DIESEL SPRAY COMBUSTION IN BURNED GAS

T. TSUBOI, T. HOZUMI, K. HAYATA and K. ISHII

Department of Mechanical Engineering, Faculty of Engineering, Yokohama National University, e-mail:tsuboi@ynu.ac.jp

79-5 Tokiwadai, Hodogaya-ku, Yokohama 240-8501, Japan

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The air in the cylinder of diesel engine contains the residual gas i.e. burned gas, before the fuel is injected into it. In order to study the effect of this residual gas in the process of diesel spray combustion, the light oil was injected into the air-rich burned gas. The experiments were performed under the tailored condition behind the reflected shock wave in a steel shock tube (internal diameter: 97 mm) with a 6 m low pressure section filled with oxygen-rich propane air mixture and a 7 m high pressure section filled with nitrogen and helium[1]. The shock tube was designed for tailored condition. However the practical experiments were performed under condition at a bit overtailored side, because the relatively constant pressure P_{5r} could be obtained under this condition.

Pre-compressed fuel (light oil, JIS No.2 and α -methyl naphthalene) was injected through a throttle nozzle (pintle diameter: 1 mm) into high temperature burned gas. Radii of flame r(L, t), where soot particles radiate in the distance L from the tube end at time t, were determined by radiation which comes through the light guide (tubes). Photodiodes were set on the tube wall at radii r= 6, 18, 30, 42 mm from the central axis of the shock tube. The locations of observation windows were L= 18, 46, 78, 110, 138, 166, 198, 230, 258, 286, 318 mm from the tube end. Monochromatic emissive powers $E(\lambda, t, L)$ at wavelengths of 0.63, 0.80, 1.10, 1.45, 2.17, 3.43, 3.90, 4.2 μ m and at wavelengths of 0.63, 0.80, 1.10, 1.50, 2.30, 3.3., 3.82, 4.27 μ m were measured at time t, and at two locations L from the tube end of the tube simultaneously. The locations of L were 18, 50, 82, 138, 170, 202, 258, 290, 322 mm. The average kcl-values, which corresponded to the soot concentration and the soot temperatures T_s , were calculated from these monochromatic emissive powers using Hottel-Broughton equation. Though emissive powers $E(t, L)_{spect}$ could be calculated from measured monochromatic emissive powers and was showed with the subscript "spect", we also measured the emissive powers directly by using pyroelectric transducersans. This was expressed by the variable $E(t, L)_{\text{pyro}}$, with subscript "pyro". We had to perform some mathematical calculations in this technique, because the pyroelectric transducers had a large time constant.

The initial mixture ratios in the low pressure section, before the fuel was injected, were $\lambda_v = [\operatorname{Air}]/[\operatorname{C}_3\operatorname{H}_8] = 20$, 50, 70, 100, 200, 400, ∞ . The experiments were performed also under various oxygen/(nitrogen+oxygen) ratios (i.e. $\operatorname{O}_2/(\operatorname{N}_2+\operatorname{O}_2)=1$, 0.5, 0.3, 0.2, 0.1). The reflected shock pressure P_{5r} under experimental condition was 1.0 MPa and the temperature T_{5r} was 1020-1100 K. The injection pressure P_{inj} was 19.4 \pm 0.2 MPa, while the amount of fuel M_{fuel} was 37 \pm 3 mg and the duration of injection t_d was 5.5 \pm 0.5 ms. The emissive powers $E(t, L)_{\text{spect}}$ were calculated by integrating the Hottel-Broughton equation using experimentally determined soot temperatures T_p and kcl-values ($=\int E(\lambda, t, L)d\lambda$). The radiation powers of entire flame surface dQ/dt were obtained by integrating the emissive powers E(t, L) over entire flame surface ($=\int E(t, L)2\pi r(L, t)dL$)/cos(β), where $\tan(\beta)=dr/dL$). The total radiation energy per injection was calculated from the integration of dQ/dt with combustion time t_c . Using Abel inversion theory, the time histories of diesel spray flame form could be followed along the central axis of spray and also radial direction. The soot temperatures T_s were between 2000 and 2500 K.

Fig. 1 shows time histories of flame configuration. The fuel spray ignited near the nozzle at the moment τ =4.5 ms after the fuel was injected. The flame spread toward the down stream and the radial direction. By using this Fig.1 one can calculate the time-dependent radiation powers of entire flame surface dQ/dt.

The ignition delay (τ) was defined as the moment when the thermal radiation due to soot particles was observed in any of the observation windows. The combustion duration t_c was defined as the duration from the ignition delay τ till the moment when the thermal radiation due to soot disappeared. Fig. 2 shows the induction period τ , combution duration t_c , and heat loss due to thermal radiation Q_T/Q_{heat} , and one can know the effect of the residual gas.

The results were as follows: (1) Above $\lambda_v (= [Air]/[C_3H_8]) = 100(\phi = 0.238)$, the ignition delay τ , combustion duration t_c and the total thermal radiation from the flame Q_T per injection were almost in the same order of shock heated air, i.e, $\tau = 4-6$ ms, $t_c = 8-12$ ms, $Q_T = 80-140$ J/injection, which corresponded to 5-9 % for



FIG. 1: Flame configuration: Gas Mixture: $[C_3H_8]$: [Air]=1:100, $T_{5r}=1020$ K, $P_{5r}=1$ MPa, Fuel condition: $P_{inj}=19.4$ MPa (200 at), $t_c=5.5$ ms, $M_{fuel}=37$ mg



FIG. 2: Influence of initial premixed mixture λ or ϕ on heat loss due to thermal radiation $Q_{\rm T}/Q_{\rm heat}$, induction period τ and combustion duration $t_{\rm c}$

combustion heat of light oil Q_{heat} .

(2) Below $\lambda_v = 100(\phi = 0.238)$ the ignition delay time decreased from around 5 ms to less than 1 ms with decreasing λ_v (with increasing ϕ), while the combustion duration increased from around 10 ms to 30 ms with decreasing λ_v . Under condition of $\lambda_v = 20(\phi = 1.19)$ the flame existed during the measuring time (=25ms), because the spray did not burn out due to oxygen-lean mixture. In the case of residual gas experiment the



FIG. 3: Influence of content of $[O_2]/(N_2+O_2)$ in mixture on heat loss due to thermal radiation Q_T/Q_{heat} , induction period τ and combustion duration t_c

temperature of the residual gas increased with increasing ϕ (with decreasing λ). The effects of temperature and oxygen concentration occurred simultaneously in this experiment, because the oxygen concentration influenced the gas temperature (due to combustion). It seems that the temperature increase influenced the ignition delay strongly, while the oxygen concentration instead of temperature influenced the combustion duration strongly.

(3) The process of combustion and ignition was also observed at constant temperature under the condition of oxygen-enriched air. The results of α -methyl naphthalene are shown in Fig. 3 and the 50 % oxygen mixture showed the strongest thermal radiation (Q_T) due to soot under the same initial temperature.

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