Discovery of Principle on Combustion Promotion by a Specific Wave Number at the Regime of Far Infrared Ray
- The Challenge to Realization of High Energy Saving and Low Emission of CO_2 -

Satoshi Okajima
Professor Emeritus of Hosei University, 3-7-2 Kajino-Cho, Koganei-City, Tokyo 184-8584 Japan

Experiments have been conducted to examine how the combustion process is affected by a specific wave number of $1200 cm^{-1}$ in the regime of far infrared ray. Because the author has found that methane and its precursor produced at the first stage of chain reaction during combustion process of fossil fuels are able to absorb significant electro-magnetic radiant energy in the regime of far infrared ray of around $1200 cm^{-1}$ in wave number. This may indicate that such electro-magnetic waves correspond to the resonance frequency of methane and its precursor generated by fossil fuel combustion. The verification for effectiveness of this concept has been done by experimental investigations of co-axial diffusion flame, liquid fuel spray combustion and practical boilers. The results obtained for the study may show that a specific wave number in the regime of far infrared ray has an ability to enhance the combustion process.

Key words: Global warming, Resonance frequency, High efficiency combustion, Low emission of CO_2

1.Introduction

Recently, there are lots of environmental problems such as global warming by CO_2 emission, air pollution by NOx, SOx and PM, exhaustion of fossil fuels and so on. One has to take our environments into care from such problems and one also has to develop the combustion technique to realize the high energy saving and low emission of CO_2 for many kinds of combustors. The basic concept of energy saving for practical combustors may be to reduce the fuel consumption corresponding to the reduction of CO_2 emission without the drop of combustion performance.

From these circumstances, the experiments have been performed to develop the high efficiency combustion technique which is able to achieve the high energy saving and low emission of CO_2 by the utilization of electro-magnetic wave in the regime of infrared ray, since the substances like methane and its chemical species produced at primary stage of chain reaction during combustion process have an ability to absorb the electro-magnetic wave around $1200 cm^{-1}$ of wave number.[1]

Especially, the present study will be focused on to elucidate how the combustion process is affected by such electro-magnetic wave. The verification for the effectiveness of such electro-magnetic wave on combustion process has been done in detail by co-axial diffusion flame of gas fuels and combustion of liquid fuel spray. [2,3,4]

Corresponding author:
S. Okajima e-mail :sofireuperg@yahoo.co.jp
Proceedings of the European Combustion Meeting 2009

2. The concept of combustion promotion mechanism by electro-magnetic wave

The author has found that methane and its precursor produced at the first stage of chain reaction during combustion process of fossil fuels are able to absorb significant electro-magnetic radiant energy in the regime of far infrared ray (wave number = $1200 cm^{-1}$, approximately 8.3μm in wave length). This may mean that such electro-magnetic wave correspond to the resonance frequency of methane and its precursor generated by fossil fuel combustion. So, the discharge of these waves to the combustion zone at the first stage of chain reaction may lead to enhance molecular motion of fuel and oxygen molecules; consequently, the flame temperature may increase due to the acceleration of combustion reaction rate.

For the combustion process of fossil fuels regardless of diffusion or premixed flames, the combustion ultimately includes the reaction of methane and its chemical species as a results of thermal decomposition during combustion process.

The radiation intensity emitted from luminous flames such as CH, C_2, OH and others are approximately in the range of 300 nm to 600 nm in wave length and also radiation intensity emitted from the radiant material used for the study are around 10×10^3 nm in wave length.[5] 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.

Prior to experiments, the author had to develop the electro-magnetic radiant materials more that 0.9 in spectral emissivity ranging form 800 to 2000 cm^{-1} in wave number.[6,7] The electro-magnetic radiant materials are composed of several kinds of ores such as electric stone and transition metals, and its radiation activity is approximately 0.35 mSv/year.

3. The verification of combustion promotion concept by electro-magnetic wave

3-1 Co-axial diffusion flames

The outline of burner configuration for the test assembly of co-axial diffusion flames is shown in Fig.1. The burner nozzle, which is made from stainless steel, is an 8 mm in inner diameter for supplying the fuel gas and also cylindrical air tube is an 80 mm in inner diameter for supplying combustion air.

The flame is established by inter-diffusion between fuel and oxygen in air flow. The water container for measuring the temperature rise by heat transfer from the diffusion flame is the cylindrical bomb of 120 mm in inner diameter and 150 mm in length and it is filled with water. The water temperature rise is measured by a fine K-type thermocouple located in central part of water container. The flame behavior and flame temperature are observed and analyzed by taking the color photographs with high-speed digital video camera installed on the image processing of two-color pyrometer.

Experiments have been carried out at environment of 20℃ and 0.10MPa in initial temperature and pressure, respectively, and the fuel used for the study is Town gas 13A, which is composed of 88.9 % in volume of methane, 6.8 % in volume of ethane, 3.1% in volume of propane and 1.2% in volume of butane.

In Fig.2 are depicted the flame temperature profiles analyzed by image processing of two color pyrometer. The left of these photographs is without electro-magnetic materials (we call it "non electro-magnetic fields") and the right is with electro-magnetic radiant materials (we call it "electro-magnetic fields"). From Fig.2 it can be obviously recognized that such electro-magnetic waves may conduct to bring the flame temperature rise and it can be evaluated as about 80℃ on the average.

Figure 3 shows the variation of water temperature rise in container against air ratio in electro-magnetic fields or not. The air ratio is defined as practical air-fuel ratio divided by stoichiometric proportion of air-fuel ratio. As seen from Fig.3, the temperature rising rate under electro-magnetic fields increases with decreasing air ratio and the values of temperature rising rate at 1.6 and 1.2 of air ratio are 4.10 and 4,32 ℃/min, respectively. On the contrary, under non electro-magnetic fields their values are 4.00 and 4.18 ℃/min at 1.6 and 1.2 of air ratio, respectively. So, the energy saving rate by electro-magnetic wave at 1.6 and 1.2 of air ratio can be evaluated as 2.5 and 3.5 %, respectively. The energy saving rate （ε） can be expressed by equation (1),

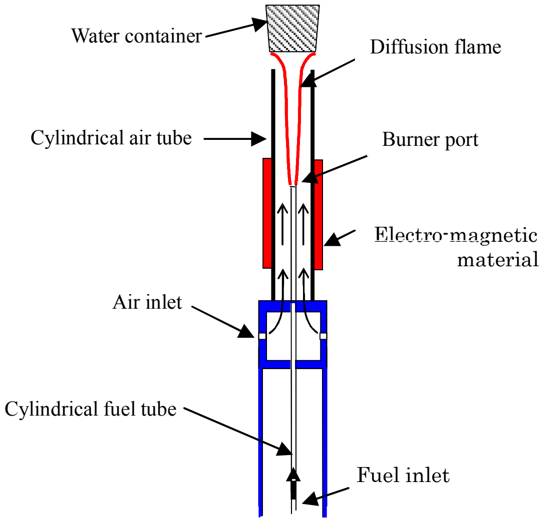

Fig.1. Burner configuration of test assembly.

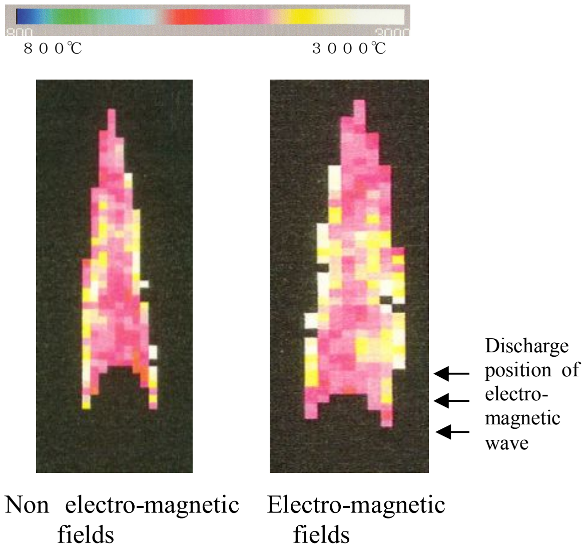

Fig.2. Flame temperature profile of co-axial diffusion flame of Town gas 13A.

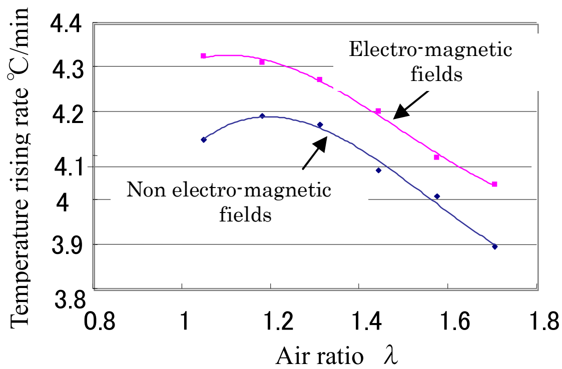

Fig.3. Variation of temperature rising rate vs. air ratio (Fuel: Town gas 13A) .

$$\varepsilon = (S - S^{/}) / S^{/} \quad (1)$$

where S is the temperature rising rate in electro-magnetic fields and $S^{/}$ is also temperature rising rate in non electro-magnetic fields.

3-2 Liquid fuel spray combustion

Figure 4 shows the outline of experimental apparatus for observation of liquid fuel spray combustion in electro-magnetic fields. The apparatus consists of spray combustion nozzle of 0.3 mm in diameter, DC power supply, air and fuel flow meters, air tank, air compressor and high speed digital video camera. The electro-magnetic radiant materials, which can continuously discharge the electro-magnetic energy, is attached the surrounding of the flame as making it possible to discharge the electro-magnetic energy to the location of flame base.

The combustion behavior of fuel spray in electro-magnetic fields are observed by taking the direct color photographs with high speed digital video camera of 200 frames per second and the mean flame temperature of fuel spray combustion is estimated by image processing of two color thermal analysis based on the color photographs obtained with high speed digital video camera.

The experiments have been performed in the condition of room temperature and one atmospheric pressure. The fuels used for the study are kerosene and heavy oil A. The fuel and air flow rates employed here are 0.4 and 4 to 7 ℓ/min, respectively.

In Fig. 5 are depicted the direct color photographs on flame behavior of kerosene spray combustion in the case where the discharge of electro-magnetic wave exists or not. Figure 6 shows the flame temperature profile obtained by two color pyrometer on kerosene spray combustion, where the fuel and air flow rate are 0.4 and 6 ℓ/min, respectively. From these photographs it is found that the flame temperature on kerosene spray combustion in electro-magnetic fields is clearly higher than that in non electro-magnetic fields. On the average it is about 150 ℃ higher than that in non electro-magnetic fields.

Figure 7 shows the variation of flame temperature of kerosene spray combustion against air flow rate in the case where electro-magnetic energy is discharged to the flame zone L and C as shown in Fig.5, and Fig.8 is also shown the temperature rising ratio of kerosene and heavy oil A against air flow rate when the discharge of electro-magnetic wave is located at L. As seen from Fig.7 the effect of electro-magnetic wave at the location L on the flame temperature is markedly higher than that at location C. This may means that the

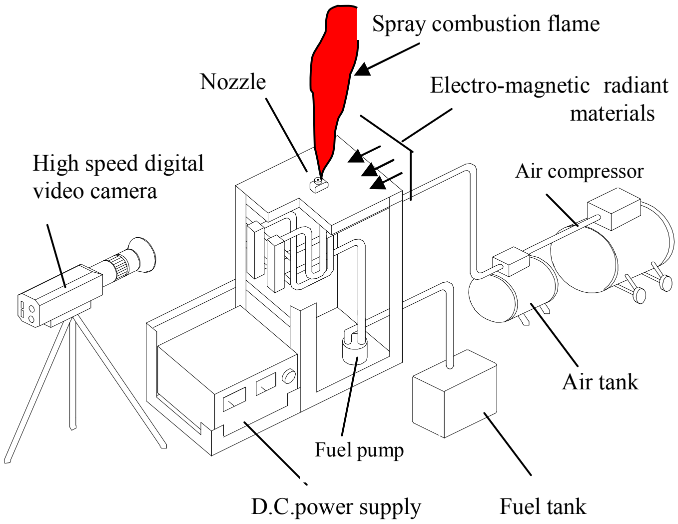

Fig.4. Experimental setup of liquid fuel spray.

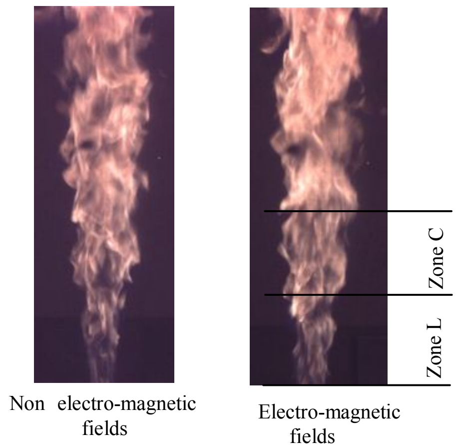

Fig. 5. Direct color photographs of spray combustion in electro-magnetic fields or not.

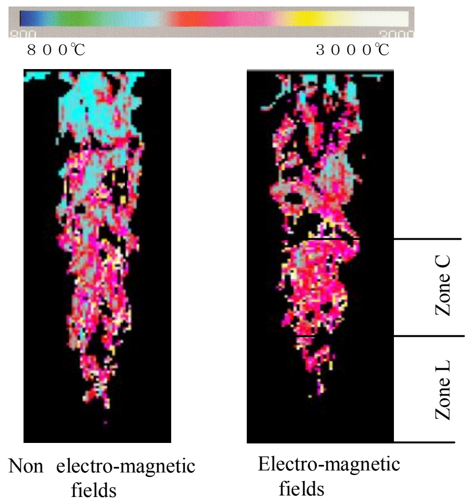

Fig.6. Flame temperature profiles of spray combustion corresponding to Fig.5.

discharge of electro-magnetic wave to the flame base is very effective to enhance the combustion reaction rate. [8] Also from Fig.8 it can be seen that at 7 ℓ/min of air flow rate, the temperature rising ratios of kerosene and heavy oil A are approximately 6.5% and 2%, respectively, and where the temperature rising ratio is defined as the ratio between the flame temperatures with and without the discharge of electro-magnetic wave at the same air flow rate.

3-3 Combustion exhaust gas of co-axial diffusion flame

The flame temperature rise under combustion in electro-magnetic fields may brings it possible to reduce the oxygen concentration and to increase the CO_2 emission in exhaust gas of fossil fuel combustion. The co-axial diffusion flame for the study is employed to measure and analyze the combustion exhaust gas. The exhaust gas emission is measured by a fine sampling probe cooled by water to freeze the chemical reaction of combustion exhaust gas.

In Figs. 9 and 10 are shown the oxygen (O_2) and dioxide (CO_2) concentration vs. air ratio in combustion exhaust gas of co-axial diffusion flame of Town gas 13A, respectively. From these figures it is recognized that O_2 concentration under combustion in electro-magnetic fields is always lower than that under combustion in non electro-magnetic fields for all of the air ratios studied. On the other hand CO_2 emission under combustion in electro-magnetic fields is also higher than that under combustion in non electro-magnetic fields. This fact indicates that the combustion in electro-magnetic fields may conduct to more enhance the combustion reaction rate during combustion process.

3-4 Demonstration test for combustion of practical boilers

From the results of these experiments, one can suggest that, for boiler combustion, it may be possible to achieve the combustion of lower air fuel ratio, because the electro-magnetic combustion may approaches the perfect combustion as a result of the increase of the flame temperature as shown in Fig.11.

Table 1 shows the energy saving rate (η) and rising rate of boiler efficiency (β) obtained by demonstration test for boiler combustion. Where A and B are the once through boiler, C and D denote the smoke tube and flue boiler and E indicates the water tube boiler. As seen from the table, the energy saving rate is 2 to 5 % and the rising rate of boiler efficiency is also 1.95 to 5%. The energy saving rate (η) and rising rate of boiler efficiency (β) can be expressed as following equations, where the coefficient of fuel consumption (f) is defined as fuel quantity required to vaporize the water per unit mass

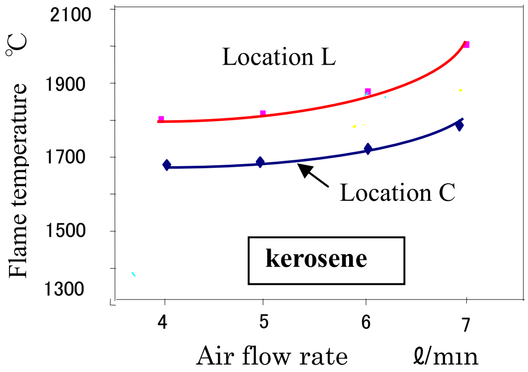

Fig.7. Temperature variation against air flow rate on kerosene spray combustion at the location L and C .

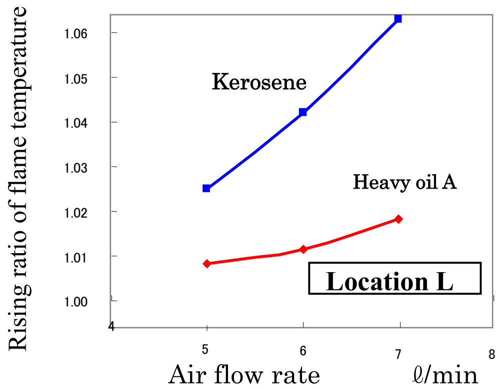

Fig.8. Temperature rising ratio of spray combustion for kerosene and heavy oil A at location L.

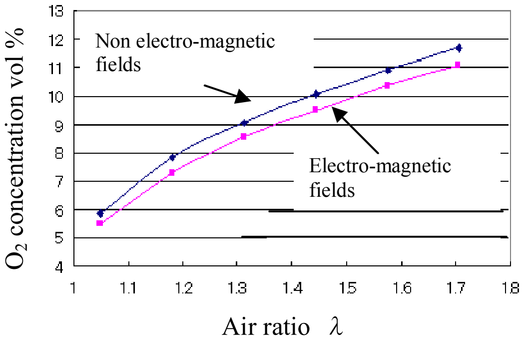

Fig.9. O_2 concentration in combustion exhaust gas.

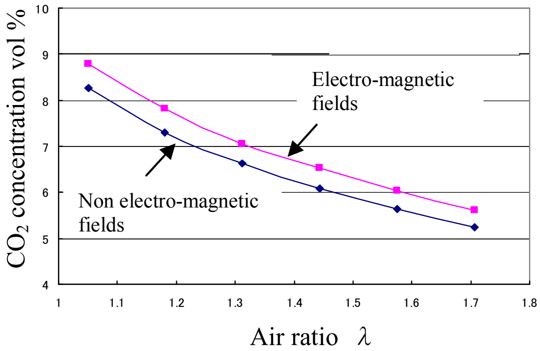

Fig.10. CO_2 concentration in combustion exhaust gas.

under steady state operation,

$$\eta = (f_b - f_a) / f_b \qquad (2)$$

$$\beta = (f_b / f_a) - 1 \qquad (3)$$

where subscripts a and b indicate the coefficient of fuel consumption under combustion in electro-magnetic fields and under combustion in non electro-magnetic fields, respectively.

In Table 2 is shown the amount of reduction of CO_2 emission corresponding to the energy saving rate obtained from the demonstration test of practical boilers, where the symbols from A to E also correspond to those of Table 1. As seen from Table 2, for the boiler combustion it is possible to reduce much more emission of CO_2 even at the energy saving rate of 2 to 5%.

4. Conclusion

Experiments have been conducted to examine how the combustion is affected by a specific wave number in the regime of electro-magnetic wave. The verification for effectiveness of electro-magnetic wave on combustion process is done by experimental studies of co-axial diffusion flames, liquid fuel spray combustion and practical boilers.

The main results obtained from the study are as follows that (1) the mean flame temperature rise obtained for spray combustion of kerosene in electro-magnetic fields is approximately 150℃ higher than that obtained in non electro-magnetic fields, (2) the effect of such electro-magnetic wave on flame temperature rise of co-axial diffusion flame of town gas is the same effect with that obtained by kerosene spray combustion, (3) the energy saving rate corresponding to reduction of CO_2 emission even at the demonstration test of boilers can be attainable in the range of 2 to 5% and rising rate of boiler efficiency is also obtained as 1.95 to 5% and (4) these results may say that a specific wave number in the regime of far infrared ray has an ability to promote the combustion process and this principle discovered for the research is very useful to achieve the high energy saving and low emission of CO_2 for any practical combustors.

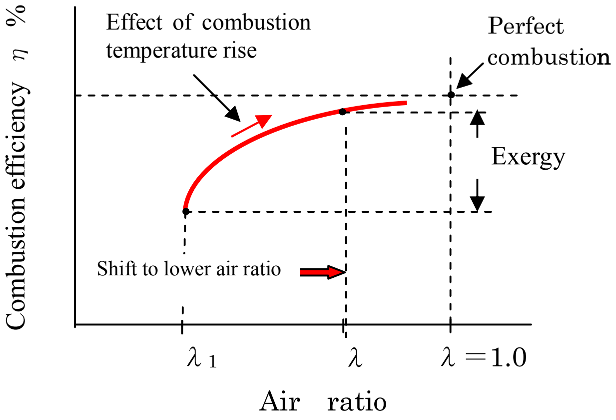

Fig.11. Explanation of energy saving mechanism under combustion in electro-magnetic fields.

Table 1. Energy saving rate (η) and rising rate of boiler efficiency.

Boiler	Capacity	Fuels	η	β
A	3 ton/h	Heavy oil	5.0%	5.1%
B	2	Town gas	5.3	5.2
C	8	Heavy oil	5.9	5.4
D	5	kerosene	3.4	4.5
E	25	Town gas	2.0	1.95

Table 2. Reduction of CO2 emission for boiler combustion.

Boiler	Fuel consumption	Reduction of fuel consumption	Reduction of CO_2
A	700,000 ℓ/year	35,589 ℓ/year	96 ton/year
B	246,316 Nm^3/year	13,129 Nm^3/year	28 ton/year
C	407,128 ℓ/year	18,076 ℓ/year	49ton/year
D	401,540 ℓ/year	23,169 ℓ/year	63 ton/year
E	2,915,280 Nm^3/year	58,305 Nm^3/year	123 ton/year

References

1. NIST Chemical WebBook (2006), NIST Standard Database Number 69.
2. S. Okajima, JARI REPORT 2007,Vol.18, No.6, CD-ROM,2007-4.
3. S. Okajima, et al., Asia-Pacific Conference on Combustion, The Combustion Institute, CD-ROM, 2007-6.
4. S. Okajima et al., 21th ICDERS, Poitier France, CD-ROM, 2007-8.
5. T. Niioka, et al. Fundamentals of Combustion Phenomena, Ohmsha, pp.151-194,2001.
6. S. Okajima et al., Chemical Engineering, Vol.56, No.12, pp.12-17,2005.
7. S. Okajima, et al., Combustion Society of Japan, 43th Symposium on Combustion, pp.512-513, 20-05-12.
8. H. Fujimoto et al., SAE2001 Transaction Journal of Engine 01-12, 2001.