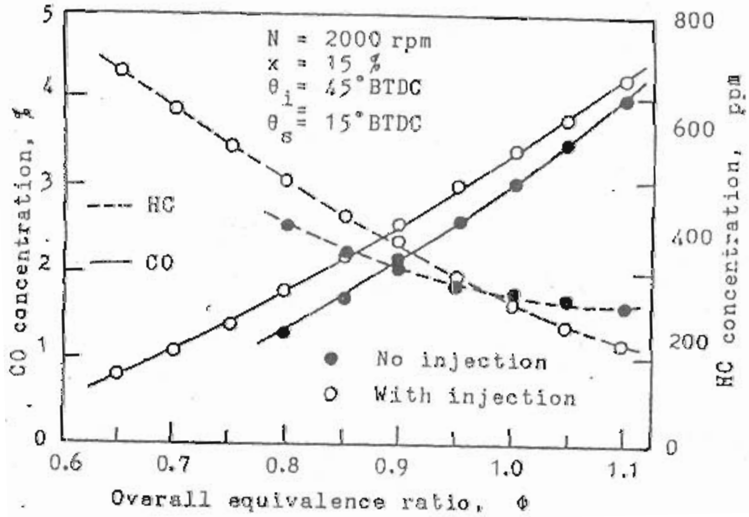


Fig. 11. Concentrations of carbon monoxide and unburned hydrocarbons with and without injection of kerosine.

Comparisons of concentrations of carbon monoxide, CO, and unburned hydrocarbons, HC, with and without injection of kerosine are shown in Fig. 11. From the figure, it can be noted that the concentration of carbon monoxide is increased with and without injection of kerosine as the overall equivalence ratio increased. Also, a slightly higher values of carbon monoxide, CO, concentration with injection of kerosine has been occured. The figure also shows that the concentration of the unburned hydrocarbons, HC, is slightly decreased with and without injection of kerosine as the overall equivalence ratio increased. However, the concentration of the unburned hydrocarbons is slightly higher with injection of kerosine for overall equivalence ratios less than 0.95.

CONCLUSIONS

An experimental investigations on the performance and emission characteristics for a spark ignition engine operating on natural gas-air mixture with and without partial injection of kerosine have been carried out. Based on the comparison results, the following conclusions may be drawn:

1. A partial injection of kerosine leads to raise the maximum pressure of every cycle in the combustion chamber of the engine. The maximum pressure shows its highest values with small mass fraction values of the injected kerosine.
2. The maximum coefficient of excess air is increased by about 30 percent, which means improvement of engine lean operating capability, with injection of small mass fraction values of kerosine. These results imply that a partial injection of kerosine improves the combustion process and increases the burning velocity of the lean gas-air mixture ratios.
3. The maximum power output is increased by 5 ~ 10 percent for constant operating conditions with a partial injection of kerosine.
4. The engine thermal efficiency, engine load characteristics and engine speed characteristics have been improved with a partial injection of kerosine.
5. The concentration of nitric oxide, NO, in the exhaust gas is reduced by 20 ~ 30 percent with a partial injection of kerosine for a constant overall equivalence ratio as well as for constant power output.
6. The concentrations of carbon monoxide as well as unburned hydrocarbons, HC, are slightly increased with a partial injection of kerosine for a certain overall equivalence ratio.

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