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The Ignition Probabity Study of Reformed Fuel to Characterise for New Automotive Fuel

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ABSTRAK

Menjelang abad yang akan datang, ahli pakar sains kita telah kenalpasti bahawa bekalan bahan api fosil menjadi amat terhad. Oleh sebab itu penggunaan bahan api dengan cara yang lebih cekap amatlah diperlukan. Kertas kerja ini memberikan penjelasan penggunaan sistem katalitik baru yang boleh memberikan faedah maksima dari proses rawatan bahanapi yang boleh memberikan pembakaran yang lebih baik, kuasa yang maksima dan bahan bahaya pencemaran yang rendah. Bahanapi terubah ini diperolehi dengan cara proses campuran dari makmal pembekal khas dan kajian kemungkinan nyalaan telah dijalankan keatas bahanapi tersebut. Kajian kemungkinan nyalaan adalah satu dari cara yang digunakan oleh penyelidik di United Kingdom bagi mengkaji perbandingan kebolehnyalaan bahanapi-bahanapi yang digunakan dalam enjin palam pencucuh. Kajian awal ini telah dibuat berdasarkan Kaedah Konsortium Pencemaran UK *bagi Pembakaran dengan Campuran Gas Ekzos Yang Tinggi dalam makmal. Kajian ini telah dibuat dengan menggunakan bom berkipas pada beberapa tahap keadaan gelora. Kajian ini telah menunjukkan bahawa campuran bahanapi terubah dengan udara mempunyai kemungkinan nyalaan yang lebih baik dan menyala pada keadaan gelora yang tinggi bebanding dengan campuran iso-oktana dengan udara. Keputusan kajian ini telah menunjukkan bahawa sistem bahanapi ini mempunyai kebolehan yang baik untuk mengalakkan penelidikan asas seterusnya untuk mendapatkan kelajuan pembakaran lamina bagi bahanapi terubah ini yang boleh dihubungkan dengan kadar pembakaran gelora dan seterusnya meningkatkan kecekapan pembakaran dalam enjin palam pencucuh.*

ABSTRACT

As we approach the next century, the scientists recognize that our supply of fossil fuel is limited. Hence, more efficient use of the fossil fuel are required. This paper give some possible use of new catalytic system that can produce the maximum benefits of fuel-treatment process which can give better combustion, maximum power with minimum noxious pollutants. The reformed fuel was obtained in the laboratory by special mixing process and the ignition study was conducted on the fuel. The ignition probability study is one of the methods used by researchers in United Kingdom to study the comparison of ignitability of fuels used in spark ignition engine. This preliminary study has been carried out, based on UK *Emission Consortium Methods for High Tolerance* EGR *Combustion in the laboratory. The study has been carried out using fan-stirred bomb with various turbulent conditions. The study has shown that the reformed fuel-air has better ignition probability* *and can be ignited even at higher turbulent condition, compared to iso-octane-air. The result has shown great potential of this system and encourage further fundamental research on the laminar burning velocity of reformed fuel which can be used to correlate to turbulent burning rate and therefore enhance the efficiency of combustion in spark ignition engines.*

INTRODUCTION

The pressure for stringent environmental protection laws, which demand more control of noxious exhaust emission, has generated interest in many new fuels. One of the ways to obtain efficient fuel combustion is to ensure the fuel burned in the engine completely at whatever turbulent conditions. This can be done through the study of probability of igniting the fuel in the engine with various turbulent conditions, which can be considered as a mean of initial rating of new fuel. These ignition probability study experiments were carried out in the fan-stirred bomb at the University of Leeds Laboratory. In this study the iso-octane was used representing nearest to petrol in chemical composition. Iso-octane-with exhaust gas recirculation (EGR) was also tested and compared with a new produced fuel called reformed fuel.

The use of lean burn engines and exhaust gas recirculation EGR has been investigated, as a means of both improving efficiency and reducing nitric oxide and hydrocarbon emissions. However the use of leaner mixture, and EGR reduce the flame propagation rate and increase the tendency to gas phase quenching, with probable engine misfire and unburned hydrocarbon emissions (William 1977; Gat & Kauffman 1980; Megatchi & Keck 1982, and Bradley et al. 1988). To compensate for the reduction in the laminar burning velocity of lean mixtures the turbulent velocities in the engines have been increased with subsequent increases in the flame propagation rates (Chainbongsai et al. 1980; Petrovic 1988; Swords et al. 1982 and Bradley et al. 1988). However, too much turbulence can also increase the tendency towards gas-phase quenching (Abdel Gayed & Bradley 1985).

Emission of carbon monoxide, oxide of nitrogen and unburned hydrocarbons has currently been reduced by the introduction of three-way catalyst in engine (Cooper 1994). The catalytic converter only attains reasonable efficiency close to stoichiometric air-fuel ratio. Other approaches have been focused on changes to fuel. A current one is to install a catalytic reformer on board the engine in the intake line, rather than a catalytic converter in the exhaust line. In the reformer, the fuel is reformed with air catalytically to give hydrogen, carbon monoxide, carbon dioxide, methane, ethylene propylene and nitrogen, before entering the engine. Of particular importance is that the presence of large amount of hydrogen in the reformed gas, (5% hydrogen can results in significant increase in laminar burning velocity for n-butane-air mixture, (Sher & Ozdor 1992). Reformed fuel is different from "reformulated gasoline". Reformulated gasoline, as described by Sawyer (1992) is the gasoline that have been modified chemical and physical properties for the purpose of reducing the air pollution from emission, which have lower aromatic content, an oxygenated additive, methyl-t-butylether (MTBE), lower olefin content, lower sulphur content and lower vapor pressure.

MATERIAL AND METHOD

The ignition probability study was concerned with the ignition or turbulent flame propagation limits of mixtures of fuel-air, with increasing turbulence intensity. The apparatus used consisted of fan-stirred explosion vessel, and Lucas ignition units and ignition switch. The vessel was fitted with Lucas spark plug. The spark gap was set at 3 mm. The study was based on method used in the UK Emissions Consortium Project (Sheppard et al. 1990). The arrangement of the Lucas ignition system is shown in Figure 1.

The explosion vessel composed a cast steel cylinder of 305 mm diameter and 305 mm length with a 150 mm diameter concentric window in each end plate. These windows were fitted with 25 mm thick optical quality glass. They provided optical access for ignition observation. The turbulence in the bomb was generated by four identical fans, each driven by an 8 kW high-speed induction motor with independent speed control, created a central region of uniform isotropic turbulence. A thermometer, with cold junction self-compensation chromel-alumel thermocouple was fitted to the bomb to record the pre-combustion mixture temperature. The ignition system comprised of an energy unit and a single spark plug of two electrodes. The Lucas ignition system was specially designed for long duration sparks, up to 10 ms, with variable high spark energy with maximum current of up to 10 Amps. Two car-ignition coils with a special ignition circuit produced the spark duration. The triggering unit was connected to the ignition unit via a fibre optic cable through a junction box. The portable triggering unit was used because it allowed convenient positioning of the unit when close observation of explosion was required.

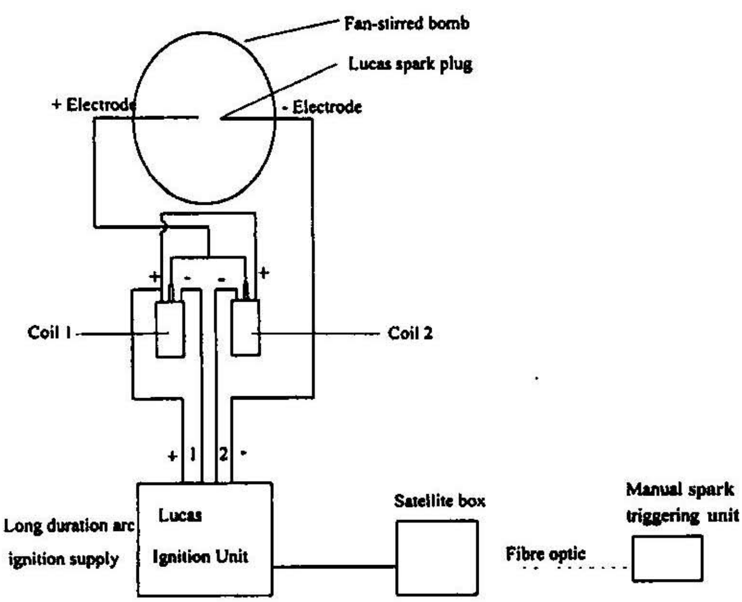

FIGURE 1. Arrangment of ignition probability study apparatus

Mixture preparation for gaseous fuels utilized the partial pressure method. Before any mixture preparation, the vessel was first flushed out to clear off any previous combustion products. The vessel was evacuated to a pressure of less than 15 mm Hg., and filled with dried atmospheric air to a pressure of one atmosphere. This was repeated at least three times. After a fourth evacuation, the mixture components were added, with smallest components first, to their respective partial pressures, calculated for the specific equivalence ratio, then the vessel was filled to a final pressure of one atmosphere with dried atmospheric air. The air was dried by passing it through a tube filled with calcium chloride.

ISO-OCTANE AND OTHER LIQUID FUELS

Iso-octane was supplied commercially with a quoted purity of 99.5%. Since iso-octane is a liquid at normal pressure and temperature, it was necessary to ensure complete vaporization of fuel before explosion. To ensure complete evaporation the initial temperature of the mixture was set at 328 K (Hamid 1986). For iso-octane mixtures, first, the bomb was heated to about 338 K by switching on the internal 2 kW electric heater and running the fans in the bomb. The iso-octane-air mixture was then prepared by first filling the bomb with air to the calculated partial pressure. This was heated to about 338 K and then a glass hypodermic syringe was used to inject the required amount of iso-octane through a special opening, a rubber bung set into the end wall of the bomb. The syringes were of two capacities: 2 ml was used for equivalence ratios up to 1.0, and 5 ml for higher equivalence ratios. After mixture preparation, a plug with sealing washer was screwed into the fuel injection opening port to prevent leakage. Droplets, which were splashed onto the windows during fuel injection, could be seen to vaporize in less than five seconds. The mixture was then stirred at high fan speed for a few minutes at 338 K before being allowed to cool to the ignition temperature of 328 K.

ISO-OCTANE-EGR MIXTURES

For the experiments involving iso-octane with simulated exhaust gas recirculation, EGR, mixture preparation was carried out by a combination of gaseous fuel and liquid fuel procedures. Simulated exhaust gas was made up of carbon dioxide, nitrogen and water vapour at the proportions found in the stoichiometric reaction of iso-octane-air. The mixture was prepared by filling the bomb with gaseous components to the calculated partial pressure. First carbon dioxide from a cylinder was added. Then the bomb inlet valve was closed and the inlet line was evacuated of excess carbon dioxide. The inlet valve was opened again and the nitrogen gas was added from the nitrogen gas cylinder to the calculated partial pressure. Following the purging of the inlet line dried air was then added to the required partial pressure. The bomb valve was closed again and the mixture was heated to the required temperature with the fans and heater. After turning off the fans and heater, the required amount of iso-octane was injected into the bomb as discussed in Section 2.1. Finally the warm water was injected into the bomb using the same procedure. The mixture was thoroughly mixed and heated by running the fans for a few minutes before firing at the pre-set temperature.

In laminar burning velocity experiments, the fans were stopped and the mixture temperature was allowed to cool to 328 *K* before ignition. In the case of turbulent burning velocity experiments the fans were operated at the required speed before ignition. Each explosion was carried out at a pressure of 1 atmosphere and a temperature of 328 *K*.

REFORMED FUEL MIXTURE

The specification of the simulated reformed fuel and its composition is shown in Table 1. The fuel was supplied in gaseous form, in a high-pressure bottle, from B.O.C. Special Gases Ltd. The percentage composition being quoted by volume. The mixture preparation for reformed fuel was no different from the normal gaseous fuel preparation. The partial pressures of the fuel and air were first calculated.

Reformed fuel-air mixtures were prepared according to the procedure described above. The fans were then set to specified speed and the ignition was fired from ignition switch at a temperature of 328 K. Observation was made whether the mixture was ignited. At each mixture strength and fan speed (turbulent intensity), ignition was attempted a number of times and the probability of successful ignition was calculated.

TABLE 1. Reformed fuel composition as supplied in high-pressure bottle

Composition	Formula	Nominal Value	Actual Value
Methane	CH_4	3.70	3.95
Ethylene	$C2H_4$	5.50	5.19
Ethane	$C2H_6$	1.20	1.21
Propylene	$C3H_6$	1.30	1.27
Hydrogen	H_2	23.00	22.84
Carbon monoxide	CO	11.00	12.07
Carbon dioxide	CO_2	8.40	9.07
Nitrogen	N_2	45.90	44.40
% by volume		100.00	100.00

RESULTS AND DISCUSSION

The results of the experimental studies of turbulent ignition probability limits for iso-octane and reformed fuel are reported. The ignition probability for reformed fuel-air mixtures for different equivalence ratios, operating at a full current of 10 amps and with a maximum arc duration of 10 ms, was recorded as shown in Figure 2. At each mixture strength and fan speed, ignition was attempted a number of times and the probability of successful ignition estimated. In this diagram, approximate envelopes for 100% and 0% probability of ignition success are drawn as functions of equivalence ratio, ϕ, and fan speed (or turbulence intensity, u'). From the 100% probability curve, it can be seen that at any equivalence ratio above 0.5, reliable ignition was achieved at all fan speeds, up to the maximum of 10,000 r.p.m. At low fan speeds, reliable ignition was obtained with mixtures of equivalence ratio as low as 0.34, at about 1000 r.p.m. Between a fan speed of 1000 and 6000 r.p.m the ignition is affected by the turbulence

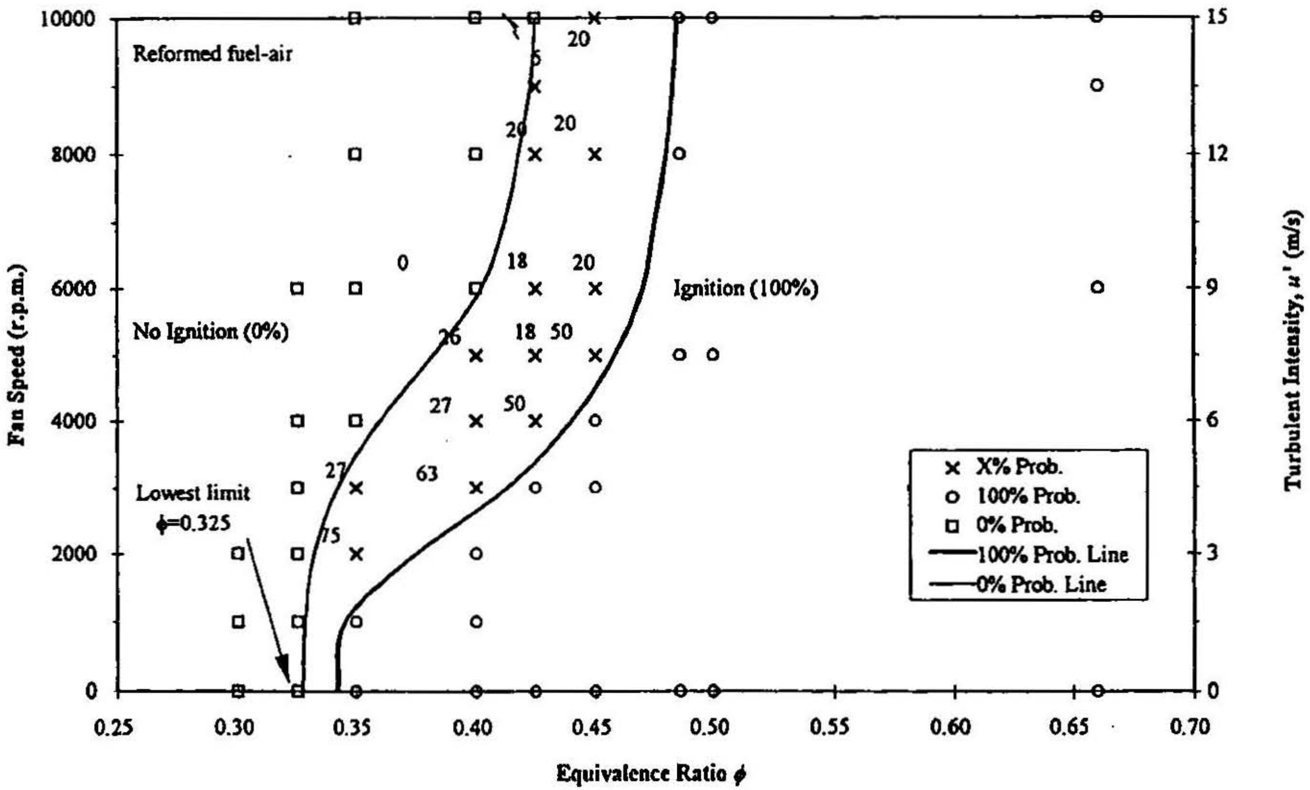

FIGURE 2. Ignition probability for reformed fuel-air mixtures at T_u = 328 K and 1 *atm*. Number on graph is percentage of success.

intensity and the equivalence ratio had to be increased gradually from 0.35 to 0.47 in order to maintained 100% ignition probability. From Figure 2 the margin separating 0% and 100% ignition probability increased considerably for fan speeds between 1000 and 6000 r.p.m. and then remained almost constant from this fan speed up to the maximum speed of 10,000 r.p.m.. The numbers given in this region indicate the probability of ignition of the mixture at the given turbulence intensity. The lowest limit below which no ignition will occur at all is estimated at equivalence ratio of 0.325 at laminar condition. This increased gradually to about 0.425 at 10,000 r.p.m. The 100% ignition probability line is important to determine the ignition limit of the mixture, and also for comparison with other fuels (Sheppard *et al.*, 1990). The almost vertical 100% probability line at fan speed higher than 6000 r.p.m. indicated that the fuel can withstand high turbulence, without quenching. Similarly, the 100% probability line almost vertical at fan speed below 1000 rpm. This low fan speeds were beneficial because they moved the kernel away from the cooling electrodes and ensuring complete ignition. The results for reformed fuel were compared with those obtained for lean iso-octane-air mixtures (Sheppard et al. 1990), Figure 3, and stoichiometric iso-octane-air with simulated EG dilution mixtures (Sheppard et al, 1990), Figure 4. For comparison purposes, the 100% probability curves for reformed fuel-air, iso-octane-air and iso-octane-air with EG dilution are all plotted against equivalence ratio in Figure 5. In these diagrams the values of equivalence ratio for iso-octane-air mixture and iso-octane-air with EG dilution have been calculated using stoichiometric equation. In all cases the iso-octane-air mixture is in combining proportions. The exhaust gas is added as a diluent. The equivalence ratio, ϕ, for iso-octane-air and the effective equivalence ratio, ϕ_{eff}, for iso-octane-air with EG dilution are defined by:

$$\phi = \frac{\left(\frac{Fuel}{Air}\right)_{actual}}{\left(\frac{Fuel}{Air}\right)_{stoich}}, \qquad \text{Eq. (1)}$$

$$\phi_{eff} = \frac{\left(\frac{Fuel}{Air_{stoich} + Exhaust\ gas}\right)_{actual}}{\left(\frac{Fuel}{Air}\right)_{stoich}} \qquad \text{Eg. (2)}$$

With this definition the exhaust gas is analogous to the excess air of a lean mixture. For reformed fuel-air mixture the "fuel" is considered as that supplied in the gaseous phase from the pressurized supply cylinder. The equivalence ratio for reformed fuel-air is calculated from Eq. (1). In terms of the fuel-air mixture supplied to the catalytic converter and engine, regarded as a single unit, it is practically more appropriate to base the effective equivalence ratio for reformed fuel on the original fuel-air ratio before reforming. This is possible if the original fuel is known or its composition can be assumed as that of a hydrocarbon in the form of C_xH_y. However, in the present case the composition of the original fuel was unknown, and hence the reformed fuel was considered as the fuel supplied.

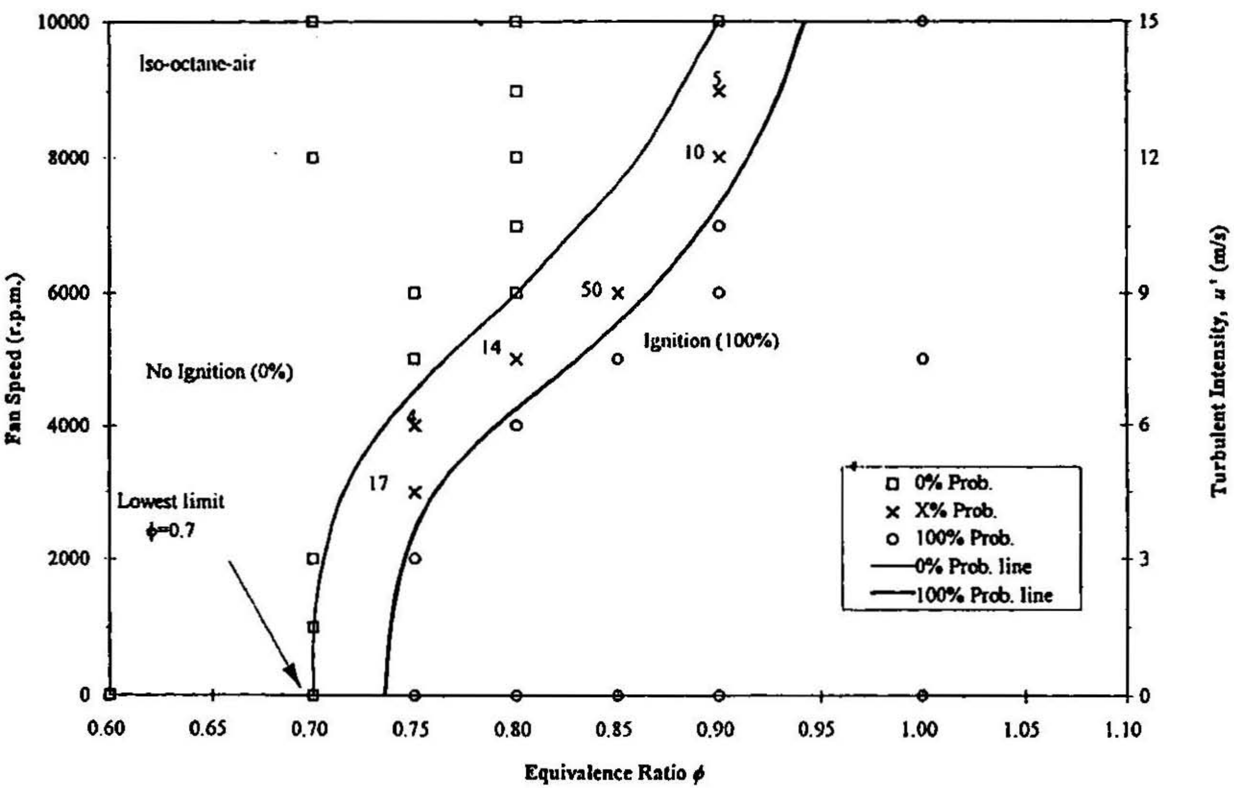

FIGURE 3. Ignition probability for iso-octane-air mixtures at T_u = 328 *K* and 1 *atm*. Number on graph is percentage of success.

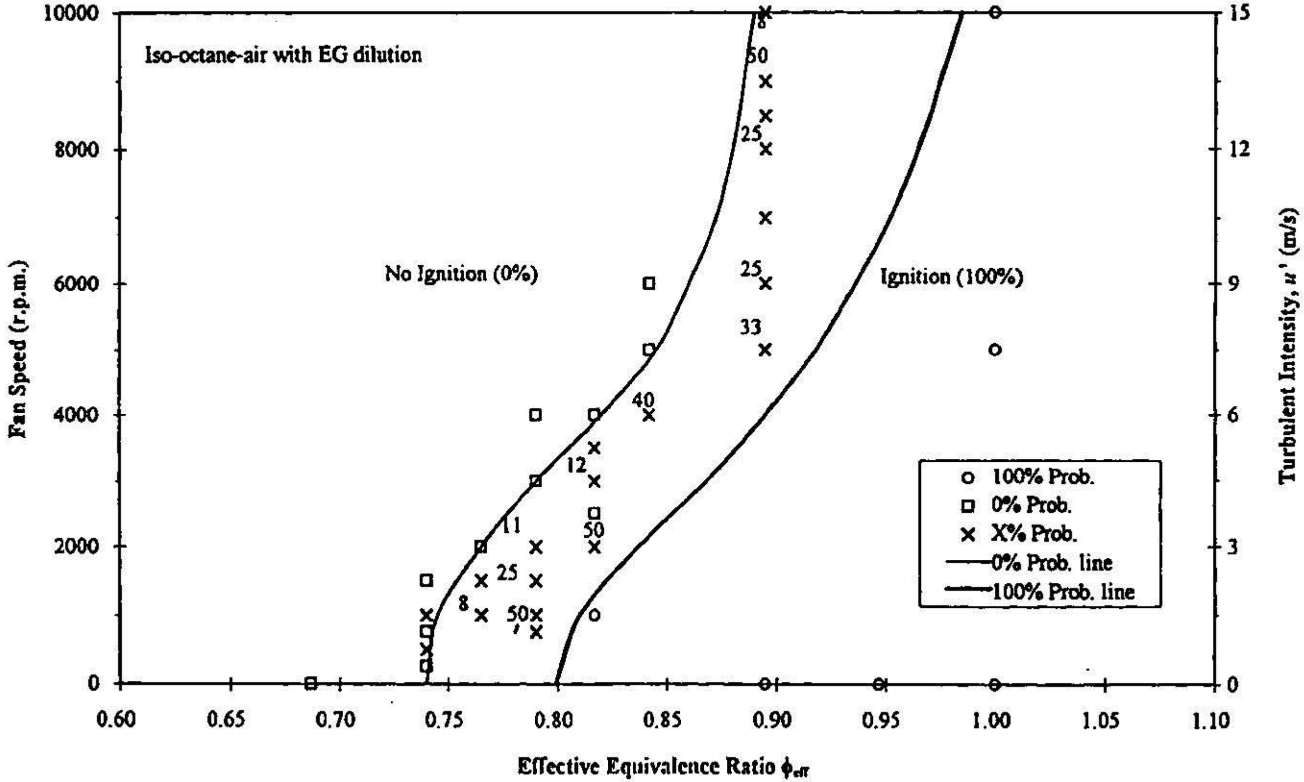

FIGURE 4. Ignition probability for stoichiometric iso-octane-air mixtures with EG at T_u = 328 *K* and 1 *atm*. Number on graph is percentage of success.

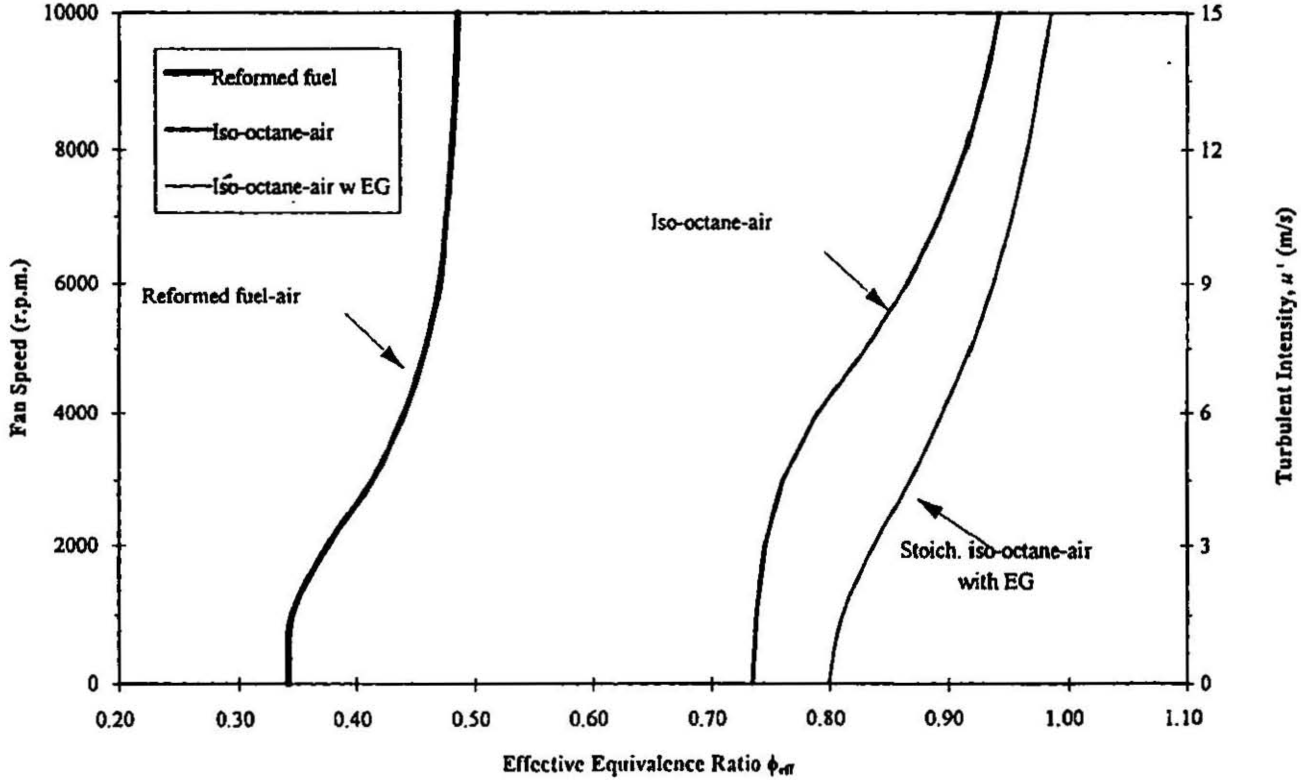

FIGURE 5. Comparison of 100% ignition probability curves for reformed fuel-air, iso-octane-air iso-octane-air with EG at T_u = 328 K and 1 *atm*.

From Figure 5 it can be seen that the reformed fuel-air has 100% ignition probability at much lower equivalence ratio, at all turbulence intensities as compared to iso-octane-air and iso-octane-air with EG dilution. The limiting equivalence ratio remained almost constant at the high fan speed between 6000 and 10,000 r.p.m.

CONCLUSIONS

The ignition probability study with reformed fuel has shown that the fuel reforming before engine intake is very useful because the process generate a high proportion of hydrogen gas during the reforming process and can assist the combustion better. The reformed fuel has a much lower ignition probability limit in both laminar and turbulent conditions than that of iso-octane-air. The lower limit of ignition probability for reformed fuel under laminar conditions of 328*K* and 1 *atm.* was found to be at an equivalence ratio of about 0.35. This is very lean and very beneficial to fuel economy, since engines could be operated under leaner conditions than usual.

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