

A STUDY OF COMBUSTION CHARACTERISTICS OF HYDROCARBON-AIR MIXTURES AT HIGH TEMPERATURE AND PRESSURE BY USING RAPID COMPRESSION MACHINE

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Abstract. Experiments have been carried out with quiescent hydrocarbon-air mixtures for determining their combustion characteristics, under high temperature and pressure using a single and an opposed rapid compression machine with spark ignition. The absolute value of pressure exponent for methane-air and propane-air mixtures increases with increasing initial temperature and the temperature exponent is estimated to be about 2.6 even at high temperature and pressure conditions.

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 [1-3]. Furthermore, many researchers have carried out computer simulations to determine the combustion characteristics of internal combustion engines [4-6]. However, the combustion phenomena in engines are influenced by residual gas, turbulence and cycle-to-cycle variation in engine cylinder and the results of simulations may not be realistic in view of these factors. Consequently, the data such as flame speed and mass burning rate at high temperature and pressure obtained using simulations are somewhat suspect.

The present experiments have been carried out using quiescent hydrocarbon-air mixtures for studying their combustion characteristics under high temperature and pressure in a single and in an opposed type rapid compression machine with spark ignition. The ranges of initial temperature and pressure established in the machines 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-air mixtures such as the maximum pressure, total burning time and burning velocity for the fuels studied.

2. Experimental Apparatus and Procedure

Figures 1 and 2 show, respectively, the single and the opposed rapid compression machine employed in this study. The bores of single and opposed rapid compression machines are 80 and 100 mm, respectively and both machines are 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 [7,8]. The compression ratio is changed by

changing the initial position of piston in the single machine 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

$$T_i = T_b^{n-1} \quad (1)$$

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

The burning velocity S_u is given by

$$S_u = (M_b/M_u)(T_u/T_b)S_f \quad (2)$$

where: M_b/M_u is the ratio of mean molecular weight of burnt to unburnt mixture, T_u/T_b is the ratio of temperatures of unburnt to burnt mixture and S_f is the product gas velocity (Flame speed).

Figures 3 and 4 show the variation in burning velocity of methane-air and propane-air mixtures with initial temperature at a constant initial pressure (1.5 MPa) and for different equivalence ratios. From these results it is found that the burning velocity increases with increasing initial temperature at any equivalence ratio. It is an interesting fact that the increase is relatively larger on the fuel rich/lean side than near the stoichiometric.

The burning velocity of methane-air and propane-air mixture at a constant initial temperature (600 K) are shown in Figs. 5 and 6, respectively. It can be seen from these figures that the burning velocity decreases with increasing initial pressure and the magnitude of decrease is almost constant at any equivalence ratio.

Table 1 shows the pressure exponent np of methane-air and propane-air against the initial temperature. The pressure dependence of burning velocity can be predicted by determining the pressure exponent np in the following empirical equation [9],

$$S_u \propto P^{np} \quad (3)$$

where P is the initial pressure of the mixture. It can be seen that the absolute value of pressure exponent np increases with increasing initial temperature. In this study, the temperature exponent nt ($S_u \propto T^{nt}$, T :initial temperature) is almost constant and its value is about 2.6.

Table 1 Pressure exponent for methane-air and propane-air

Initial temperature	Methane	Propane
	Pressure exponent (absolute value)	Pressure exponent (absolute value)
600 K	0.37	0.39
650 K	0.59	0.59
700 K	0.85	0.86

Conclusions

Experiments were carried out to determine the burning velocity and its pressure and temperature dependence at high temperature and pressure conditions by using a single and an opposed rapid compression machines. The main results are as follows; 1) The absolute value of pressure exponent of methane-air and propane-air mixture increases with increasing initial temperature; 2) The temperature exponent is estimated to be about 2.6. 3) The increase in burning velocity at constant initial pressure is relatively larger on the fuel rich/lean side than near the stoichiometric.

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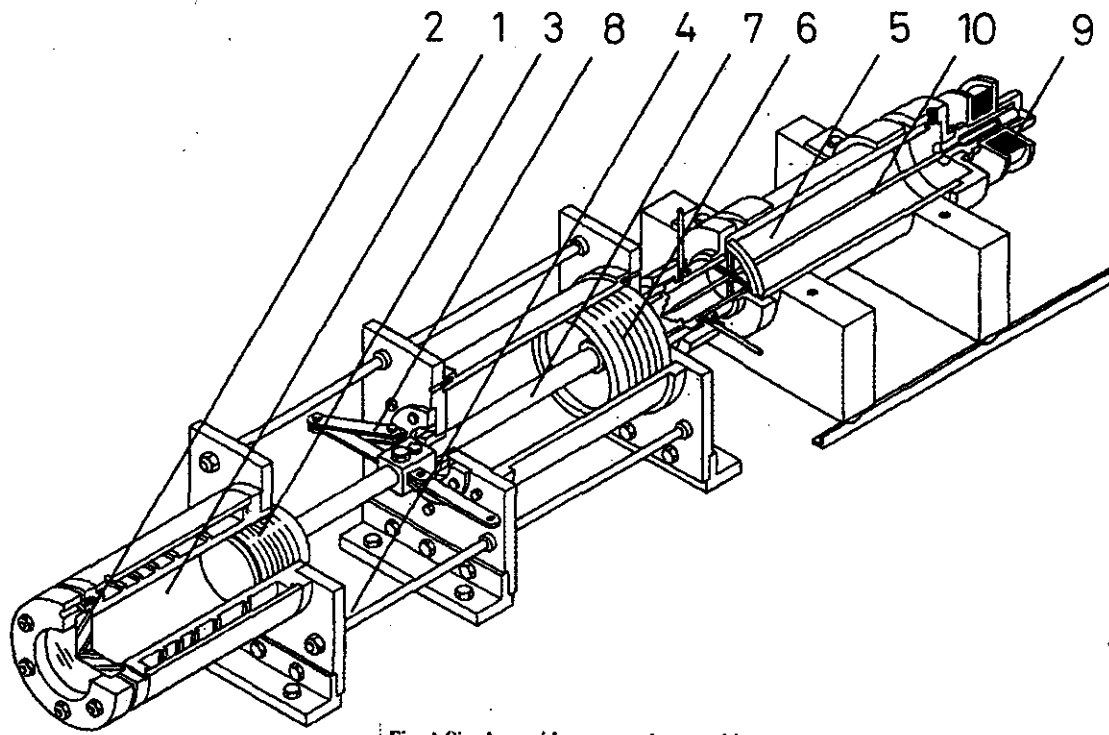


Fig. 1 Single rapid compression machine

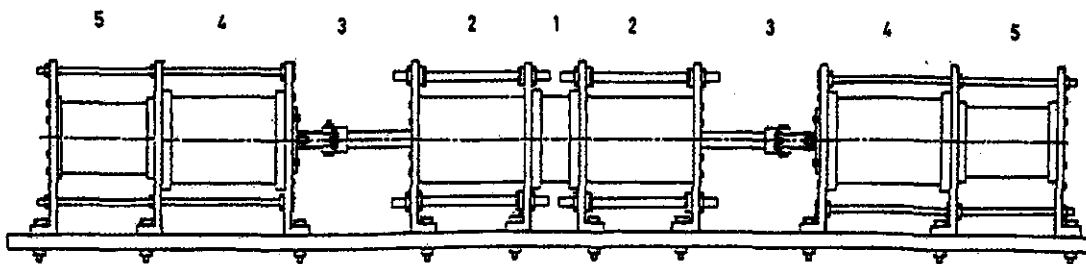


Fig. 2 Opposed rapid compression machine

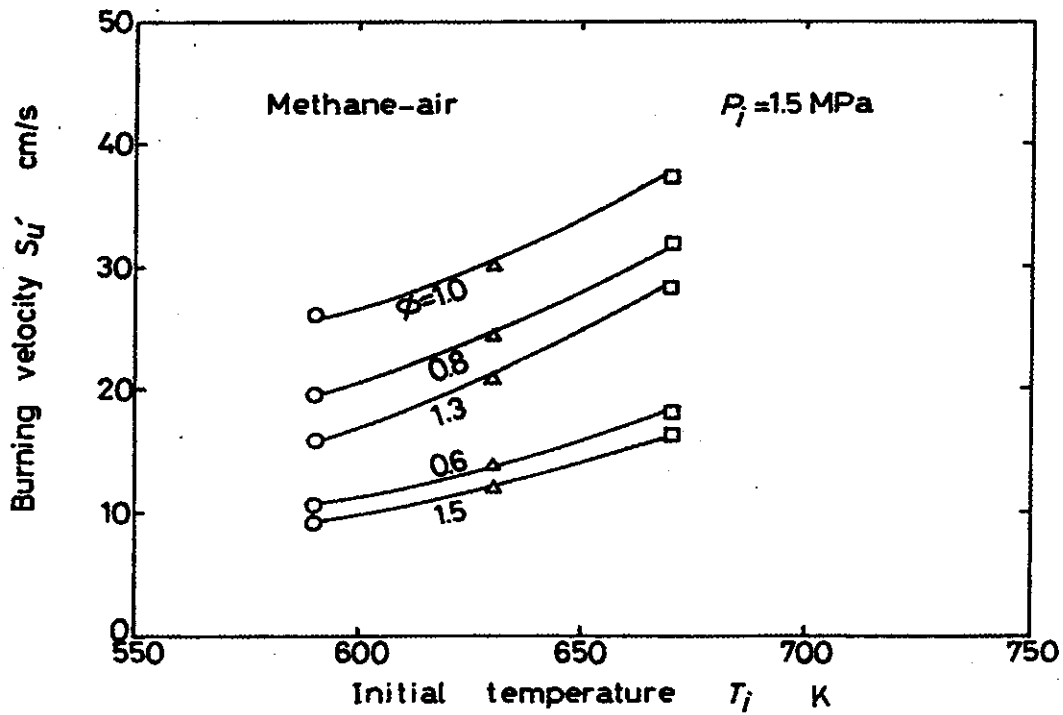


Fig. 3 Burning velocity of methane-air mixture (constant pressure: 1.5 MPa)

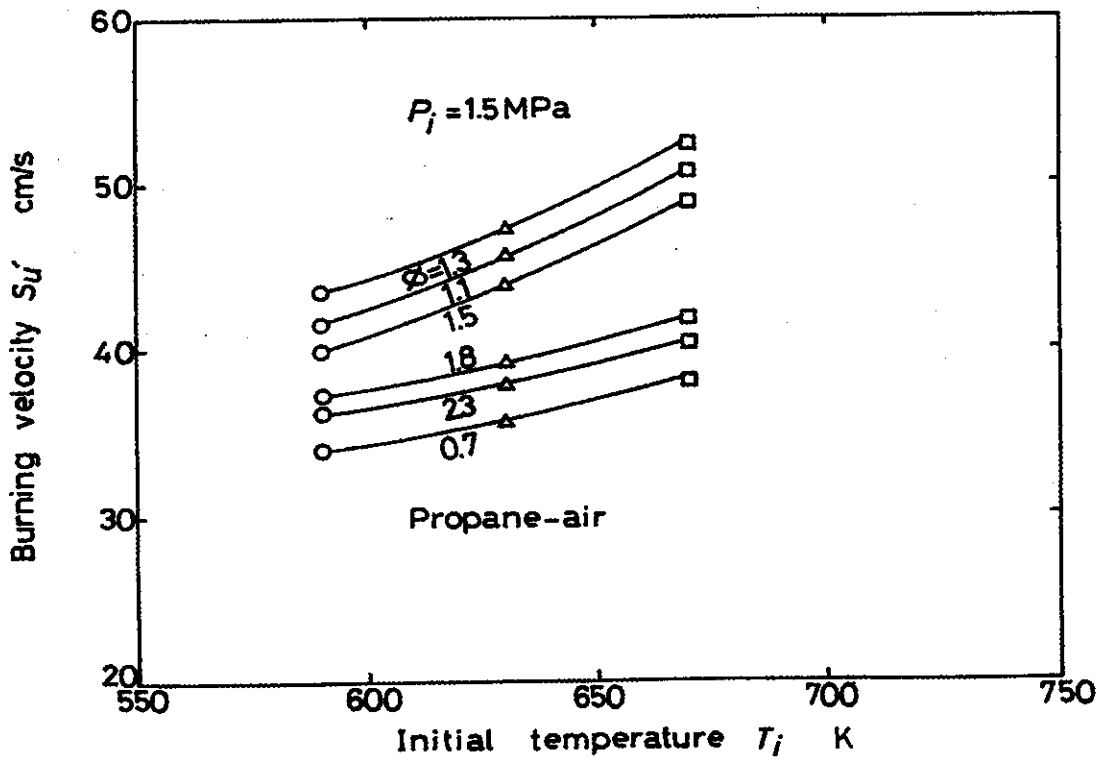


Fig. 4 Burning velocity of propane-air mixture (constant pressure: 1.5 MPa)

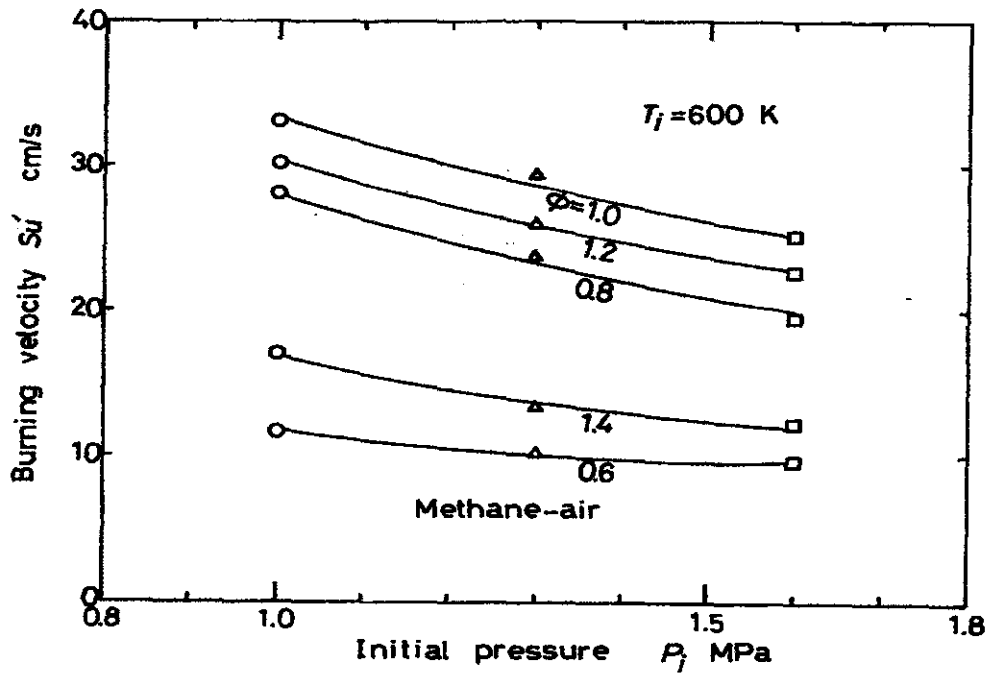


Fig. 5 Burning velocity of methane-air mixture (constant temperature: 600 K)

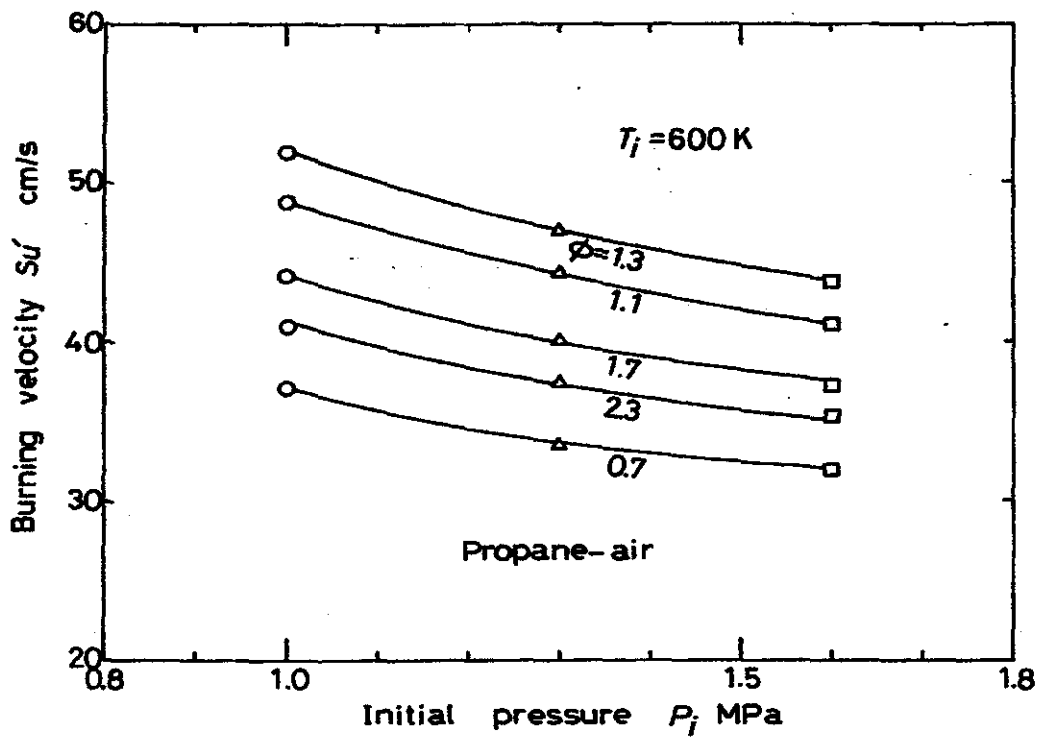


Fig. 6 Burning velocity of propane-air mixture (constant temperature: 600 K)