Effect of Electro-Magnetic Energy on Flame Propagation Behavior of Methane-Air Mixtures in a Closed Bomb

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Abstract: Experiments have been performed to examine the effect of electro-magnetic wave on flame behavior propagating in a closed combustion bomb under microgravity. The electro-magnetic wave employed for the study is more than 0.9 in spectral emissivity at the regime of 800 to 2000cm^{-1} of wave number. The results show that the discharge energy from electro-magnetic wave as the resonance frequency makes it possible to accelerate their combustion rate and, for methane-air mixtures the combustion promotion rate by means of the discharge of electro-magnetic energy to methane considerably increases with decreasing equivalence ratio and the behavior of irregular flame propagation in the electro-magnetic fields may be observed during the combustion process.

1 Introduction

Recently, we are faced with very difficult problems such as exhaustion of fossil fuels, global warming by CO_2 emission, air pollution by NOx, SOx, PM and so on. We have to protect our environments from such destruction and also we have to establish the combustion technique to realize the high energy saving, and low CO_2 emission to many kinds of combustors.

From the viewpoint of this circumstance, we have developed successful technique to enhance the combustion rate of hydrocarbon fuel by utilization of electro-magnetic energy at a certain wave number in the range of far infrared rays.

The principal of the electro-magnetic combustion technique is as follows that the hydrocarbon fuel includes the combustion process involving methane structure or methyl radical as a result of thermal decomposition. Methane molecule has an ability to absorb the electro-magnetic energy of 1200 cm^{-1} in wave number. The discharge of these rays to methane as the resonance frequency makes it possible to more accelerate the vibration mode of methane, and therefore they lead to enhance the collision frequency and collision energy between fuel molecular and oxygen. Consequently, the flame temperature gives rise to increase due to the promotion of combustion reaction rate.[1]

The study has been carried out to examine the effect of electro-magnetic wave on the behavior of flame propagation in a closed combustion bomb under microgravity. The microgravity environment is very suitable condition to analyze the combustion behavior because the realization of spherical flame propagation even for very lean mixtures can be perfectly established.

2 Experimental methodology

In Fig.1 is shown the test assembly for observing the flame propagation behavior in a closed combustion bomb under microgravity. The test assembly is a rectangular shape of 600×700×350ｍｍ and weight is approximately 40 kg and it contains a cylindrical closed combustion bomb made of duralumin, a high speed digital video camera for the observation of burning process, an ignition equipment (CDI system) and an optical system involving mirrors and relay devices.

The size of the closed combustion bomb is 124 mm in inner diameter and 246mm in length and the electro-magnetic energy sheet is fixed in inner walls of closed combustion bomb. The optical path for observing the burning behavior in a closed combustion bomb is arranged as possible to take a long distance in the space of test

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assembly by employing the two plane mirrors (see Fig.1). The needle electrodes for ignition are accurately centered in the closed combustion bomb and its diameter is 1.0 mm and gap width is 3.0 mm. The observation of flame radius is carried out at 30mm from the central position of the closed combustion bomb because it can be almost negligible for pressure rise by combustion.

In this study, the authors have developed the substances (we call it "Energy Sheet") which continually discharge the electro-magnetic wave of approximately 0.9 in spectral emissivity at wave number of the range of 800 to 2000cm^{-1}. The authors already described in previous papers how the electro-magnetic wave at range of infrared ray was influenced the combustion behavior.[2] However, the authors can not describe the compositions of above-mentioned substances from the patient problem.

Figure 2 shows the drop tower facility to achieve the microgravity environments. The height of falling tower is 2.7 m and the observation time is approximately 0.6 second. The gravity level inside the test assembly during free fall is approximately 10^{-5}g by means of air drag shield.[3]

Experiments have been conducted at 0.10 MPa and 293K of initial pressure and temperature, respectively. The equivalence ratio studied is the range from stoichometric proportion to near the lower flammability limit. The mixture strength is controlled and produced by the law of partial pressure of fuel gas and air. The mixing gas of nitrogen and oxygen is employed as substitution of air. The fuel investigated for the study is Town Gas (13A) which is mainly composed from methane. In order to verify the effect of electro-magnetic wave emitted from energy sheet on combustion improvement, flame shape and its travel distance against elapsed burning time are examined by taking the direct color photographs with high speed digital video camera. The camera speed adopted for the study is 400 frames per second.

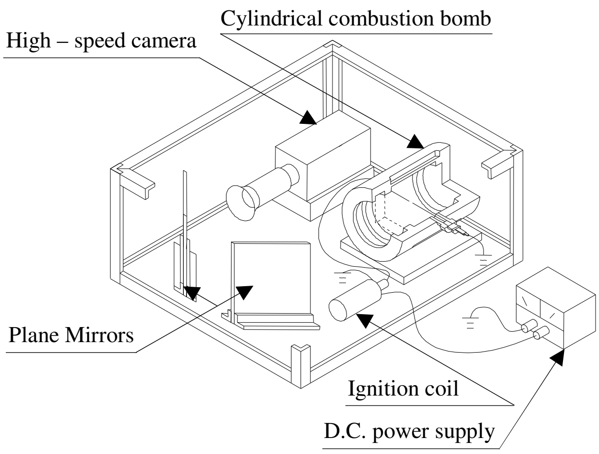

Fig.1. Test assembly

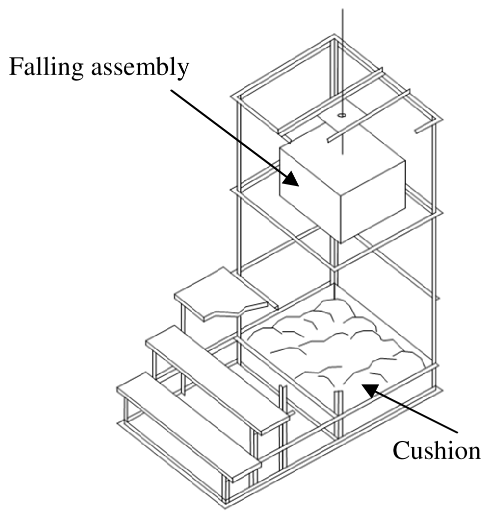

Fig.2. Falling tower

3. Experimental result and discussion

Figures 3 and 4 show the direct photographs of flame propagation on methane-air mixtures at 0.6 of equivalence ratio under normal and microgravity, respectively. Where the white circle of outside depicts the inner walls of the combustion bomb and the inside dotted line also depicts the flame configuration. As can be seen from these photographs, in the vicinity of lower flammability limit the flame is markedly affected by buoyant force induced from gravity so that the flame shape is considerably destroyed from spherical. On the contrary the flame behavior obtained under microgravity even for very lean mixtures is perfectly spherical during the combustion process. This means that under microgravity the most fundamental combustion characteristics such as flame propagation speed can be observed with very high accuracy.

In Figs.5 to 8 are shown the distance of upward flame propagation with elapsed combustion time as a parameter of equivalence ratio at range from 0.9 to 0.6. On these figures it is shown that the flame travel distance

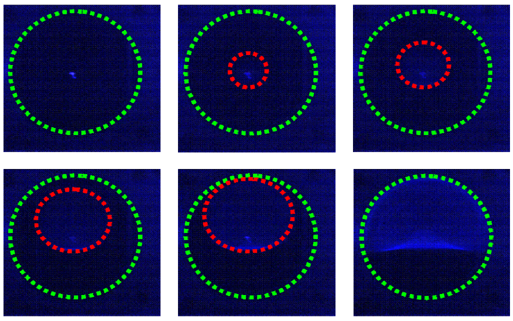

Fig.3. Combustion photographs of methane-air mixtures at 0.6 of equivalence ratio under normal gravity

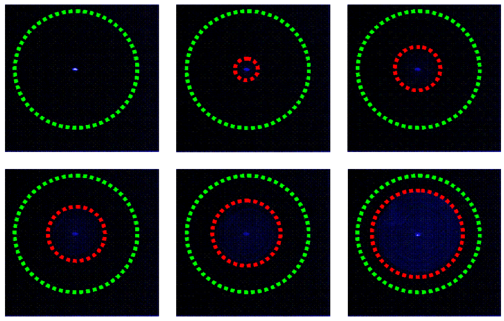

Fig.4. Combustion photographs of methane-air mixtures at 0.6 of equivalence ratio under microgravity.

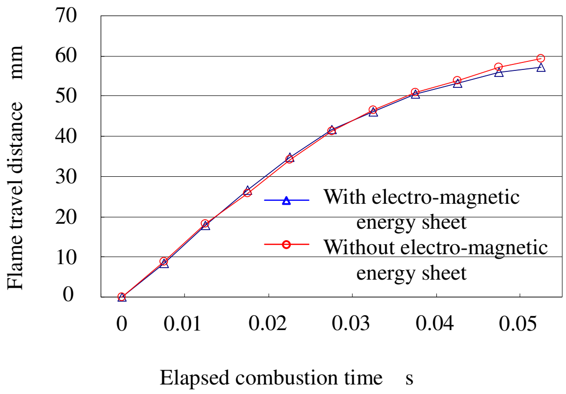

Fig.5. Flame travel distance of methane-air mixtures at 0.9 of equivalence ratio.

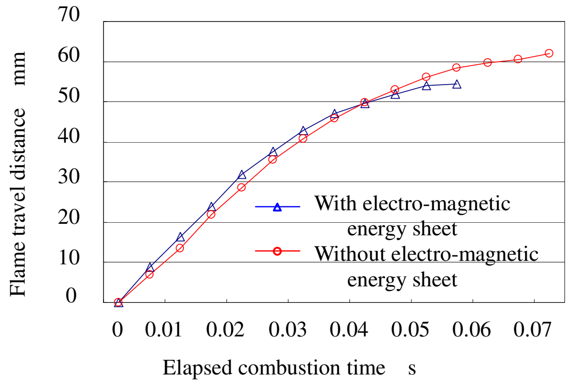

Fig.6. Flame travel distance of methane-air mixtures at 0.8 of equivalence ratio.

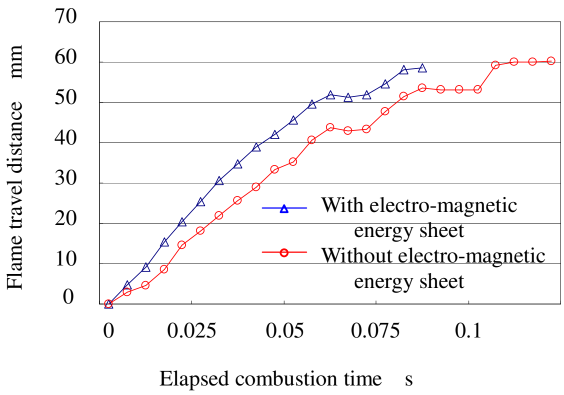

Fig.7. Flame travel distance of methane-air mixtures at 0.7 of equivalence ratio.

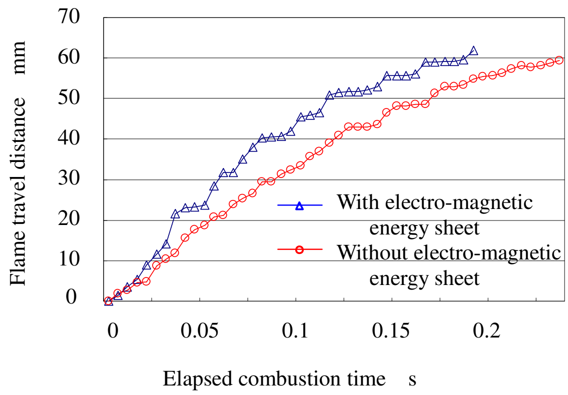

Fig.8. Flame travel distance of methane-air mixtures at 0.6 of equivalence ratio.

is depicted in the case where the electro-magnetic energy sheet is attached in inner walls of closed combustion bomb or not. From these results it can be seen that the flame propagation behavior becomes more irregular approaching the lower equivalence ratio and such irregular flame propagation is more sensitive in the electro-magnetic fields, and the effect of electro-magnetic energy sheet on flame travel distance is larger also approaching the lower equivalence ratio.

Figure 9 denotes the combustion time against equivalence ratio until the flame radius reaches 30mm from the center of closed combustion bomb in the case where electro-magnetic energy sheet is attached or not in the walls surface of combustion bomb. From this figure the experimental fact indicates that the effect of energy sheet is not so much at 0.8 and 0.9 of equivalence ratio and, on the contrary its effect is larger at 0.7 and 0.6 of equivalence ratio.

Figure 10 shows the combustion promotion rate ε against equivalence ratio estimated from Fig.9, where the combustion promotion rate is defined as follows ;

$$\varepsilon = (t_2 - t_1)/ t_1$$

where t_1 and t_2 are combustion time with energy sheet and without energy sheet until the flame radius reaches 30mm from the center of closed combustion time, respectively. From this figure it is understood that the combustion promotion rate increases with decreasing equivalence ratio and at 0.6 and 0.9 of equivalence ratio these values are approximately 28% and 3%, respectively.

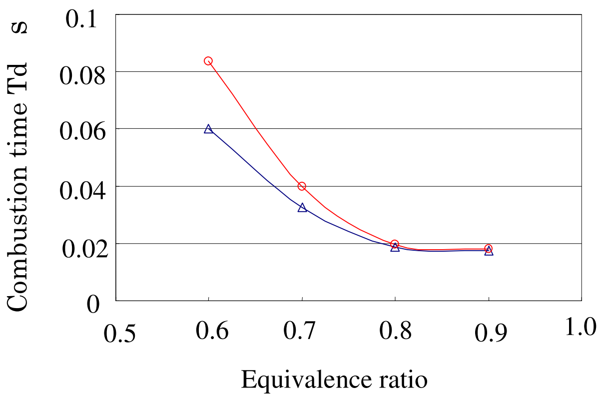

Fig.9. Combustion time until the travels of flame radius at 30 mm from center of combustion bomb after ignition.

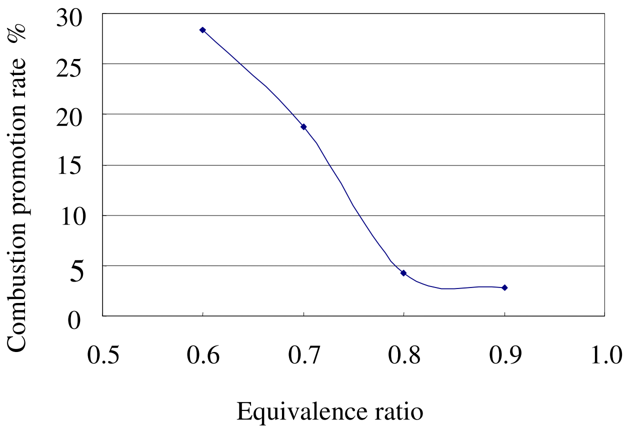

Fig.10. Combustion promotion rate of methane-air mixtures by electro–magnetic energy.

4. Conclusion

Experimental studies have been conducted to elucidate how the flame propagation behavior in a closed bomb are affected by electro-magnetic energy at a certain wave number as a resonance frequency. The acquisition obtained for the study are summarized that (1)The discharge energy from electro-magnetic wave at $1200 cm^{-1}$ and 0.9 of spectral emissibity into the combustible mixtures of methane-air makes it possible to accelerate their combustion rate, (2) For methane-air mixtures, the combustion promotion rate due to electro-magnetic energy considerably increases with decreasing equivalence ratio and (3) The behavior of irregular flame propagation in the electro-magnetic fields may be observed during the combustion process.

5. References

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