INFLUENCE OF EXHAUST GAS RECIRCULATION ON COMBUSTION CHARACTERISTICS UNDER HIGH TEMPERATURE AND PRESSURE USING OPPOSED RAPID COMPRESSION MACHINE

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Abstract. The release of NOx, SOx, HC and CO2 from internal combustion engines is still a major issue in the development of modern engines. Especially when new concepts like EGR (Exhaust gas recirculation) are developed, detailed information about the pollutant formation is required. However, the experiments of actual standard engines are generally very complicated processes including the residual gas of last cycle and the flow in an engine cylinder. Thus, experimental data measured using actual engines become unreliable.

To obtain the essential data on combustion of hydrocarbon-CO2-N2-O2 mixtures, the experiments have been performed under conditions of high temperature and pressure, which are achieved by a spark ignited opposed rapid compression machine. The main conclusions are follows: (1) Flame speed decreases with increasing the concentration of carbon dioxide. (2) The reduction rate of the flame speed decreases with increasing the compression ratio.(3) The ratio of decrease of flame speed increases with increasing carbon dioxide concentration.

1. INTRODUCTION

Combustion characteristics of hydrocarbon-air mixtures at high temperature and pressure are important for predicting the performance of internal combustion engines and high speed jet engines. Some data are available on the combustion characteristics of hydrocarbon-air and natural gas mixtures in internal combustion engines.1, 2, 3 Furthermore, many researchers have carried out computer simulations to determine the combustion characteristics of internal combustion engines.4, 5, 6 The release of NOx, SOx, HC and CO2 from internal combustion engines is still a
major issue in the development of modern engines. Especially new concepts like EGR (Exhaust gas recirculation) is developed, detailed information about the pollutant formation is required. However, the experiments of actual standard engines are generally very complicated processes including the residual gas of last cycle and the flow in an engine cylinder. Thus, experimental data measured using actual engines become unreliable.

To obtain the essential data on combustion of hydrocarbon-CO$_2$-N$_2$-O$_2$ mixtures, the experiments have been performed under conditions of high temperature and pressure, which are achieved by a spark ignited opposed rapid compression machine. The ranges of initial temperature and pressure established in the machine are 293 to 1000 K and 0.1 to 1.5 MPa, respectively. Under these conditions it has been possible to obtain the fundamental combustion characteristics of hydrocarbon -CO$_2$-N$_2$-O$_2$ mixtures such as the maximum pressure, total burning time and flame speed for the fuels studied.

2. EXPERIMENTAL APPARATUS AND PROCEDURE

Figure 1 shows the opposed rapid compression machine employed in this study. The bore of opposed rapid compression machine is 100 mm, this machine is rapidly driven using compressed air (0.5 MPa) drawn from a reservoir equipped with electric valves and the average polytropic index is about 1.34. The compression ratio is changed by changing the initial position of piston and by either changing the stroke or the diameter of the combustion chamber in the opposed machine. A spark plug, a pressure transducer (Piezo-type), ionization probes and water jacket to regulate the temperature are equipped with combustion chamber. The flame speed $S_f$ is measured by the ionization probe located at two different positions from the center of the combustion chamber where the pressure rise is less than 5% of its final value and the pressure is nearly constant. Methane and Propane gas of 99% purity are used as fuels and a mixture of 79% nitrogen and 21% oxygen by volume is used as a substitute for air.

3. RESULTS AND DISCUSSION

The initial temperature $T_i$ of the premixed gas after compression can be determined from

$$T_i = T_b \varepsilon^{n-1}$$

where $T_b$ is the initial temperature of the premixed gas before compression, and $n$ and $\varepsilon$ are the polytropic index and the compression ratio, respectively.

Figures 2 and 3 show the maximum burning pressure ratio of propane-CO$_2$-N$_2$-O$_2$ mixtures against equivalence ratio as a function of compression ratio. From these results, it is found that the
maximum burning pressure ratio increases with decreasing the concentration of CO₂ in propane-CO₂-N₂-O₂ mixture.

Figures 4 and 5 show the total burning time of propane-CO₂-N₂-O₂ mixtures against the equivalence ratio. From these results it can be seen that the total burning time decreases with decreasing the concentration of CO₂ in propane-CO₂-N₂-O₂ mixtures.

The flame speed of propane-CO₂-N₂-O₂ mixtures with equivalence ratios as a function of CO₂ concentrations shown in Figure 6 and 7. From these results it is found that, with increasing the CO₂ concentration the flame speed decreases and its maximum value is obtained at 1.2 of equivalence ratio due to the effect of thermal dissociation.

Fig. 8 shows the ratio of decrease of flame speed with equivalence ratio as a function of CO₂ concentration. As seen from this figure, with increasing the compression ratio the ratio of decrease of flame speed decreases, furthermore it is relatively large on the fuel lean/rich side than on the stoichiometric.

4. CONCLUSIONS

Experiments were carried out to determine the combustion characteristics of propane-CO₂-N₂-O₂ mixtures at high temperature and pressure conditions by using an opposed rapid compression machine. The main results are as follows; 1) Flame speed decreases with increasing the concentration of carbon dioxide in the mixtures. 2) The reduction rate of the flame speed decreases with increasing the compression ratio. 3) Ratio of decrease of flame speed increases with increasing carbon dioxide concentration in the mixtures.

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**Fig. 1.** Opposed rapid compression machine

**Fig. 2.** Ratio of maximum burning pressure($\varepsilon=5$)
Fig. 3. Ratio of maximum burning pressure ($\varepsilon=7$)

Fig. 4. Total burning time ($\varepsilon=5$)
Fig. 5 Total burning time ($\varepsilon=7$)
Fig. 6 Flame speed ($\varepsilon=5$)

Fig. 7 Flame speed ($\varepsilon=7$)
Fig. 8 Ratio of decrease of flame speed