Kobe University Repository : Kernel

タイトル Title	Soot particle behavior in a flame by propane gas mixed with wood powder(MARITIE STUDIES, AND SCIENCE AND ENGINEERING)(MARITIE STUDIES, AND SCIENCE AND ENGINEERING)
著者 Author(s)	Nishida, Osami / Wang, Baojun / Oda, Hayato / Fujita, Hirotsugu / Harano, Wataru / Yamada, Shigeo
掲載誌・巻号・ページ Citation	神戸大学海事科学部紀要 = Review of the Faculty of Maritime Sciences, Kobe University,2:151-156
刊行日 Issue date	2005-07-31
資源タイプ Resource Type	Departmental Bulletin Paper / 紀要論文
版区分 Resource Version	publisher
権利 Rights	
DOI	
URL	http://www.lib.kobe-u.ac.jp/handle_kernel/00422411

Create Date: 2017-12-18

Soot particle behavior in a flame by propane gas mixed with wood powder

Osami NISHIDA, WANG Baojun[*1], Hayato ODA[*2], Hirotsugu FUJITA, Wataru HARANO, Shigeo YAMADA[*3]

(Received April 8, 2005)

Abstract

The world energy resource mainly depends on the fossil fuel, but it will be used up in tens of years. On the way to search renewable and environment-friendly energy resource, the biomass has been utilized for many years, but the corresponding problems including the thermal efficiency and pollution need to be resolved. At the present time, LPG (major components are propane and butane) has a great potential to be utilized and with less exhaust pollutants. This paper focuses on applying the propane gas and wood powder to form mixed fuel flame. As a fundamental research, two experiments are carried out to investigate the soot particle behaviors. One is the soot particle diameter measurement by G.Mie's light scattering theory, the results show that the soot particle diameter of the mixed fuel flame is greater than that of the propane gas flame. Another is the soot particle density measurement by weight difference method. The results show that the soot particle density of the mixed fuel flame is greater than that of the propane gas flame. The experiments make clear that the wood powder can be applied to form a mixed fuel flame with propane gas.

1. Introduction

The world energy resource now mainly depends on the fossil fuel, while it is becoming rare and expensive because of its non-regenerative character. In 2000, the R/P (remaining reserves to annual production ratio) for oil and natural gas is 42 years[1]. And the fossil fuel threatens the global environment during energy conversion process. It is necessary to find new energy or new energy utilization method to save the fossil consumption. Among the new energies, the biomass is a renewable and clean energy with large utilization potential. The using of biomass can bring great economic and environmental benefits with lower carbon dioxide emission than fossil fuel[2]. The typical biomass includes the wood and its by-product, agriculture by-product and waste, municipal sewage, marine organism, etc. To offer energy, the biomass can be utilized by direct combustion, gasification, bio-oil production, methanol and ethanol production methods according to its particular characteristics and facility's scale[3].

A great deal of wood powder is produced in sawmills and furniture processing plants. It is often used as raw material of fiberboard or burned in a cycling fluidized bed boiler, but not easy to be burned in a small-scale boiler. This paper tries to find a way to use the wood powder in a small-scale boiler by co-firing with LPG (liquefied petroleum gas), it is necessary to investigate the basal performance of the co-firing. The diameter of the wood powder used is less than $250 \mu m$, density of natural state is $231.8 kg/m^3$. LPG is a by-product of natural gas processing or a product that comes from crude oil refining and is composed primarily of propane and butane, emitting less carbon dioxides and nitrogen oxides in the exhaust. It is applied widely in public livelihood, industry and traffic field. Since LPG is largely propane, the characteristics of propane sometimes are

*1 Graduate School of Science and Technology, Doctor of Maritime Science
*2 Graduate School of Science and Technology, Master of Marine Engineering
*3 Osaka Prefecture Forest Owners Association

taken as a close approximation to those of LPG. So, the propane gas is used to form the flame in the experiment.

The biomass will emit lots of poisonous or greenhouse effect substances while being combusted. Among them, the most poisonous ones are nitrogen oxides, carbon dioxide and soot particle. The objective of the experiments in this paper is to study the soot particle diameter and density of the mixed fuel flame, to compare them with those of the propane gas flame on the same conditions.

2. Experiment method and apparatus

2.1 Diameter measurement experiment

The diameter of the soot particle is obtained *in-situ* by applying G.Mie's light scattering theory[4]. It begins with the electromagnetic Maxwell equations and is often applied in nanometer scale particle measuring[5][6][7]. The basal function of the theory is,

$$I_2 = \frac{I_0 \lambda'}{8\pi^2 r^2} i_2(\alpha, m, \theta)$$

here, I_2 is the intensity of horizontal component of the scattering light, I_0 is the intensity of the incident light, λ' is the wavelength of the incident light in the ambient media and $\lambda' = \lambda / m_0$ where λ (514.5*nm* in experiment) is the wavelength of the incident light and m_0 (1.0) is the refractive index of ambient air, r is the measuring distance (120*mm*), i_2 is the horizontal scattering function of diameter parameter α ($\alpha = \pi D / \lambda'$, D is the soot particle diameter), refractive index of particle m (1.60 and 1.56-0.524i[6] for standard Latex and soot particle, respectively) and scattering angle θ (60°, 120°) (the angle between the incident light and scattering light direction), and

$$i_2 = |S_2(\theta)|^2$$

$$S_2(\theta) = \sum_{n=1}^{\infty} \frac{2n+1}{n(n+1)} \{b_n \cdot \pi_n(\cos\theta) + a_n \cdot \tau_n(\cos\theta)\}$$

$$a_n = \frac{\psi'_n(\beta)\cdot\psi_n(\alpha) - m\psi_n(\beta)\cdot\psi'_n(\alpha)}{\psi'_n(\beta)\cdot\xi_n(\alpha) - m\psi_n(\beta)\cdot\xi'_n(\alpha)}$$

$$b_n = \frac{m\psi'_n(\beta)\cdot\psi_n(\alpha) - \psi_n(\beta)\cdot\psi'_n(\alpha)}{m\psi_n(\beta)\cdot\xi_n(\alpha) - \psi_n(\beta)\cdot\xi_n(\alpha)}$$

$$\beta = m\alpha$$

$\pi_n(\cos\theta), \tau_n(\cos\theta)$ is the Legendre function.

$\psi_n(\alpha), \xi_n(\alpha)$ is the Raccati-Bessel function.

The above theoretical scattering function i_2 is solved out with computation code by applying *MatlabR12.1* software. The results between the soot particle diameter and scattering function i_2 and the ratio of i_2 are shown in Fig.1. Following these results, the soot particle can be determined uniquely by the ratio of i_2 in the region of diameter ≤234*nm*.

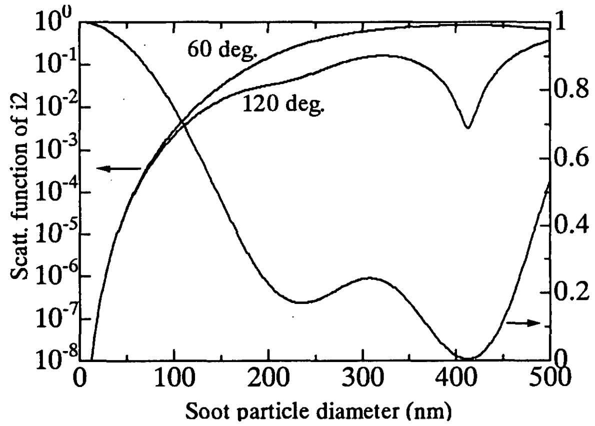


Fig.1 Soot particle scattering function i_2 and the ratio of scattering function of i_2 at 60° and 120°

The experiment device is schematically shown in Fig.2. An argon ion GLG4380 laser unit emits a laser beam with wavelength of 514.5*nm* as the incident light. The incident light penetrates the flame and then be captured by a beam trapper. Two optical lens units are located at the 60° and 120° scattering angle position. Each lens unit is constituted of four lenses with focus length of 120, 75, 75 and 50*mm* and a pinhole with diameter of 0.2*mm*. The scattering light is collected by the lens unit and transferred to the HAMAMATSU H6870 photo-multiplier. The photo-multiplier transmits the light signal to an electrical one. The electrical signal is amplified by a

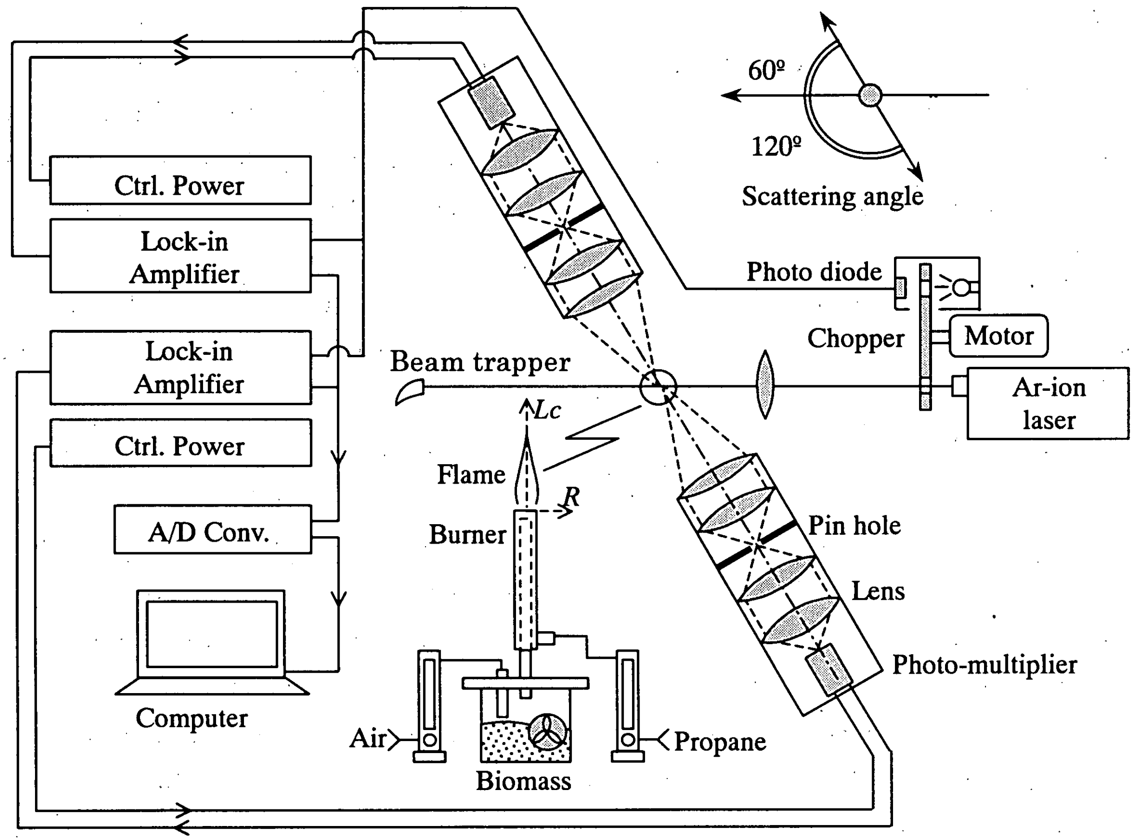


Fig.2 Experiment apparatus used for soot particle diameter measurement

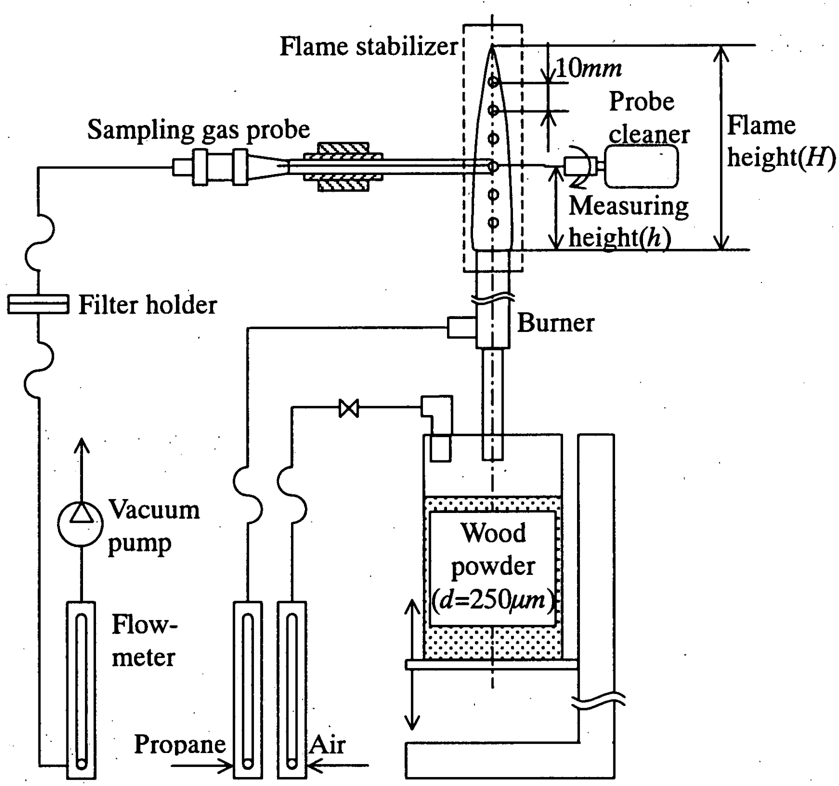


Fig.3 Experiment apparatus used for soot particle density measurement

LI-570A type lock-in amplifier, then led to an A/D converter where it is converted to a digital one, and gathered by the computer. The reference signal of the lock-in amplifier is achieved from the chopper located on the incident beam, ensures only the scattering light with the same frequency of the incident light be collected by the computer.

The propane gas is led to the outer pipe (d_{in} =10*mm*) of the double concentric burner. The air is firstly led to a tank where the wood powder with diameter less than 250*μm* is filled, thus carries the wood powder to the inner pipe (d_{in} =6*mm*) of the burner. A mini-electrical fan is located in the tank to ensure the wood power be carried by the air. At the top of the burner, the propane gas and wood powder mixed fuel flame will be formed and the incident laser light will penetrate it. The burner is placed on a 3-dimensionally adjusted platform to match the incident light.

The experiment apparatus is originally adjusted with the polystyrene polymer with standard diameter of 50±2.0nm and 155±4nm respectively. Then the experiment is carried out as the following steps. Firstly, start up the laser unit and the data processing apparatus. Secondly, supply the propane gas and air at pre-decided flow rate and fire the flame, record the data of the mixed fuel flame, then stop the wood powder supply and record the data once. Thirdly, adjust the burner to another height to repeat the recording. The incident light is set at the axial center of the flame (*R*=0), and the measurement height (*Lc*) is set to 10, 20 and 30*mm*.

2.2 Density measurement experiment

The soot particle density is obtained by the weight difference method. A positive volume combusting gas is inhaled from the flame and flows to a pre-dried filter. The filter attached with soot particle is re-dried to get the weight. The soot particle density is calculated by the filter weight difference and the inhale volume.

Fig.3 schematically shows the apparatus for this experiment. The firing apparatus and the wood powder are almost same as the former besides a flame stabilizer is set up to prevent the flame from unsteadiness. A sampling gas probe is inserted to the axial center of the flame, the filter holder installed with GB100R filter is set behind the probe. A vacuum pump working at 0.2*l/min*×4*min* inhales the sampling gas from the flame. Inside the sampling gas probe, a motor-driven cleaner is used to prevent the soot particle from accumulation.

The filter samples are taken with and without wood powder mixing on the same firing conditions. The propane gas flow rate is kept at 0.1*l/min*, the flow rate of air is 0.2, 0.4 and 0.6 *l/min*, the measuring height *h*(distance between the burner top and sampling probe axial center) is from 10 to 50, 60 or 70*mm*, depending on the flame height *H*. To avoid air be inhaled, the measurement stops at the flame upper position with a 0.5 or 1*mm* margin.

3. Experiment result

3.1 The soot particle diameter result

Fig.4 shows a scene of the experiment when the wood powder is mixed, the flame height is nearly 40*mm*, *Lc*=30*mm*, *R*=0. There is a blue and translucent part in the lower 5*mm* part, then it extends to be dazzled.

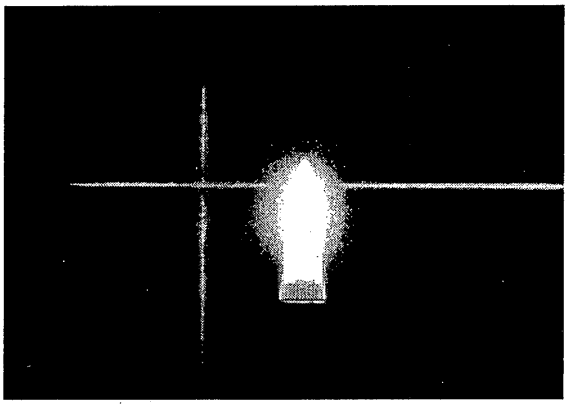
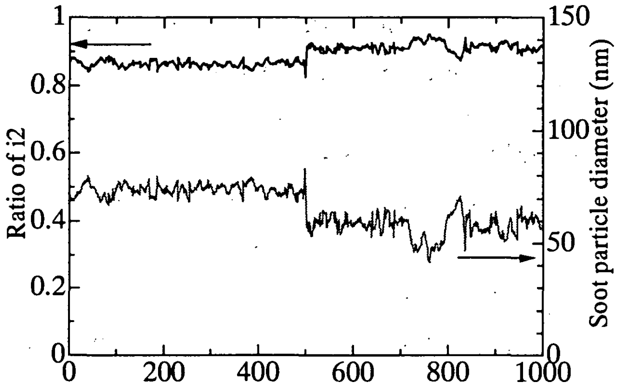
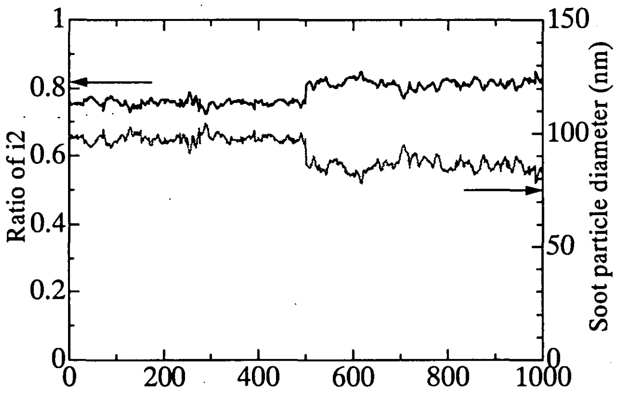


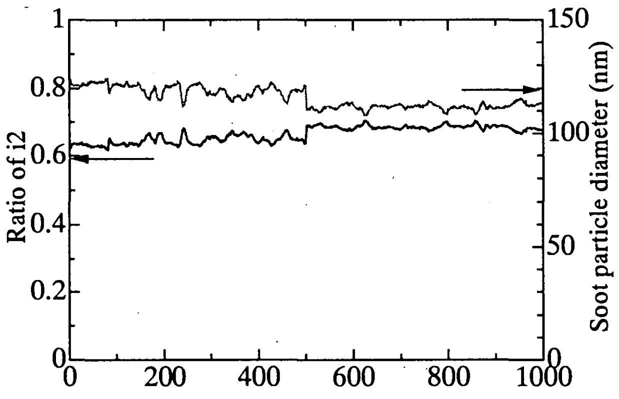
Fig.4 Flame of mixed fuel
(*air*=0.4*l/min*, *propane gas*=0.1*l/min*)



(a) Lc=10*mm*



(b) Lc=20*mm*



(c) Lc=30*mm*

Fig.5 Ratio of i_2 (120/60) and soot particle diameter
(*air*=0.4*l/min*, *propane gas*=0.1*l/min*)

The experiment result is shown in Fig.5(a) when Lc is10*mm*. The wood powder supply is stopped when 500 seconds elapsed. Therefore, there is an abrupt change in the curve, and it is also similar in Fig.5(b) and Fig.5(c). When the mixed fuel flame is measured, the ratio of i_2 is averagely 0.87, while it is averagely 0.94 when propane gas flame is measured. Accordingly, the soot particle diameter is averagely 74*nm* in the mixed fuel flame, while it is averagely 58*nm* in the propane gas flame. Fig.5(b) shows the result when Lc is 20*mm*. The ratio of i_2 is averagely 0.76 and 0.82 on the two conditions, while the soot particle diameter varies from averagely 97*nm* to 86*nm*. Fig.5(c) shows the result when Lc is 30 *mm*. The ratio of i_2 is averagely 0.65 and 0.68 on the two conditions, while the soot particle diameter varies from averagely 120*nm* to 112*nm*.

As a whole, there is an increase of the soot particle diameter when the wood powder is mixed to the propane gas flame. The increase is 16, 11 and 8*nm* at the Lc =10, 20 and 30*mm* position. This is resulted from the cenosphere and char[8] produced by the firing of wood powder, and the number of the soot particle will also increase.

3.2 The soot particle density result

Fig.6 is a sample of the measured filter on condition that flow rate of air is 0.2*l/m*, the flow rate of propane gas is 0.1*l/m*, the flame height H is 80*mm*. The upper 3 rows of filters are taken from the mixed fuel flame, while the lower 3 rows are from the propane gas flame. A certain of measurement point is inserted when there is a great change between the adjacent two points, for example, h=45*mm* and h=55*mm* is inserted in the case of Fig.7.

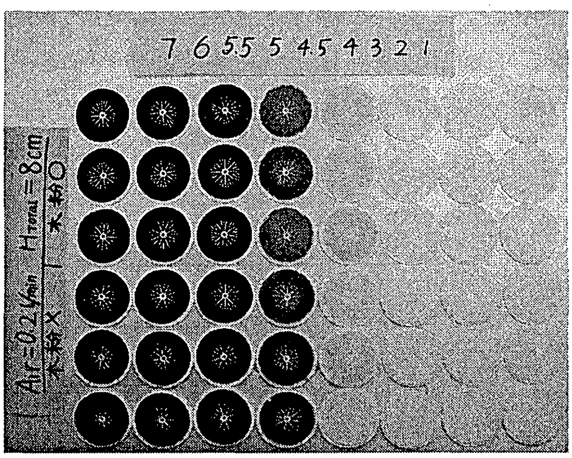


Fig.6 Sample of particles on filter

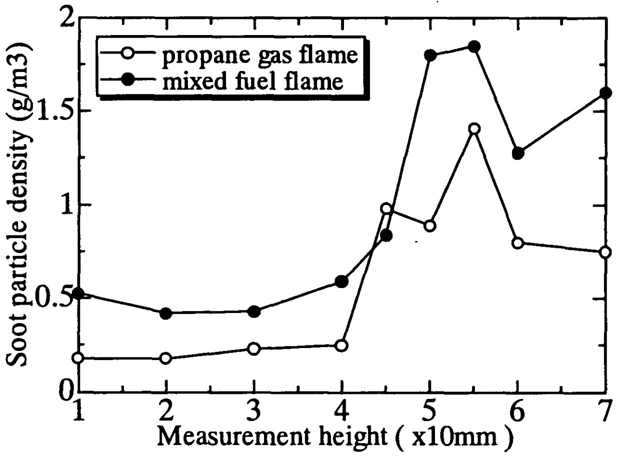


Fig.7 Soot particle density
(*H*=80*mm*, *air*=0.2*l/min*, *propane gas*=0.1*l/min*)

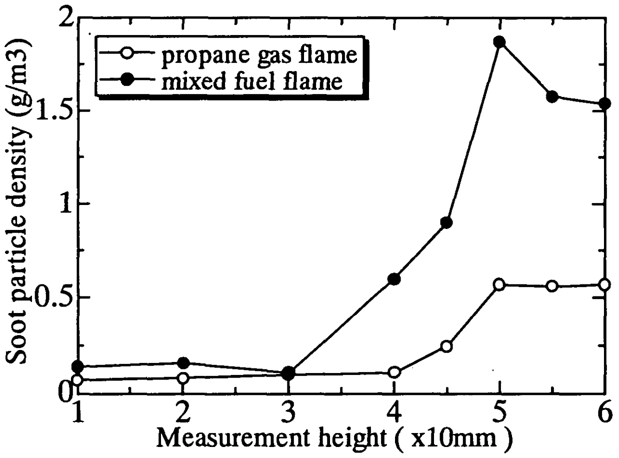


Fig.8 Soot particle density
(*H*=70*mm*,*air*=0.4*l/min*,*propane gas*=0.1*l/min*)

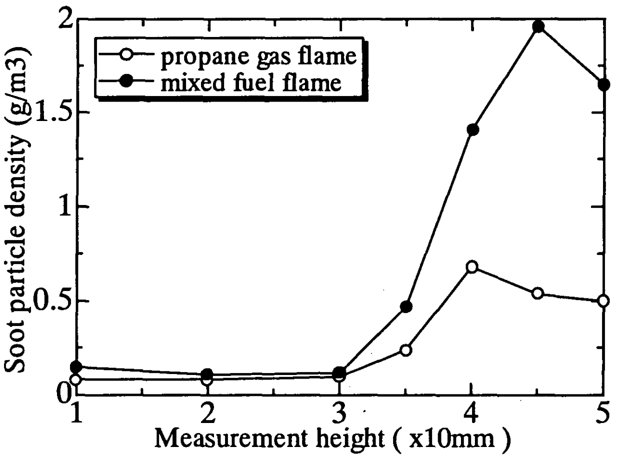


Fig.9 Soot particle density
(*H*=55*mm*,*air*=0.6*l/min*,*propane gas*=0.1*l/min*)

Fig.7 shows the result when the flow rate of air is 0.2*l/m*, the density in the mixed fuel flame nearly always be greater except in the position of *h*= 45*mm*. On condition of the flow rate of air is 0.4 and 0.6*l/m*, the flame height is 70 and 55mm respectively, as shown in Fig.8 and Fig.9. In the part of *h*=30*mm*, there is a little density difference in two kinds of flames, but it is greater when h>30*mm*.

4. Conclusion and discussion

1) The wood powder of diameter less than 250*μm* can be formed flame mixed with propane gas on the experiment conditions.

2) G.Mie's light scattering theory is well applied to measure the soot particle diameter. The soot particle diameter of the mixed fuel flame is averagely 74, 97 and 120*nm* in *Lc*=10, 20, 30*mm* position, greater than that of the propane gas flame.

3) The soot particle density of the mixed fuel flame is greater than that of the propane gas flame, and the density difference increases greatly in the upper part of the flame.

References

[1]日本エネルギー学会: エネルギー便覧―資源編; コロナ社, pp.17(2004)

[2]Charles L. Peterson, Todd hustrulid: Carbon cycle for rapeseed oil biodiesel fuels; Biomass and bioenergy, Vol.14, No.2, pp.91-101 (1998)

[3]横山伸也: バイオエネルギー最前線, 森北出版株式会社, pp.80-81 (2001)

[4]H.C. van de Hulst: Light scattering by small particles, Dover publications, Inc., pp. 114-130 (1981)

[5]Osami Nishida: Determination of the coarse aerosol size by Mie scattering Theory; Rev. KUMM, No.35, pp.55-70 (1987)

[6]H. Fujita, O.Nishida: Diameter measurement of soot particles in diffusion flame by Mie scattering image; Proceed. of JSME, No.004, pp.5-9-10 (2000)

[7]O.Nishida, Wang Baojun, et al: The soot particle diameter in a gas flame with biomass mixing; Proceed. of JIME, No.72, pp. 93-94 (2004)

[8]水谷幸夫: 燃焼工学(第 3 版);森北出版社, pp.214(2002)