Combustion Characteristics of Unused Bamboo Using New Compact Combustor

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***Abstract*-Experimental study is to develop the biomass furnace combustor which can effectively employ unused bamboo as a fuel. Consideration is given to the combustion gas components and combustion gas temperature in the combustor and the thermal efficiency. It is found from the study that (i) unused bamboo can take place self-combustion and the stable combustion yields and can be maintained, (ii) combustion temperature distribution appears along the vertical direction in combustor, (iii) the concentrations of nitrogen oxide and sulfur oxides are lower than the discharge standard value, (iv) the collected maximum ash size is less than 1mm, and (v) higher thermal efficiency over 50% yields.**

Keywords- Unused biomass, Compact combustor, Stable Combustion, combustion analysis, thermal efficiency

I. INTRODUCTION

The issue of climate change, alongside with prediction of fossil fuel depletion, has become one of the main factors for the increasing demand of renewable and low CO2 emission energy. In addition, by the increasing competition of renewable energy production, renewable energy has become the fastest growing source of energy.

Many countries are promoting to utilize more of renewable energy resource and reducing greenhouse gases, which made biomass as renewable energy resource and alternative source of energy to fossil fuel getting more attention. The abundance in supply and the ability to reproduce through the biomass source lifecycle, has made biomass energy become a promising source of renewable energy [1]. Furthermore, its zero net CO2 emission also made biomass become feasible source of energy to reduce greenhouse gas emission and prevent climate change. Biomass is an interesting energy source for several reasons. This is because biomass energy can contribute to sustainable energy development. In particular, wood and bamboo are widespread and used in various industries. Leaves, branches and barks which also belong to the biomass energy, are discarded in the logging camp because of the expensive collection and transportation costs [2]. These unused biomasses (20,000 m3/y) are discarded in Japan [3] and are not fully utilized [4]. Combustion which is very suitable to treat unused biomass, is the last resort to utilize biomass energy [5]. The corresponding combustion technology and device at the above scale can be employed. However, the smaller scale farm can not utilize it due to transportation cost or other problems. Thus, the technology of compact and low-cost combustor which can combust the biomass at a small scale, is substantially required.

The aim of the present study is performed on a development of the compact combustor and the corresponding stable combustion using unused biomass. Consideration is given to the combustion gas temperature and combustion gases produced in the combustor. New combustor can maintain steadily self combustion and the combustion temperature is kept in the rage of 800 oC～1000 oC. The concentrations of nitrogen oxide and sulfur oxides are lower than the discharge standard value.

II. EXPERIMENTAL APPARATUS AND METHOD

The combustion system which is consisted of feeder, combustor, heat exchanger, cyclone separator and measurement devices, is shown in Fig. 1, and the corresponding photograph is depicted in Fig. 2. Unused biomass and air are fed by the forced draft fan and the biomass is combusted in the combustor. The hot combustion gas produced in the combustor is flowed from the top of combustor and the millimetre-sized ash is collected at the bottom of combustor. The hot combustion gas enters into heat exchanger and after the hot combustion gas is cooled in the heat exchanger, the cooled combustion gas flows through the cyclone separator, resulting in the recovery of the micro-sized ash. At the same time, the hot water is produced in the cyclone separator and the cool combustion gas without ash is discharged from the chimney.

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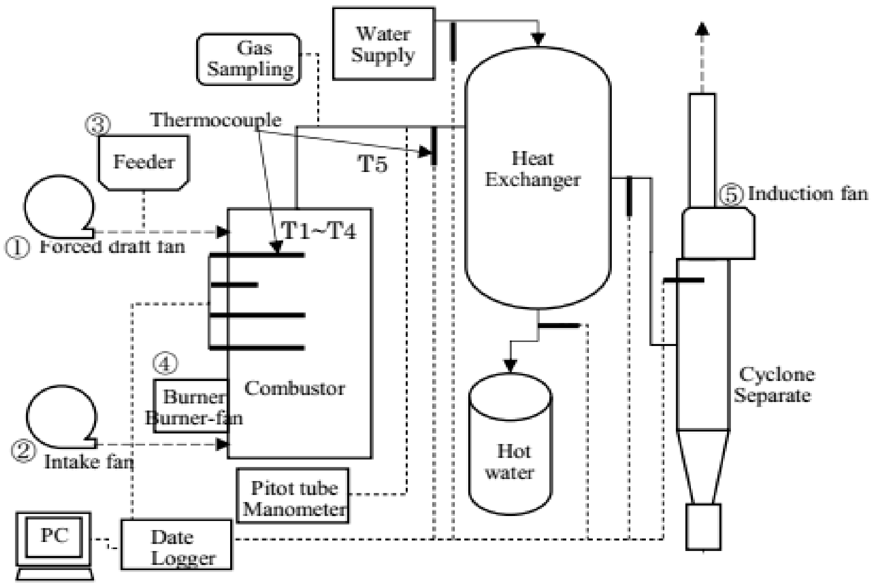

Fig. 1 Combustion system

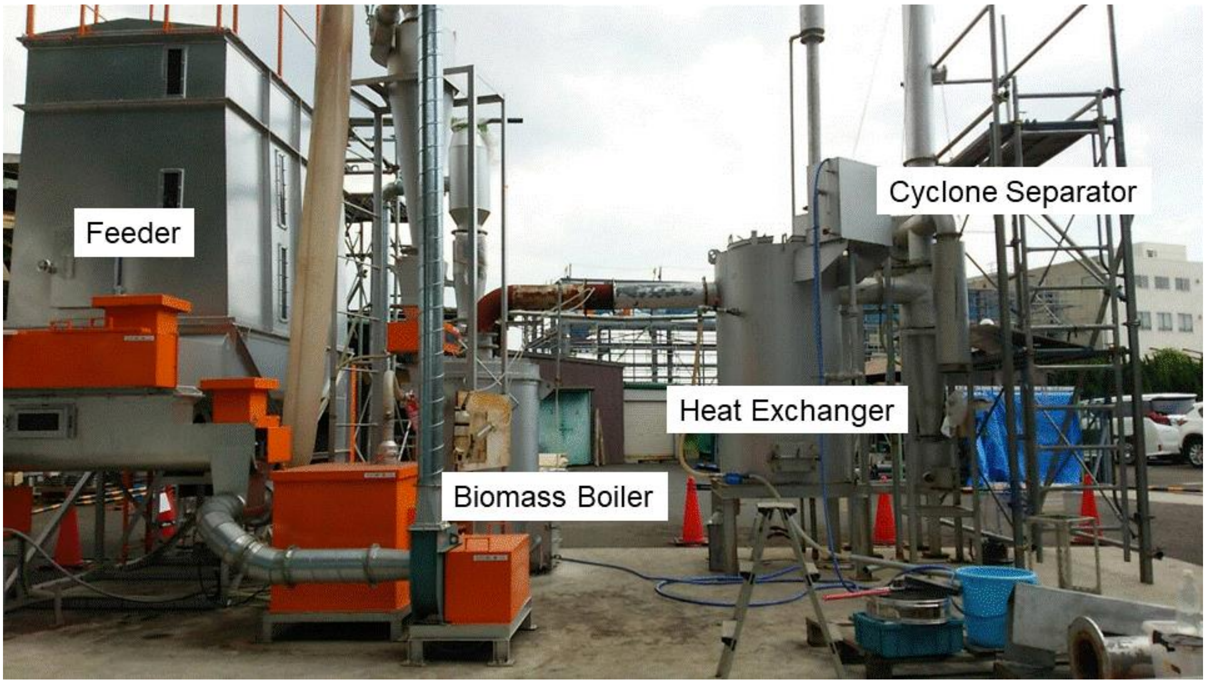

Fig. 2 Experiment device

Here, three combustion steps in the combustor are employed and following its step, the combustion with the use of unused biomass is performed. The corresponding system flow is as follows:

Step 1 (preheating process): the combustor is heated from normal temperature to 530 ^{o}C by burner.

Step 2 (combustion auxiliary process): the combustor is heated from 500 ^{o}C to 900 ^{o}C by burner and combustion of unused biomass.

Step 3 (self-combustion process): the self-combustion by only the unused biomass is steadily achieved with the air of burner until the experiment is over.

Figs 3(a) and (b) illustrate the overview and structure of the combustor developed here, respectively. The fuel mixed with air, i.e., a mixture of unused biomass and air is injected to the upper inlet port of the combustor. The inlet pipe is fixed at the lateral face of the combustor and in the circumferential direction. Thus, the fuel-air mixing flow becomes spiral flow inside the combustor, resulting in amplification of combustion. This structure plays an important role in a fuel drying and an extension of combustion time of fuel. The swirling flow yields a sufficient floating time of the fuels and attenuates the

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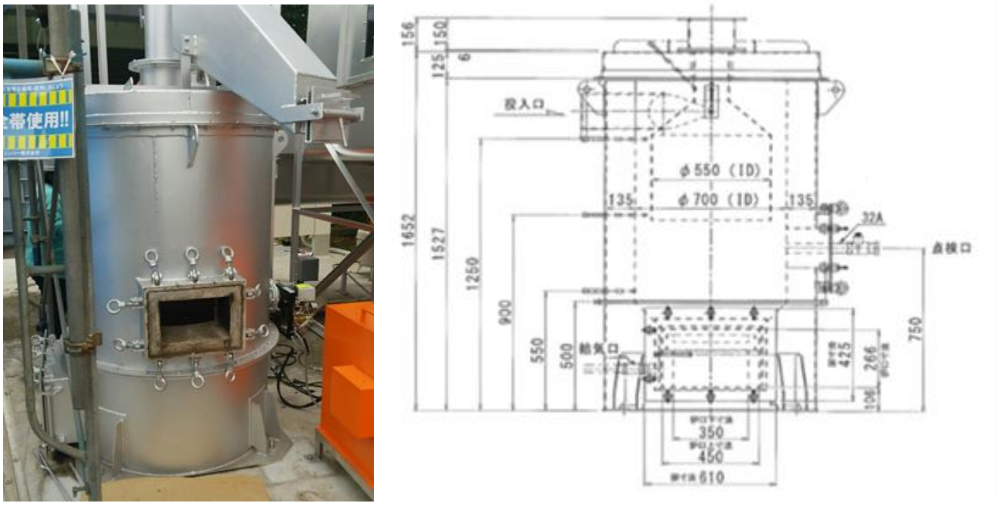
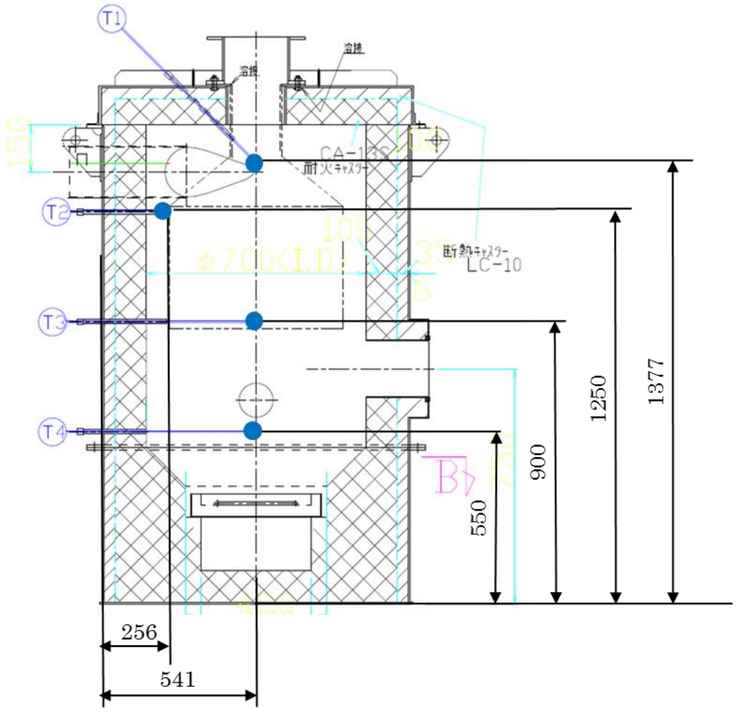
deposition of unburned fuels at the bottom of the combustor. In order to monitor and measure the combustion gas temperature in the combustor, four K-Type thermocouples are inserted in the combustor and the corresponding locations (T1, T2, T3, T4) are depicted in Fig. 3(b). Note that T2 is set in the vicinity of the injection port of the fuel-air mixing flow. The combustion gas temperature at the outlet of the cyclone separator is also measured by the thermocouple (named as T5). At the corresponding location, the gas samples are collected by reservoir bag at time intervals of 30 minutes during the self-combustion process. The combustion gases, i.e., O2, CO2, NO, N2O, NOx and SOx are detected and measured by the gas analyser (Testo Limited, Testo 350). The position of sampling is located at the gas duct between combustor and heat exchanger.



(a) Photograph of the combustor



(b) Location of TC

Fig. 2 Combustor employed in the present study.

In order to make waste material for the use as a fuel, the corresponding moisture content is a key point for combustion condition such as pulverized coal combustion. In this study, the moisture content and its caloric value are measured. The water content meter (A&D, MF50) and calorimeter (SHIMADZU, CA-4AJ) are employed here. As for unused biomass, bamboo is employed as a fuel, as shown in Fig. 4. The corresponding properties are summarized in Table 1.

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Fig. 4 A sample of bamboo

TABLE I PROPERTY OF UNUSED BIOMASS

Fuel	Size	Bulspecific gravity (kg/m^3)	Moisture content (%)	Lower calorific value (kcal/kg)
bamboo	(less than 5mm)	0.275	6.00	4294

III. RESULTS AND DISCUSSION

The timewise variation of the combustion gas temperature is shown in Fig. 5 at different measurement positions, i.e., T1, T2, T3, T4 and T5, as a parameter. It is observed in Fig. 5 that as time progresses, the gas temperature is substantially increased and particularly, the temperature at T4 in the combustor achieves 500 oC about 15 minutes later. Here, the corresponding time interval implies the pre-heating time, but its interval depends on the ambient temperature and climate. After that, the combustion changes the combustion auxiliary process, that is the burner works and at the same time unused bamboo is supplied in the combustor as a fuel. It is observed that the highest temperature is indicated at T3, because the burner position is set near T3 and simultaneously the unused biomass burns in the combustor. After the combustor is sufficiently heated, the burner is discontinued.

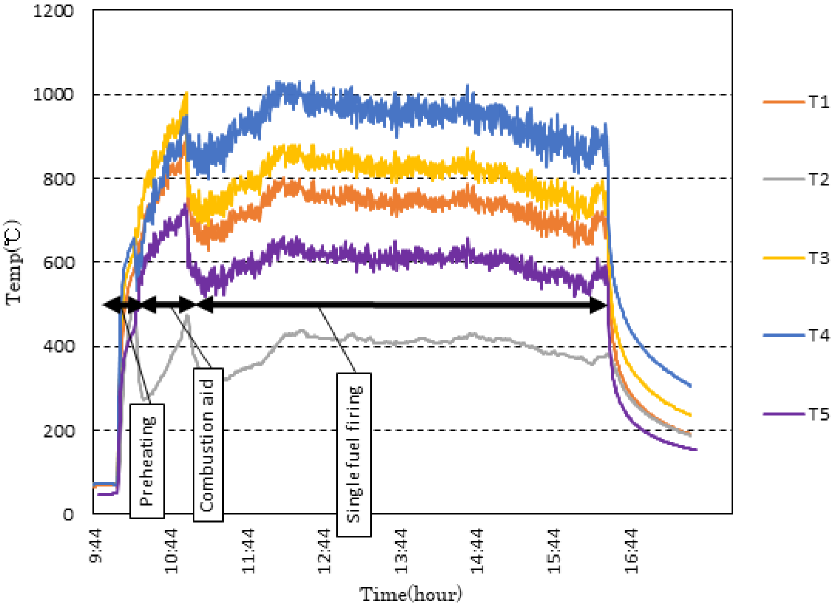

Fig. 5 Temperature distribution of unused bamboo

One observes that the highest temperature yields at T4 in the self-combustion process. In other words, since T4, T3, and T1 are gradually far away from the main combustion zone, i.e., the bottom area, the corresponding temperature attenuates gradually along the vertical direction in the combustor. This is because bamboo collects on the bottom of combustor and the self-combustion process takes place. Therefore, highest combustion gas temperature yields near the bottom area and temperature gradually attenuates in the direction of the combustor exit, resulting in larger temperature difference among T1, T3 and T4. All curves of temperature are relatively stable as a time progresses, and the combustion temperature in the combustor

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is maintained in the range of 800 ºC to 1000 ºC. After combustion in combustor, the ash is collected in the cyclone separator. The microscopic photograph of the collected ash is depicted in Fig. 6. One observes that the size of almost of ash is less than 1mm.

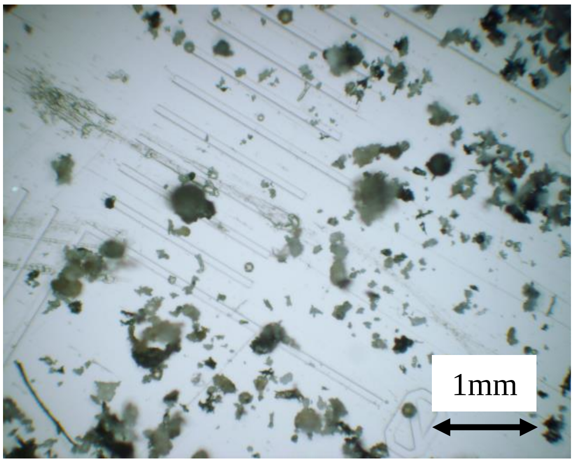

Fig. 6 Ash of unused bamboo

In order to maintain the stable self-combustion process, feed rate of fuel was adjusted from 10.0 kg/h to 50.0 kg/h by controlling the frequency of the current supplied to motor of the feeder, because the moisture content and caloric value depend on the combustion temperature. By try and error, the optimum values to obtain the temperature distribution of Fig. 5 are determined and are summarized in Table 2.

TABLE II OPTIMUM INITIAL CONDITION

Fuel	**Feed rate (kg/h)**	**Input energy (M cal/h)**	**Amount of theoretical air (Nm^3/h)**
Bamboo	31.60	135.7	158

Attempt is made to measure the combustion gases. Table 3 shows the analytical results of the combustion gases and for reference, the discharge standard value relating to air pollution is illustrated in Table 4. Comparing Table 3 with Table 4, it is found that NOx and SOx are lower than the discharge standard value, while CO is higher than the discharge standard value. This is because the concentration of CO is affected by temperature, that is the combustion gas temperature (T1) at the upper part of combustor is less than 800 oC and can not sufficiently make CO react to CO2.

TABLE III OPTIMUM INITIAL CONDITIO

	Average concentration(ppm, 6%O_2)							
	CO	NO	N_2O	NO_X	SO_X	H_2S	O_2	CO_2
Bamboo	4378.5	10.4	33.5	44.0	10.1	16.1	13.5	7.1

TABLE IV OPTIMUM INITIAL CONDITIO

CO(ppm)	100
NO_X(ppm)	350
SO_X(ppm)	150

Next is to study the thermal efficiency,η, of compact combustor developed here. The definition of thermal efficiency is shown as:

$$\eta = \frac{(T_{ave} - T_{air})C_p Q_{ave}}{F \times H_l} \quad (1)$$

Here, Tave is combustion temperature [ºC] at T5, Tair is average atmospheric temperature [ºC], Cp is specific heat

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[kcal/(Nm3ºC)] of combustion gases, Qave is volume flow rate [Nm3/h] at the outlet of combustor, F is mass flow rate [kg/h] of biomass (i.e., bamboo), and Hl is lower heating value [kcal/kg] of biomass. Table 5 summarizes the thermal efficiency and the corresponding values to estimate it. The thermal efficiency is larger than 50%.

TABLE V THERMAL EFFICIENCY FOR BIOMASSES

	T_{ave} [°C]	T_{air} [°C]	C_p [kcal/Nm^3 · °C]	Q_{ave} [Nm^3/h]	F [kg/h]	H_l [kcal/kg]	η [%]
Bamboo	607	35.4	0.3296	438.6	31.60	4294	60.9

IV. CONCLUSIONS

Experimental study has been performed to develop the original compact combustor, which can effectively combust unused bamboo. Consideration is given to the combustion gas temperature and combustion gases produced in inside the combustor. The results obtained here are summaries as:

a). Unused bamboo can take plate self-combustion and be steadily combusted and the combustion temperature is kept in the rage of 800 ºC～1000 ºC.

b). Combustion temperature distribution appears in the combustor along the vertical direction of the bottom area to the combustion gas exit.

c). The concentrations of nitrogen oxide and sulfur oxides are lower than the discharge standard value, but the concentration of carbon monoxide was higher than the discharge standard value.

d). Thermal efficiency of unused bamboo is higher than 50%.

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