Observation of Microexplosion in Light Oil-Water Emulsion Spray Flame

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Introduction

It is said that the microexplosion of droplets is effective in reducing the emission of particulate matters through the secondary atomization. At the same time, the water contained in the emulsified fuel has considerable effects in reducing the emission of nitrogen oxides through the lowered flame temperature. The simultaneous reduction of particulate matters and nitrogen oxides is an important technical problem for automobile and combustion engineers to solve urgently.

Several researchers reported the process variations of microexplosion phenomena and the effects of emulsion properties on them. Most of them, however, observed single droplet or droplet array whose diameters are 100 μm to several mm, therefore few reports mentioned the structure of emulsion spray flames so far.

In present study, we attempt to observe the microexplosions in spray flames with a high-speed video camera providing adequate spatial and temporal resolution.

Light Oil-Water Emulsions

Light oil-water emulsions were manufactured using a batch-type homogenizer, where seven-staged stainless-steel stirring vanes with a 50mm tip diameter (rotating speed: 1800 rpm) were installed in a 55mm i.d., 250mm long acrylic tube, which was kept at 30 deg.C by a constant-temperature water jacket. Light oil and water were stirred for 60 minutes after adding an emulsifying agent. The composition of the emulsion was 70% of water, 28% of light oil and 2% of emulsifying agent (HLB value: 6.0) by volume. Fuel #0 was light oil without water, and Fuels #1 was W/O (water-in-oil) type emulsion.

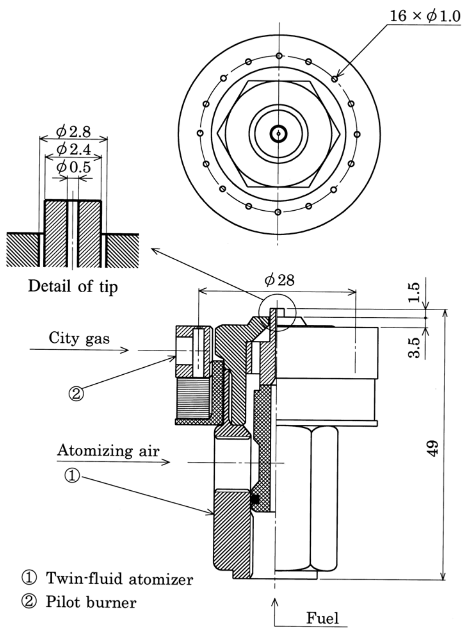


Figure 1. Burner

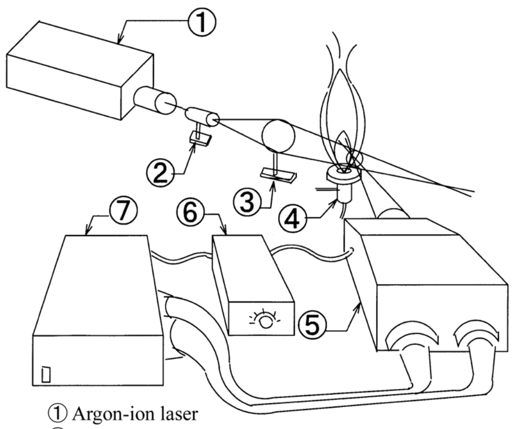
Experimental

Fuel was injected upwards from an external-mixing type air-assist atomizer placed in an open space, and a spray flame was stabilized by a natural gas pilot diffusion flame. The structure of the atomizer and the pilot burner is shown in Fig. 1. The fuel injection nozzle is of 0.5mm diam., and the atomizing air is injected through the surrounding annular slit of 2.4mm/2.8mm diameters. For pilot burner, 16 nozzles of 1.0mm diam. are arranged on a pitch circle of 28mm diam. located at 5mm below the fuel nozzle. Experiments were conducted with the flow rates of emulsion, atomizing air and natural gas kept at 6.00 ml/min., 6.52 l/min and 2.09 l/min, respectively.

The microexplosion of droplets was observed and recorded using the optical system shown in Fig. 2. This is a simple Mie scatter imaging system. The light source is an Ar^+ laser (wavelength 488nm, emitting power 1.4W). The beam from the laser is expanded by a beam expander, and condensed again by a flat-convex lens. The beam diameter on the burner axis is about 20 mm. Quasi-forward Mie scatter image of the spray droplets of the burner is recorded by a high-speed video camera (PHOTRON FASTCAM I, frame rate: 40,500 frames/sec, memory size: 16384 frames) arranged 11 deg. from the laser beam.

Temporal mean temperature profiles in the flames were observed using a Pt/Pt-13%Rh bare thermocouple of 0.2mm wire diam. The data were not corrected for radiation and conduction losses.

The origin of measurement area was set at the center of the nozzle tip. z denotes the vertical height from the nozzle tip, and r represents the radial distance from the center of the nozzle tip.



① Argon-ion laser
② Beam expander
③ Plano-convex lens
④ Spray burner
⑤ High-speed CCD camera
⑥ Control unit for image intensifier
⑦ Control unit for high-speed CCD camera

Figure 2. Measuring system

Results and Discussion

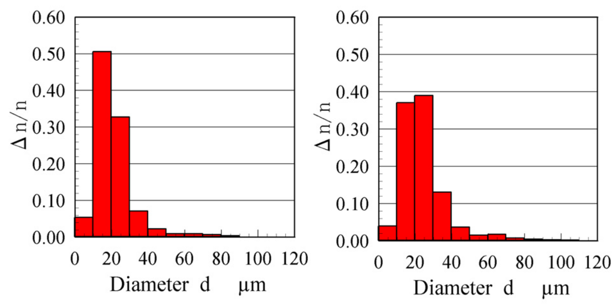
The size distribution of droplets was measured by the magnesium-oxide layer method, where the suspended droplets were captured on a glass slide coated with a soft magnesium-oxide layer and their sizes were determined by measuring the resultant traces using a microscope with back-light illumination. Each slide was set in a sampling port of 5mm diam. with a shutter, and placed downwards at 300mm above the injection nozzle on its axis. As a result, the size distribution patterns as shown in Fig. 3 were obtained in cold flow conditions. Although the droplet size of the emulsified fuel is somewhat larger than that of the light oil, it is considered that it could not affect so much on the combustion behavior. The microscopic pictures of fuel #1 before and after being injected by the air-assist atomizer are shown in Fig. 4. The fuel "after injection" was captured and gathered into a pool on a slide glass. The comparison between "before injection" and "after injection" samples was made to check the rate of drainage due to the intense shear in the injection nozzle.

Rather uniform water droplets of 1-3μm diam. are dispersed in both before and after injection samples for fuel #1. The dynamic viscosity of these fuels measured at 30 deg.C by Redwood standard was listed in Table 1.

Typical examples of the process of droplet microexplosion recorded by the high-speed video camera are shown in Fig. 5. The imaged area of each frame is 6.0mm square, and the frame rate is 40,500 frames/sec. The size of

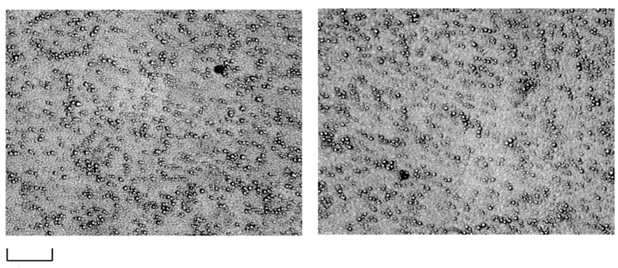
Table 1. Properties of fuels

	Fuel #0	Fuel #1
Light oil content %	100	70
Water content %	0	28
Emulsifying agent %	0	2.0
HLB value		6.0
Stirring period min	0	60
Specific gravity	0.837	0.888
Dynamic viscosity at 30 deg.C mm^2/sec	4.87	11.34



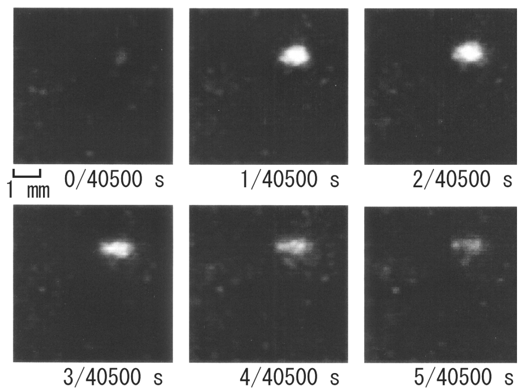
(a) Fuel #0 (b) Fuel #1

Figure 3. Size distributions of spray droplets (at 300mm from the tip on the axis).

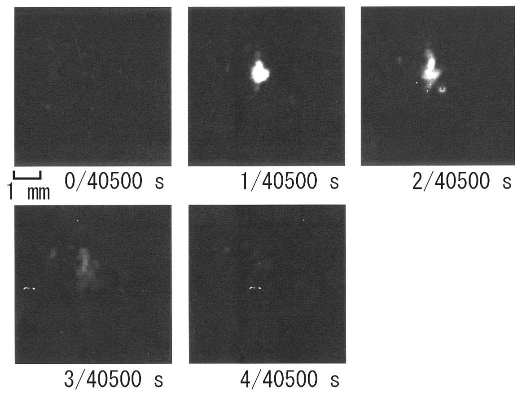


(a) Before injection (b) After injection

Figure 4. Microscopic photographs of emulsified fuels.



(a) z = 50 mm, r = 0 mm



(b) z = 95 mm, r = 10 mm

Figure 5. Sequential images of the microexplosion.

image, however, does not correspond to the actual droplet size due to the rather coarse pixels of the high-speed video camera (64 x 64 pixels, so that the pixel density is 10.7 pixels/mm of the imaged field of view).

As indicated in Fig. 5 (a), microexplosion was observed in the sequential images. Although the spatial and temporal scale of this microexplosion could be estimated about 1mm and 1/10000s respectively, this example is one of the largest time scale microexplosion observed. Most microexplosions were captured as one or two sequential images whose duration time were not more than 1/20000s and their scales were less than 1mm as shown in Fig. 5 (b).

Therefore, the microexplosions recorded were counted regardless of type and intensity, and summed up. The result is shown in Fig. 6 with flame temperature profile. The temperature is higher for emulsified fuels from near-nozzle region to the height around z = 60mm, thereafter, the tendency being reversed. The temperature is lower for emulsified fuel than for pure light oil, probably due to the effect of the heat of water vaporization and vapor dilution. This fact implies that the effect of microexplosion mainly appears in the near-nozzle region below z = 60 mm. Since only the microexplosion of small droplets was observed in near-nozzle region below z = 60 mm, it could be possible that the main factor taking effect on the reaction rate of the emulsion spray flame is not microexplosions of large droplets, as an established theory says, but those of small droplets.

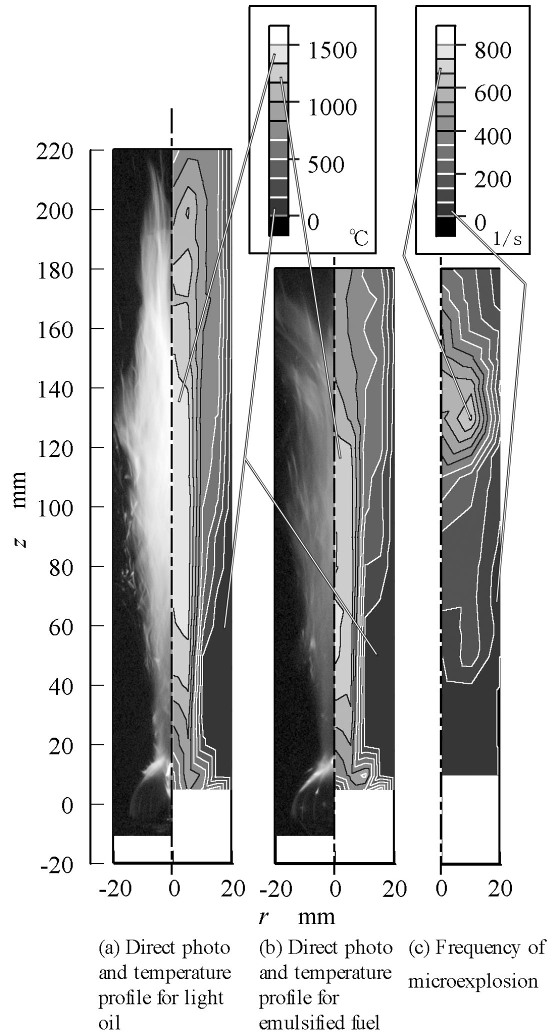


Figure 6. Direct photographs, temperature profiles and frequency of microexplosions.

In addition, we took some sequential images to clarify the temporal and spatial scale of small droplet microexplosions with an ultra high speed CCD camera whose maximum frame rate was 1 million frames/sec. However, the number of frames in each shot was only 103; therefore we could not get enough number of microexplosion shots with this camera for statistical examination. Fig. 7 shows one of the sequential images of a microexplosion observed at z = 90 mm on the axis of a flame. Imaging region is 2.4 x 2.0

mm, frame size is 156 x 130 pixels, the pixel density is 65 pixels/mm and the frame rate is 500,000 frames/sec. It is confirmed that a small droplet whose diameter is less than 25μm explodes and disappear in 5 frames. This result means that the temporal scale of the microexplosion is around 10μs and the spatial scale of it is 200-300μm.

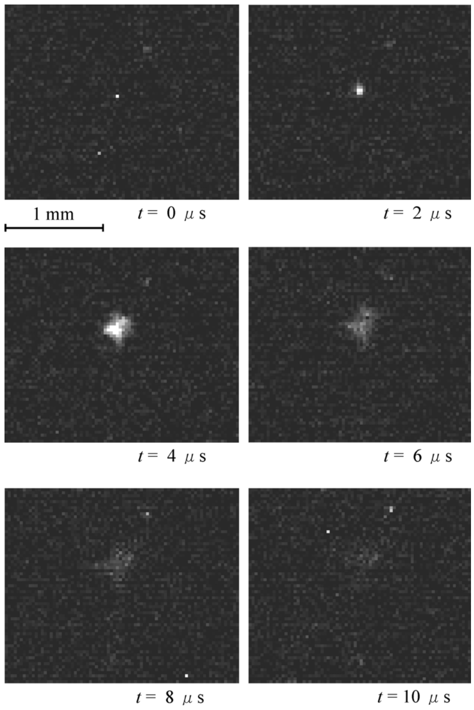


Figure 7. Sequential images of microexplosion captured with ultra high speed camera.

Conclusions

The microexplosion of emulsified fuel droplets was successfully observed, and the distribution pattern of local frequency of explosion occurrence was estimated in open spray flames of water-in-oil type light oil-water emulsion formed using an air-assist atomizer with a ring pilot burner. The process of microexplosion of each droplet was recorded by a high-speed video camera. The conclusions obtained are as follows.

(1) The reaction rate of light oil-water emulsified fuel flame is accelerated in its near-nozzle portion, and it is thought that the occurrence of microexplosion is main factor of that.

(2) It is highly probable that the microexplosions mainly taking effect on the reaction rate are not large droplet origin, as established theory says, but small droplet origin.

(3) The temporal and spatial scale of the microexplosion of small droplet is around 10μs and 200-300μm respectively.

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