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LAMINAR BURNING VELOCITY OF ISOOCTANE-AIR, METHANE-AIR AND METHANOL-AIR MIXTURES AT HIGH TEMPERATURE AND PRESSURE

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Introduction

Recent studies in internal combustion engines indicate that the laminar burning velocity plays an essential role in determining several important aspects of the combustion process. Among these are:

1) The ignition delay which affects the range of equivalence ratios over which an engine can be operated and the cycle to cycle fluctuations [1],

2) The thickness of the wall quench layers which are the primary source of unreacted hydrocarbons and carbon monoxide in engines [2],

3) The minimum ignition energy to ignite the charge [3].

At the present time very little information about the laminar burning velocity of practical fuels at the pressures and temperatures encountered in internal combustion engines and burners exists [4]. To obtain such information a spherical combustion bomb which can be heated to 500 K has been constructed. In the approach taken, the pressure record provides the primary data for calculating laminar burning velocities. The combustion bomb has been instrumented with ionization probes and thin film heat transfer gauges to check the assumption of spherical symmetry and to measure the heat transfer to the wall of the combustion bomb. Flame front velocity has also been measured using a double beam Schlieren system as an additional check on the assumptions made in analyzing the data.

The purpose of the present paper is to describe the facility and to present preliminary results obtained in an unheated combustion bomb. Measurements with a heated combustion bomb will be presented later.

Experimental Apparatus

The experimental facility is shown in figure 1. It consists of a 6 inch I.D. spherical combustion bomb designed to withstand a pressure of 10,000 psi. Standard 14-mm spark plugs with extended electrodes were used to form the spark gap at the center of the bomb.

Dynamic pressure was measured with a Kistler pressure transducer and a balanced-pressure indicator was used for absolute calibration. The arrival time of the flame front at the wall was measured using ionization probes at three positions on the perimeter of the combustion bomb. These probes were used to check for spherical symmetry of the flame. Thin film heat transfer gauges were also used to measure the arrival time of flame at the wall. It is also planned to use them to measure the heat transfer to the bomb wall.

For direct measurement of flame front velocity a dual beam Schlieren system using a He-Ne laser was employed. The time between the deflection of two narrow closely-spaced parallel beams was measured and the flame front velocity was determined by the ratio of the distance between two beams to the measured time. Figure 2 shows the apparatus.

An oscilloscope triggered by the spark was used to record the outputs of the various transducers simultaneously. Ultimately it is planned to use an analog to digital converter with an on-line data processor.

Analysis of Pressure-Time Data

In the analysis of the data it is assumed that for a flame radius greater than a centimeter or two, it is a good approximation to assume that the thickness of the flame front is negligible and that the gas within the bomb consists of a burned fraction x at thermodynamic equilibrium and an unburned fraction 1-x frozen at its original composition. It is further assumed that the pressure p is uniform, the flame front is smooth and spherical, the unburned gas is isentropically compressed, heat loss is negligible and the average energy of the burned gas is equal to the energy computed for the average temperature, $\bar{T}_b$, of the burned gas. Under these conditions the equations for conservation of mass and energy can be expressed:

$$v = x\,\bar{v}_b + (1 - x)\,\bar{v}_u \tag{1}$$

$$e = x\,\bar{e}_b + (1 - x)\,\bar{e}_u \tag{2}$$

where v and e are the initial specific volume and energy of the gas in the bomb, $\bar{v}_u(p)$ and $\bar{e}_u(p)$ are the specific volume and energy of the unburned gas and $\bar{v}_b(p,T_b)$ and $\bar{e}_b(p,T_b)$ are the specific volume and energy of the burned gas.

The values of $\bar{v}_b$ and $\bar{e}_b$ were calculated for given $p, \bar{T}_b$ and equivalence ratio ϕ_o using the equilibrium gas model of Martin and Heywood [5]. Equations (1) and (2) were solved for the two unknowns $\bar{T}_b(t)$ and $x(t)$ using the Newton-Raphson iteration method. The burning velocity S_u, the flame front velocity S_f and the gas velocity S_g were then calculated from the equations $S_u = M\,\dot{x} / \rho_u A_f$, $S_f = \dot{R}$ and $S_g = S_f - S_u$, where ρ_u, A_f, and R_f denote unburned density, flame area, and flame radius respectively.

burning velocities for stoichoimetric methane-air mixture at two different initial pressures of 30 and 60 psia. The point "p" indicates the pressure at which the signal from the ionization probes occurred. The smooth curves are the fitted burning velocity measurements to be discussed later, and the dashed-curves are extrapolations of the fitted curves.

Preliminary measurement of flame front velocity were also made using a double beam Schlieren system. The two methods agreed to within $\pm$ 15%.

Summary of Results

The calculated burning velocities for methane, isooctane, and methanol at different unburned mixture densities and temperatures have been fitted to the following relation

$$S_u = S_{uo} \ (T_u/T_{uo})^{\alpha} \ (\rho_u/\rho_{uo})^{\beta} \ = \ \left(\frac{T_u}{T_{uo}}\right)^{\alpha-\beta} \qquad (3)$$

where S_{uo} is the laminar burning velocity at the reference temperature T_{uo} = 300° K and atmospheric density ρ_{uo}. α and β are fitted exponents. If the initial condition of the mixture is the same as reference condition then equation (3) becomes

$$S_u = S_{uo} \ (\rho_u/\rho_{uo})^{\varepsilon} \qquad (4)$$

where $\varepsilon = \alpha(\gamma_u - 1) + \beta$ and γ_u is the specific heat ratio of unburned gas.

Table 1 shows the parameters S_{uo}, α, β, ε, and their standard deviations as functions of equivalence ratio for the temperature and pressure ranges indicated. There are no values of α and β given for methanol-air mixtures at equivalence ratios of 1 and 1.2 because at a temperature of 300 K the vapor pressure of methanol was too low to permit measurements over a sufficient range of pressure to determine α and β independently.

The measured values of burning velocity for methane-air mixtures are in good agreement with the previous work done by Bradley and Mitcheson [6], and Babkin and Kozachenko [4]. Calculated burning velocities for isooctane-air mixtures are very close to those predicted by Heimel and Weast [7]. No previous measurements for methanol could be found.

Future work will be concentrated on measuring burning velocities of both pure and blended fuels at higher pressures and temperatures in the heated bomb.

Table 1

ϕ	$S_{uo} \pm \Delta S_{uo}$ (cm/sec)	$\alpha \pm \Delta\alpha$	$\beta \pm \Delta\beta$	$\varepsilon \pm \Delta\varepsilon$	$\alpha - \beta$
Methane $1<p<50$ atm. $300<T_u<550$ K					
0.8	29.46±0.94	1.54±0.09	-0.38±0.01	0.17±0.01	
1.0	35.86±0.77	1.29±0.06	-0.26±0.01	0.19±0.01	
1.2	31.32±1.09	1.52±0.09	-0.38±0.01	0.19±0.02	
Isooctane $1<p<25$ atm. $300<T_u<550$ K					
0.8	33.43±1.5	2.41±0.14	-0.36±0.02	0.42±0.02	2.77
1.0	35.25±1.3	1.85±0.13	-0.12±0.02	0.45±0.01	1.97
1.2	27.63±1.04	1.3 ±0.13	-0.05±0.03	0.46±0.01	1.35
Methanol $1<p<15$ atm. $300<T_u<550$ K					
0.8	31.72±2.09	2.12±0.30	-0.28±0.07	0.45±0.02	
1.0	44.33±1.48	-	-	0.50±0.01	
1.2	40.80±1.14	-	-	0.47±0.01	

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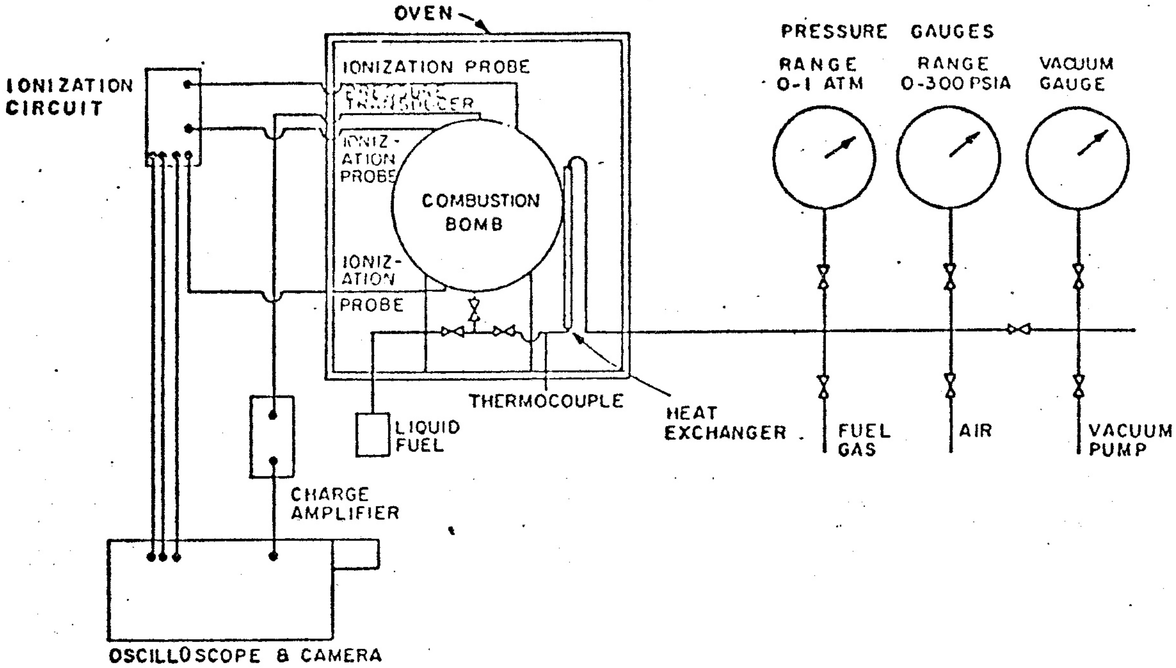
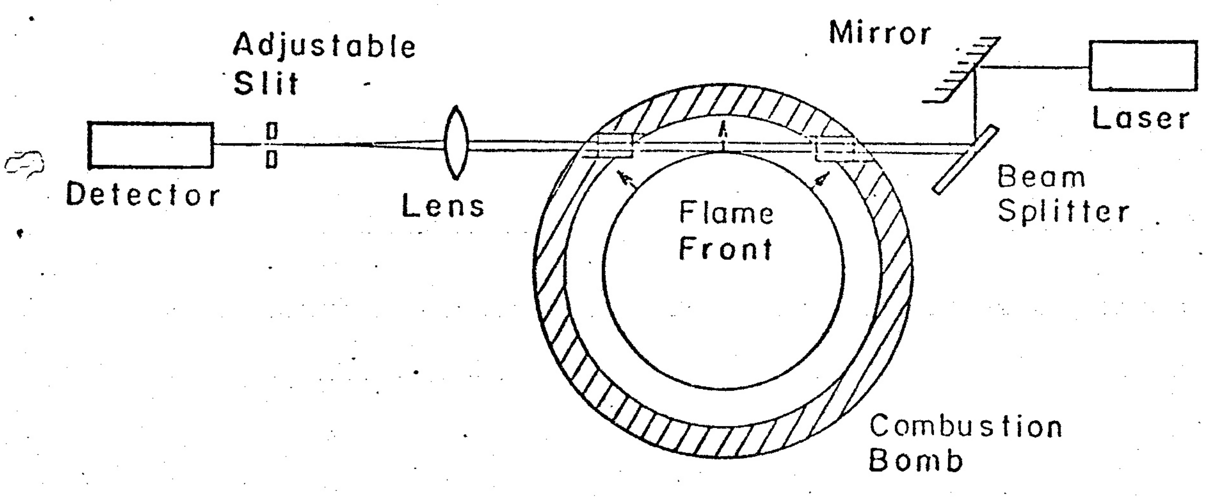
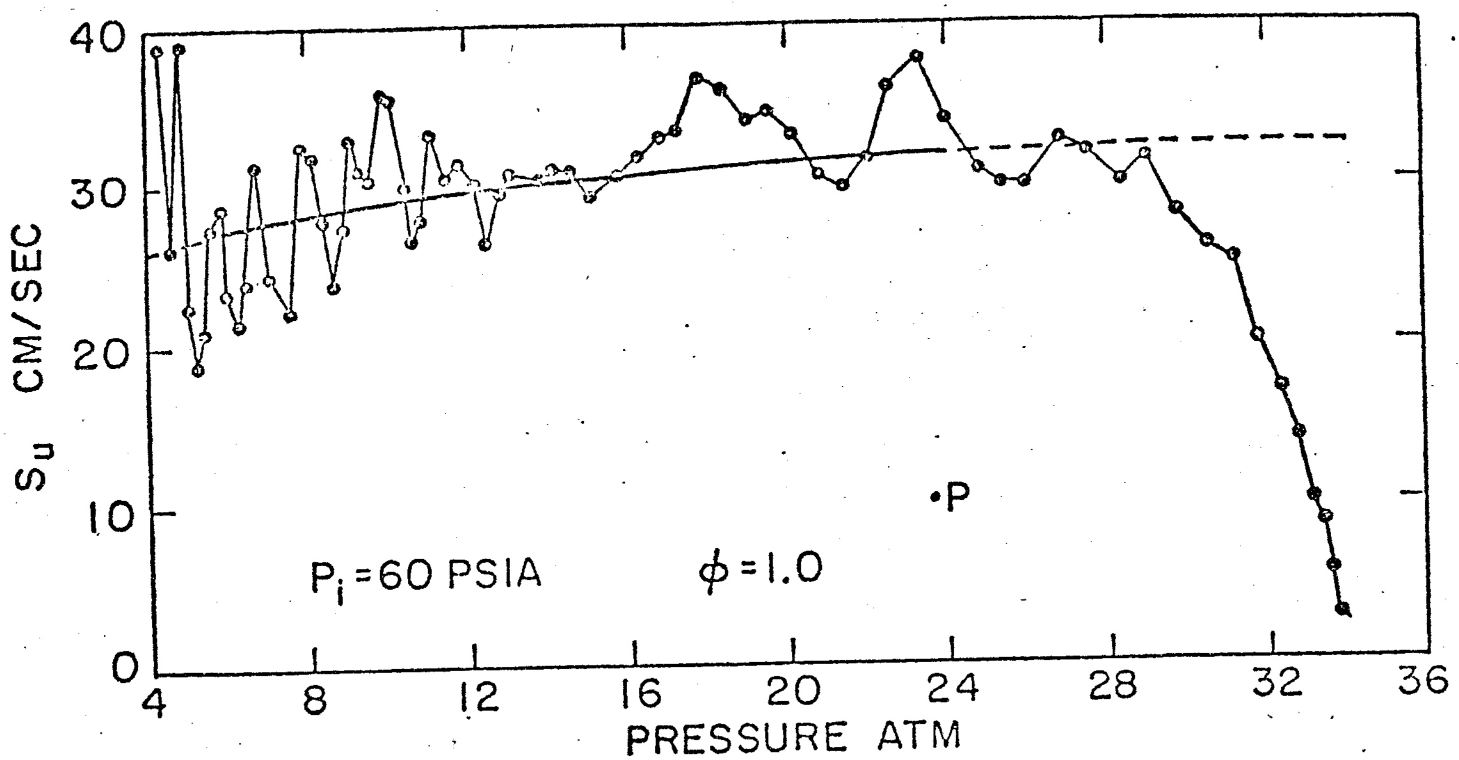


Figure 1. Schematic diagram of heated constant volume spherical bomb test facility.



Double Beam Schlieren System

Figure 2.



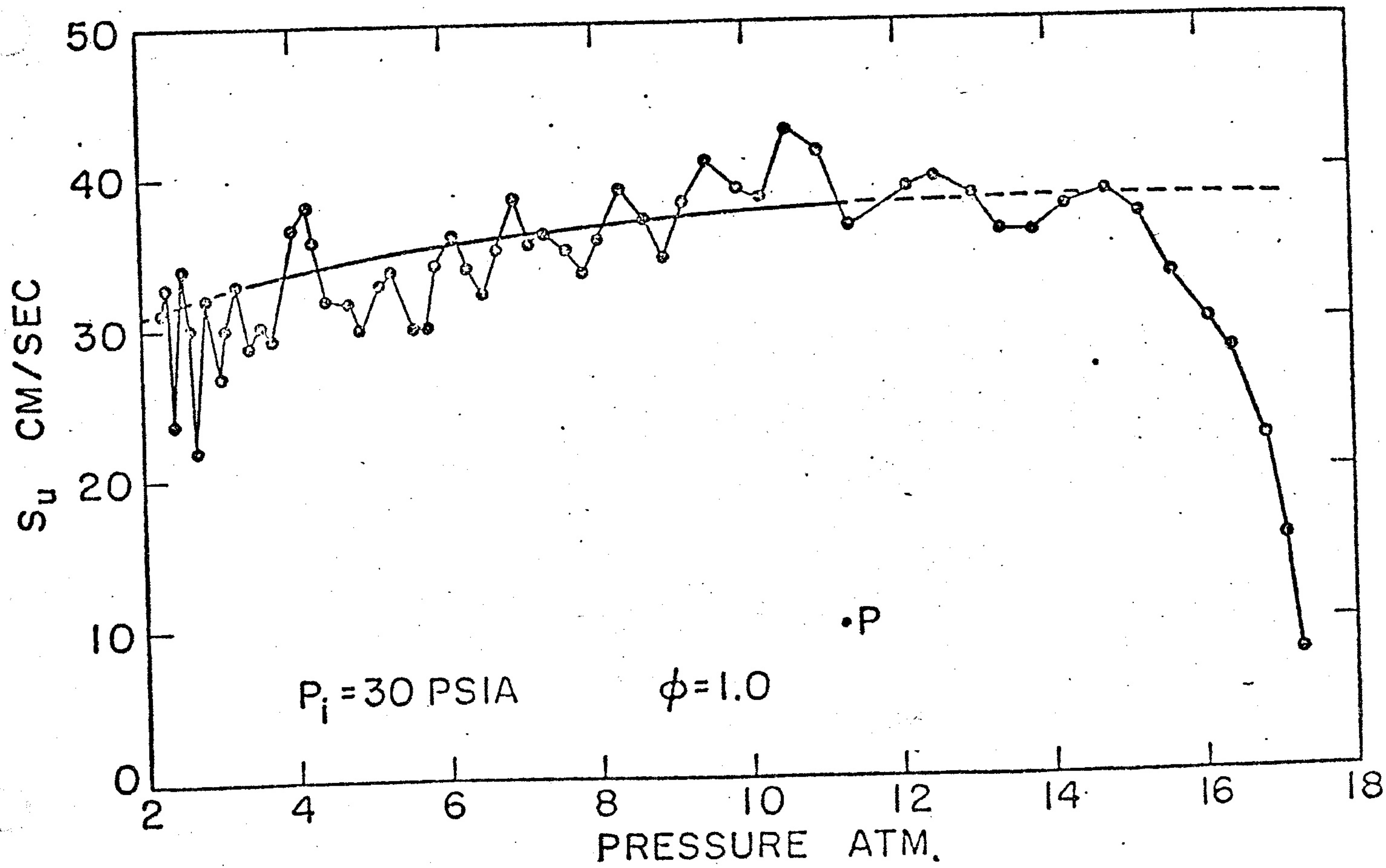


Figure 3. Burning Velocity of Stoichiometric Methane-Air Mixture with Initial Temperature of 300 K.