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■TECHNICAL REPORT■

Experimental Observation on Single Fuel Droplets Burning in the Fields of a Specific Wave Number at Far Infrared Ray

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Abstract: The experimental study of hydrocarbon fuel droplets burning in the electro-magnetic environments has been carried out to examine the effect of electro-magnetic wave on the combustion of fuel droplets. The characteristics of electro-magnetic wave developed for the study are around 1200 cm^{-1} in wave number, which corresponds to the absorption band of methane molecule. The combustion process of hydrocarbon fuels ultimately includes the reaction of methane and methyl with oxygen as a result of thermal decomposition. So it is very important to examine whether the combustion of hydrocarbon fuel droplets is promoted by electro-magnetic wave or not. The fuels used for the study are n-heptane, n-hexadecane, methanol, benzene, kerosene and heavy oil A. The initial droplet diameter is approximately 1.70 to 1.85mm. The acquisitions obtained here show that such electro-magnetic wave may be very effective to accelerate the combustion rate of hydrocarbon fuel droplets by utilization of resonance frequency to methane molecule.

Key Words: Electro-Magnetic Wave, Resonance Frequency, Hydrocarbon Fuel Droplets, High Efficiency Combustion

1. Introduction

At present, the policies of energy saving on exhaustion of fossil fuels, realization of low emission of CO_2 on global warning and the reduction of air pollution substances such as NOx and SOx are strongly required. So, one has to develop high efficiency combustion techniques for realizing the high energy saving and low CO_2 emission for all kinds of fuels. On this way, the challenges for countries around the world are to develop the technologies like hybrid vehicles for energy saving and hydrogen fuel cells for reducing air pollutant substances.

Under these circumstances, we have developed the new combustion concept by utilization of electro-magnetic wave. The gas phase reaction of liquid fuel combustion includes a number of elementary reactions. So, we have focused on the effect of electro-magnetic wave on intermediate products, especially methane and its reaction precursor generated by thermal decomposition in combustion process of hydrocarbon fuels. Because methane and its reaction precursor are able to absorb much electro-magnetic energy around wave number (1/wave length) of 1200 cm^{-1} shown in Fig.1 [1]. Such waves belong to the range of far infrared ray.

In this way, the authors have developed the electro-magnetic radiant materials (we call it radiant materials for short) with more than 0.9 in spectral emissivity, which continuously discharges the electro-magnetic wave at the wave numbers in the range of 800 to 2000 cm^{-1} (Fig.2).

The effect of such electro-magnetic wave on combustion of hydrocarbon fuel droplets is examined using the radiant materials. The surface temperature of radiant materials is kept the constant at approximately 298K.

The electro-magnetic radiant materials are composed of several

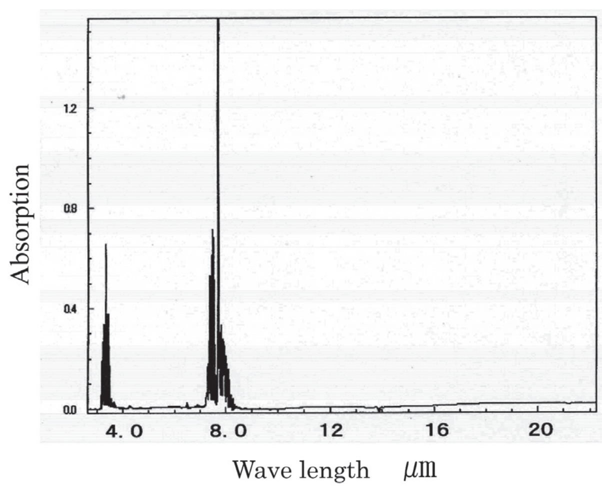

Fig.1　Absorption spectrum of methane molecule (data from NIST).

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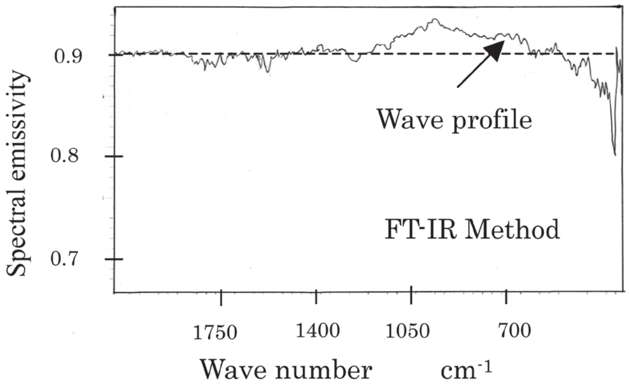

Fig.2 Spectral emissivity of electro-magnetic radiant materials developed by the study.

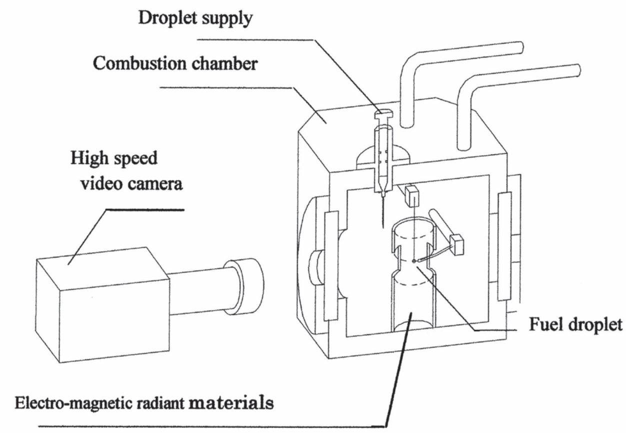

Fig.3 Test assembly.

kinds of ores such as electric stones and transition metals and its radiatioactivity is approximately 0.04μSv/h.

In connection with the experiments of fuel droplet combustion in electro-magnetic fields, the authors had already performed to elucidate the effect of such electro-magnetic wave on the fundamental characteristics of methane co-axial diffusion flames and the fuel spray combustion of kerosene and heavy oil A. The effectiveness of the electro-magnetic wave to combustion behavior of hydrocarbon fuels has been verified in detail [2-4].

2. Combustion Promotion Principle by means of Electro-Magnetic Wave

It is well known that low-hydrocarbon fuels such as methane are able to absorb the electro-magnetic energy around 1200 cm^{-1} in wave number. The discharge of the electro-magnetic ray to methane and its precursor may lead to accelerate the vibration modes caused by resonance frequency, and then to enhance the collision energy and the collision frequency between molecules of fuel and oxygen in air. Consequently, the flame temperature increases due to the acceleration of combustion reaction rate [5].

The radiation intensities discharged from the luminous flames such as CH, C_2, OH and others are approximately in the range of 300 nm to 600 nm in wave length [6] and also radiation intensities emitted from the radiant materials used for the study are around 10×10^3 nm in wave length. It may be recognized that the radiation bands among luminous flames and radiant materials are at difference of about 15 to 30 times. This means that there is probably no interference among these electro-magnetic waves. On the contrary, the combustion products of CO_2 and H_2O can almost absorb the electro-magnetic wave (around 8～10μm in wave length) emitted from radiant materials so that the discharge of the wave to the flame regime produced such combustion products is not effective to promote the combustion rate. So, the effect of discharge of such wave on combustion rate is only significant at the location of flame base occupied by blue flames.

3. Experimental Apparatus and Procedure

Figure 3 shows the test assembly, which consists of a combustion chamber, an ignition equipment, an electro-magnetic radiant materials and a high-speed video camera [7]. The combustion chamber is a rectangular shape of 200×200×180mm. The quartz fiber for suspending the fuel droplet is located in the central position of the combustion chamber and the ignition is instantaneously done by electrically heated fine nichrome wire. The hydrocarbon fuel droplet is surrounded by the radiant materials. The configuration of radiant materials surrounding the fuel droplet is cylindrical shape of 80 mm inner diameter and 120 mm length [8,9].

The behavior of fuel droplets burning in electro-magnetic fields are observed by taking the direct photographs with high speed video camera and the combustion lifetimes of fuel droplets are measured to evaluate the effect of electro-magnetic wave on the fuel droplet combustion. The combustion lifetime is defined as the time from ignition to the disappearance of luminous flame around the fuel droplets. The mean flame temperature during the combustion process of fuel droplets is also determined by image processing of two color thermal analysis based on color photographs obtained with high speed video camera of 200 frames per second.

4. Experimental Results and Discussions

Figure 4 depicts one-shot photographs on combustion behaviour of n-hexadecane droplets under various ambient pressures in the presence and absence of radiant materials. From these photographs it may be suggested that the flame shape of n-hexadecane droplets with radiant materials is always larger than that without radiant materials for all of the ambient pressures

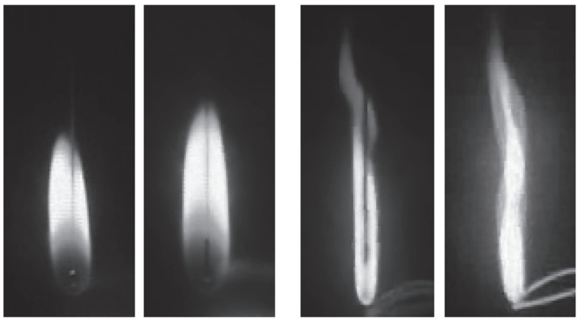

Fig.4 One shot photographs on combustion behavior of n-hexadecane droplets under various pressures in the presence and absence of radiant materials.

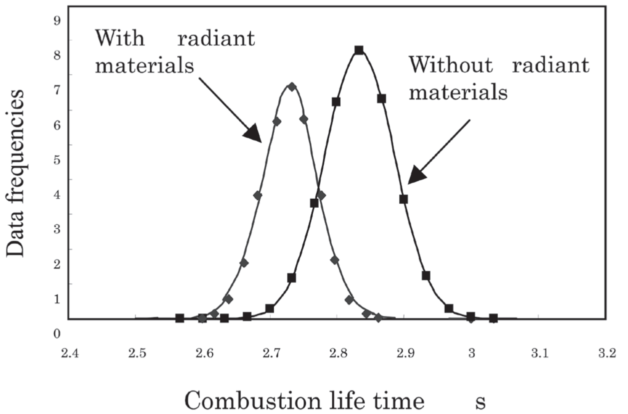

Fig.5 Typical (Normal) distribution of combustion lifetime of kerosene droplets at 25°C surface temperature of radiant materials.

investigated.

Figure 5 shows the typical (normal) distribution of combustion lifetime of kerosene droplets. Table 1 shows the value of combustion lifetime and its reduction rate for six kinds of fuel droplets. The reduction rate ε of combustion lifetime is defined as follows:

$$\varepsilon = [(T_1 - T_2) / T_1] \times 100\ \% \qquad (1)$$

where T_1 and T_2 are the combustion lifetime without and with the radiant materials, respectively. From Table 1 it is found that the reduction rates of combustion lifetime of n-heptane, n-hexadecane, methanol, benzene, kerosene and heavy oil A are 4.15%, 4.80%, 1.92% 0.71%, 3.53% and 1.28%, respectively. These discrepancies in combustion lifetime of fuel droplets mainly result from the difference in amount of methane and its reaction precursor generated by thermal decomposition [10].

In Figs. 6 and 7 are shown the typical examples of the variation of flame temperature of fuel droplets burning in electro-magnetic field against the elapsed combustion time when the fuel

Table 1 Combustion lifetime and reduction rate of n-heptane, n-hexadecane, methanol, benzene, kerosene and heavy oil A.

Combustion lifetime without radiant materials: T_1
Combustion lifetime with radiant materials: T_2
Reduction rate of combustion lifetime: ε

Fuels	T_1	T_2	ε
n-Heptane (C_3H_8)	2.65	2.54	4.15
n-Hexadecane (C_6H_{14})	2.50	2.38	4.80
Methanol CH_3OH	3.12	3.06	1.92
Benzene (C_6H_6)	2.80	2.78	0.71
Kerosene	2.83	2.73	3.53
Heavy oil A	3.12	3.08	1.28

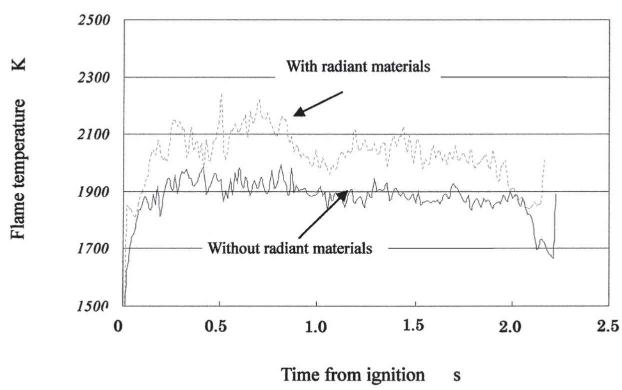

Fig.6 Flame temperature of n-heptane droplets burning at 0.1MPa and 298K with and without radiant materials.

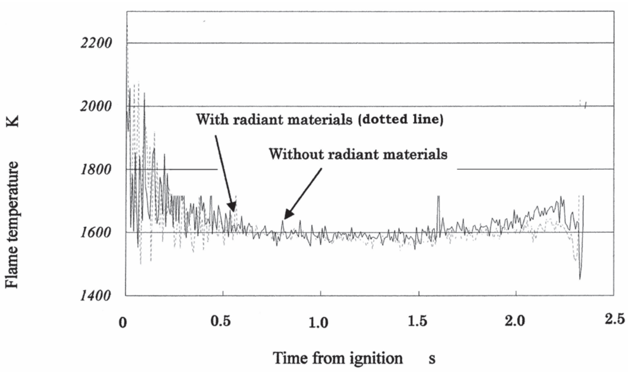

Fig.7 Flame temperature of benzene droplets burning at 0.1MPa and 298K.

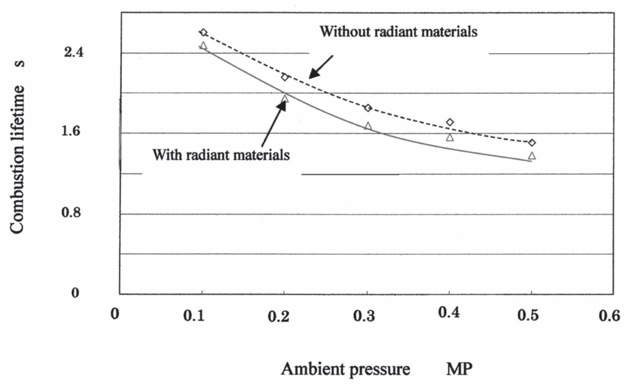

Fig.8 Combustion lifetimes of n-heptane droplets burning under elevated pressure at 298K.

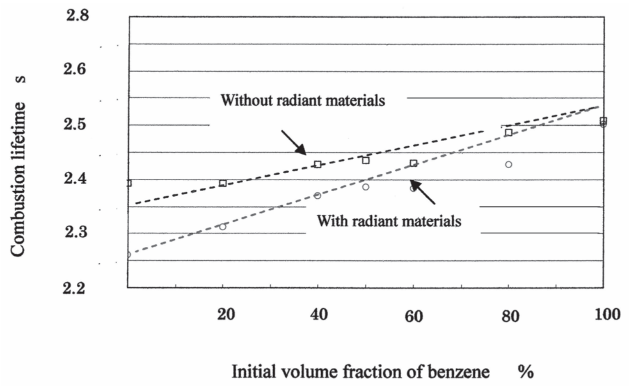

Fig.10 Combustion lifetime for blend fuel droplets of n-heptane/benzene at 0.1MPa and 298K.

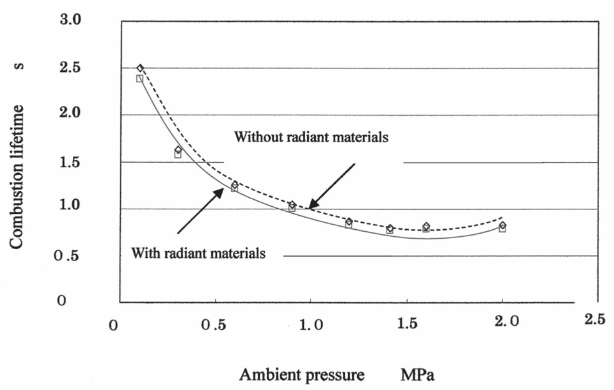

Fig.9 Combustion lifetimes of n-hexadecane droplets burning under elevated pressure and 298K.

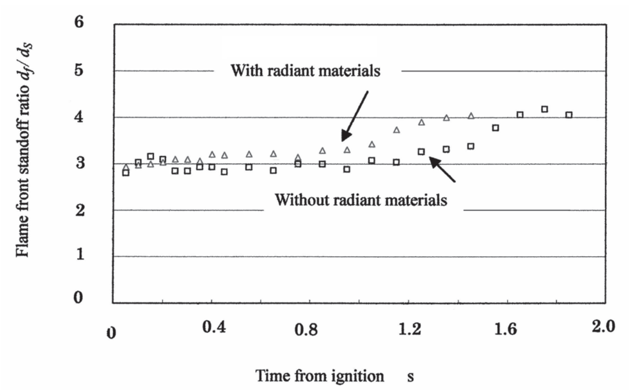

Fig.11 Flame front standoff ratio on n-heptane droplet combustion.

droplets are surrounded by the radiant materials as compared to when it is not. The flame temperature is analyzed by the image processing of two color pyrometer based on the experimental data obtained with high speed camera. From these figures it can be seen that, for n-heptane droplets, the electro-magnetic wave employed for the study leads to increase the flame temperature during combustion process. The rise of mean flame temperature caused by the electro-magnetic wave seems to be 100K to 150K. However, for benzene droplets there is no temperature rise even with the radiant materials, since benzene is not expected to produce significant gas phase methane [10].

Figures 8 and 9, respectively, show the combustion lifetime of n-heptane and n-hexadecane under elevated pressures in the range of 0.1MPa to 2.0MPa, with and without the radiant materials. From these figures, it can be recognized that the effect of the electro-magnetic wave on the combustion of fuel droplets may be unchanged even in environments of elevated pressure. Thus, it may be predicted that the effect of electro-magnetic wave on fuel droplet combustion does not be affected by physical properties under elevated pressures like latent heat of evaporation, thermal conductivity and density of fuel vapor.

Figure 10 shows the combustion lifetime for different blend fuel droplets between n-heptane and benzene. From this figure we can recognize that there is no marked effect to promote the combustion rate even for blend fuel droplets. The combustion rate of blend fuel droplets may be only proportional to the amount of methane molecules and its precursors generated by thermal decomposition.

In Fig. 11 is shown the flame front standoff ratio of n-heptane droplets burning in the presence of radiant materials as compared to that in its absence. The flame front standoff ratio is defined as d_f/d_s, where d_f and d_s are flame diameter and droplet diameter (diameters are measured horizontally at the center of fuel droplets), respectively. From this figure, it can be seen that, in the presence of the radiant materials, the flame front standoff ratio continuously more increases with increasing combustion time as compared with that of the absence of radiant materials. This may be due to the flame temperature rise by the effect of the radiant materials. However, it is considered that such behavior as seen also from Fig.4 may be governed by the residence time of chemical spices in flame zone and by the change of diffusion effect in electro-magnetic fields. So, further experiments will be

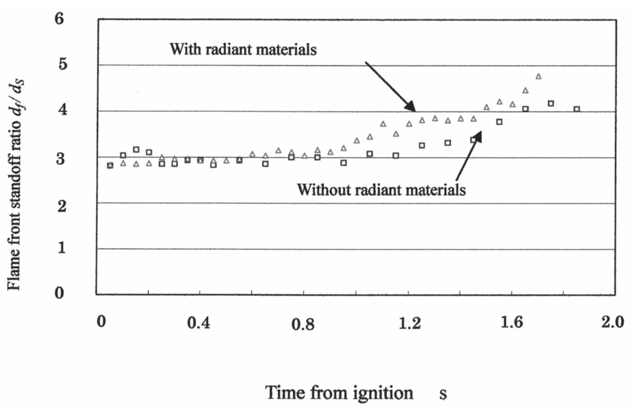

Fig.12. Flame front standoff ratio for blend fuel droplets (n-heptane/benzene) at 0.1MPa and 298K.

carried out in the future to verify these phenomena.

Figure 12 also shows the flame front standoff ratio of blend fuel droplet combustion between n-heptane and benzene in the presence of radiant materials as compared to that in its absence. The initial volume fraction of benzene is 0.5. From this figure, it can be understood that the flame front standoff ratio also continuously increases with increasing combustion time with radiant materials even for blend fuel droplets.

From these experimental results obtained for the study, it would be summarized that the substances like methane and its precursor produced by thermal decomposition of hydrocarbon fuel droplets during the combustion process may be able to absorb electro-magnetic wave around 1200 cm^{-1} in wave number so that the accelerated movements such as the vibration modes of these substances lead to be encouraged by electro-magnetic wave. The rise of flame temperature by resonance frequency to methane and its precursor may cause enhanced evaporation of fuel droplets and leads to reduce the combustion lifetime.

5. Conclusion

Experiments have been conducted to elucidate the effect of electro-magnetic wave emitted from the radiant materials on the promotion of fuel droplet combustion. The main results obtained for the study are as follows:

(1) The reduction rate of the combustion lifetime of fuel droplets burning in certain electro-magnetic field may be about 5.51% for n-heptane droplets, 4.80% for n-hexadecane droplets, 2.0% for methanol droplets and 0.26% for benzene droplets at room temperature and atmospheric pressure. The increase of mean flame temperature of n-heptane fuel droplets burning in electro-magnetic field is in the range of 100K to 150K.

(2) The effect of electro-magnetic energy on the combustion of fuel droplets remains unchanged at elevated pressure even for different compositions of n-heptane / benzene.

(3) The electro-magnetic wave around 1200 cm^{-1} in wave number and spectral emissivity more than 0.9 has an ability to accelerate the combustion rate of fuel droplets as a result of resonance frequency. This means that such electro-magnetic wave may be very effective to accelerate the burning rate of spray combustion.

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