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# Design of a Small Boiler for Hothouse by Utilization of Wasted Bamboo

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***Abstract***

In order to make full use of the wasted bamboo planted in Shizuoka prefecture, Japan, this paper aims to design a small type of boiler where wasted bamboo is combusted, and from which the heat energy was taken out to heat the circulated water through a heat exchanger that is mounted inside the boiler. Then the heated water is circulated to a hothouse to keep the temperature inside to some extent. During research, firstly a series of fundamental studies including pyrolysis and SEM observation was conducted and activation energy under different conditions was calculated. Secondly, the concept diagram of the small boiler was proposed. Thirdly, design calculation based on numerical prediction was carried out. As a result, the relations between bamboo consumption with air temperature as well as solar radiation quantity was investigated.

***Keywords****:* wasted bamboo, boiler, bamboo consumption, hothouse and numerical prediction.

## 1. Introduction

Energy problem has triggered the wide used of biomass in the world. Usually wood is used as recyclable fuel to warm water or generate electric power[1]. However, in Shizuoka prefecture the amount of the wasted bamboo had caused problems such as extra land occupation by the bamboo, every year a large quantity of bamboo will be cut and disposed. How to make use of those wasted bamboo is a very challenging task.

As Shizuoka Prefecture is famous of hothouse mellow, in winter tons of heavy oil as fuel is needed to warm the hothouse. Hence, it is important to use the wasted bamboo as fuel for the hothouse instead of using heavy oil.

As shown in Fig.1, this paper aims to design a small type of boiler in which the wasted bamboo is combusted, from which the heat energy is released to heat the water through a heat exchanger that is mounted inside the boiler. The heated water will be supplied to a greenhouse to keep the temperature inside at a proper level.

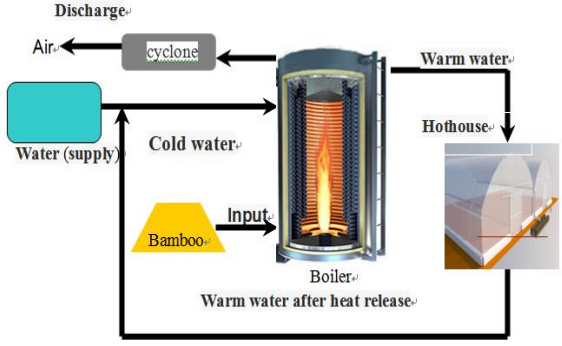


Fig.1 Concept of using wasted bamboo to warm a hothouse

During research, firstly a series of fundamental studies including pyrolysis analysis based on TG-DTA(Thermogravimetry-Differential thermal analysis) and SEM(Scanning Electron Microscope) observation were conducted and activation energy under different conditions was calculated. Secondly, the concept diagram of the small boiler was proposed and the characteristics of bamboo combustion was calculated. Thirdly, by establishing a hothouse model, the energy supply process analysis of warming the hothouse was performed based on numerical prediction. Finally, bamboo consumption quantity influenced by atmospheric air temperature and solar radiation quantity was calculated.

## 2. Fundamental experiments

### 2.1 Bamboo sample

Fig.2 shows the bamboo powder obtained by grinding the bamboo.

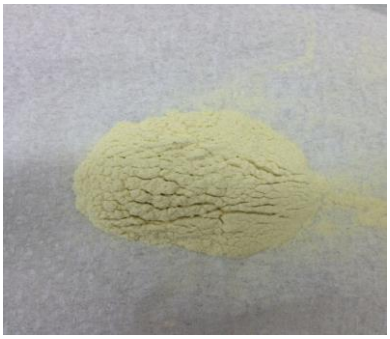

Fig.2 Bamboo powder

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### 2.2 Water-swelling property

Since water swelling property influences the combustion characteristics, experiment in which water added to 3 compressed bamboo power samples was carried out. These 3 compressed bamboo power blocks were obtained by compress the bamboo powder under 3 different pressure conditions by using a specially designed mold shown in Fig.3.

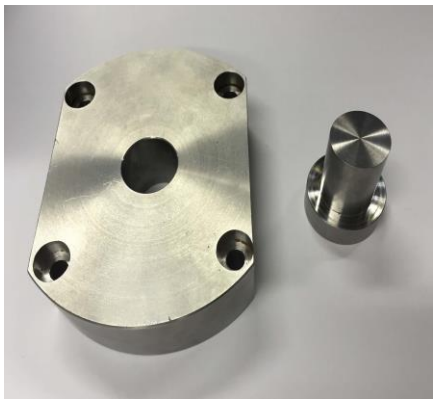


Fig.3 Mold for compressing bamboo powder sample

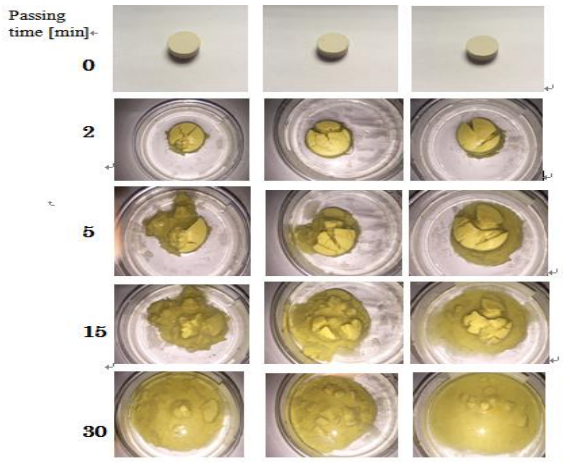
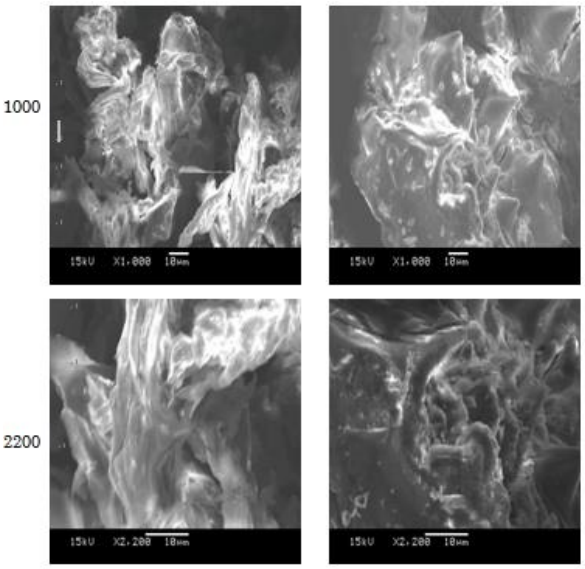



Fig.4 Water swelling properties investigation with 3 different mold pressure

Three blocks of bamboo molded under three pressure conditions were prepared in side three containers and water of the same quantity was added As shown in Fig,2, as time passed, the molded bamboo block collapsed as water contents rose, which indicated that the bamboo block with different density were not influenced by water.

### 2.2 SEM observation

SEM was used to check the texture of the bamboo while the wood sample was observed too for comparison.The SEM observation results were shown in Fig,3. It was found that the size of bamboo is smaller than that of the wood, which means the bamboo has a more stable structure.




Bamboo Wood

Fig.5 SEM observation results

### 2.3 Prolysis experiment and activation energy

Prolysis experiment on bamboo was conducted based on a TG-DTA apparatus(Fig.6) under different temperature–rising ratios and catalysis.

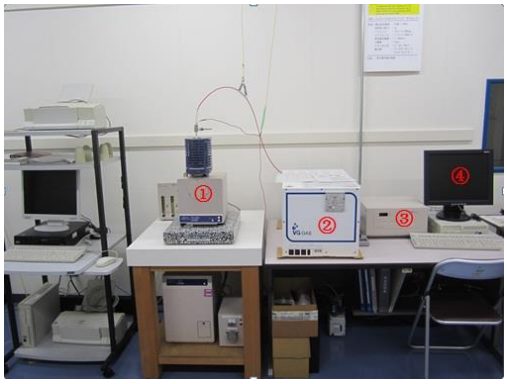



Fig.6 TG-DTA apparatus

Activation energy for each condition was calculated by using Eg3.1-3 as follows

$$a = \frac{W_0 - W}{W_0 - W_\infty} = \frac{\Delta W}{\Delta W_\infty} \quad (1)$$

$$-\ln(1-a) = \frac{K}{\phi} T \quad (2)$$

$$\ln K = -\frac{E}{RT} + \ln A \quad (3)$$

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Here α is mass change ratio, A is frequency factor, K is Arrhenius constant, and E is activation energy and R is gas constant, respectively.

Calculated activation energy for temperature-rising ratio of 20.40, 60 degree centigrade/min in case of without using Nacl or using Nacl as catalyst is shown in Fig.5.

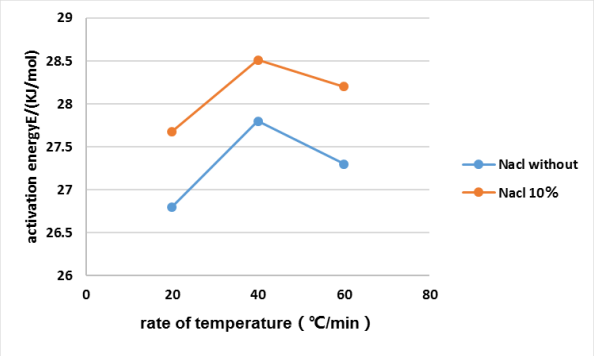


Fig.7 Calculated activation energy

In Fig.7, x-axis stand for temperature-rising ratio and y axis stands for activation energy. When temperature rising ratio is 20 degree centigrade/min, the activation energy is lower, which means pyrolysis is easier to happen. In case of adding NaCL as catalyst, the effect of lowering the activation energy was not confirmed

### 3. Designing calculation

The concept model of the proposed boiler is shown in Fig.8. The lower part is the furnace, the upper part is heat exchanger. During operation process, the bamboo fuel is conveyed into the furnace by a screw conveyer and is burn on the grill with the aid of first air and second air. Combustion gas is introduced into the heater exchanger through the smoke tube. Inside the heat exchanger, the circulating water is heated, and then sent to the greenhouse. The combustion gas is introduced into a cyclone separator and exhausted out after ash is removed.

Since then thermal energy coming from the combustion process is needed to keep the temperature inside the greenhouse unchanged, for example, 25 degree centigrade , the relationship of the bamboo consumption quantity among atmosphere temperature and solar radiation quantity should be investigated.

#### 3.1 Heat released from greenhouse

In regard with the energy balance of the greenhouse, the heat absorbed comes from warm water, solar radiation energy while the heat released is the heat transferred to the environment by natural convection.

In Fig.9, the model of the greenhouse is shown. This model is arc-shaped, some geometric parameters are listed in Table.1.

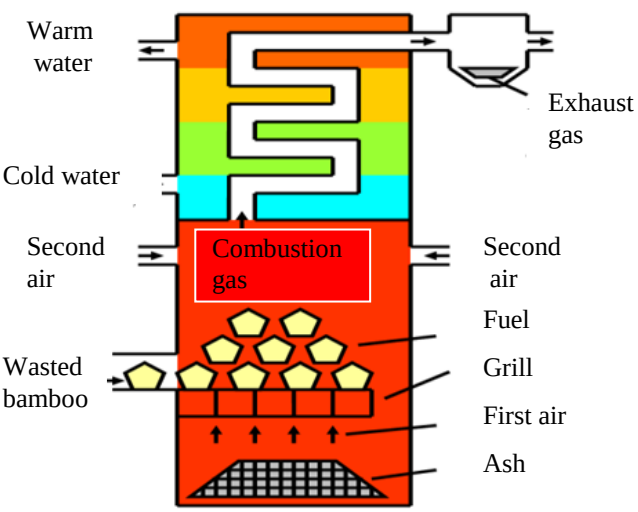


Fig.8 Concept model of the proposed boiler

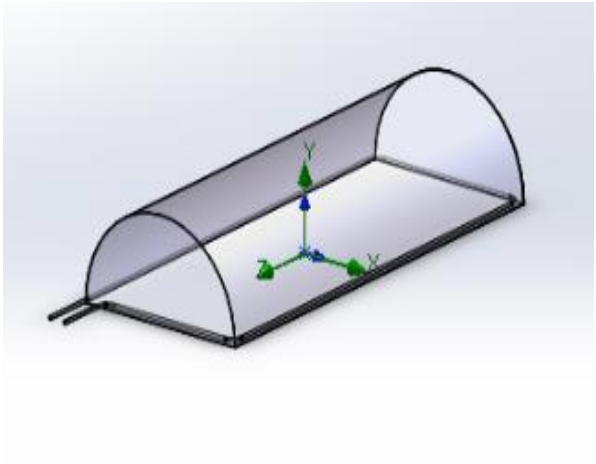

Fig.9 Hothouse model

Table.1

| Length [m] | Wall thickness [m] | Arc shape diameter [m] | Volume [$m^3$ ] |
|---|---|---|---|
| 10 | 0.001 | 4 | 62.8 |

As for calculating heat release from greenhouse, the following equations are employed.

$$Gr_D=D^3g\beta(T_i-T_o)/\nu^2 \quad (4)$$

$$Nu=\alpha D/\lambda=C(Gr_D\cdot Pr)^n \quad (5)$$

$$1/k=1/\alpha+\delta/\lambda \quad (6)$$

$$Q=k(T_i-T_o)A \quad (7)$$

Calculation conditions and results are listed in Table.2

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Table.2

| | | | | |
|---|---|---|---|---|
| atmospheric temperature [°C] | 2 | 7 | 12 | Volume [$m^3$ ] |
| Heat released[W] | 19,326 | 14,557 | 10,039 | 62.8 |

### 3.2 Bamboo Consumption quantity

Assuming the boiler efficiency is 75%, with the aid of Solidworks, the bamboo consumption quantity for keeping the temperature inside the greenhouse at 25 degree centigrade under different conditions such as atmospheric temperature and solar radiation quantity is calculated

The outer diameter of the tube for warm water is 0.06 m and its inner diameter is 0.05 m, Other analysis conditions are listed in Table.3.

Table.3

| Material for greenhouse wall | Material for tube | Flow state | Grid number | Volume [$m^3$ ] |
|---|---|---|---|---|
| PVC | cupper | Turbulent | 200,000 | 62.8 |

Fig,10 shows the relation between atmospheric temperature and bamboo consumption. When inlet water temperature is 60 degree centigrade, and solar radiation is 770W/m2 , Bamboo consumption quantity is 89.1kg 、 75.1kg 、 65.8kg in the condition of atmospheric temperature=2, 7, 12 degree centigrade, respectively. The higher the atmospheric temperature, the smaller the bamboo quantity.

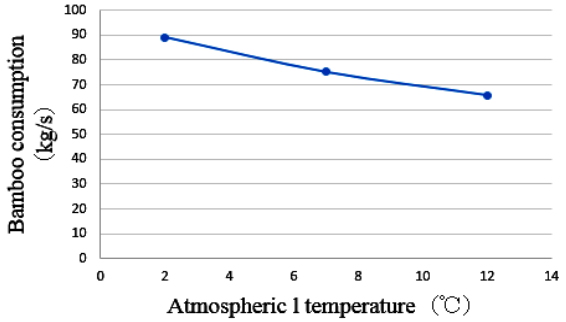


Fig.10. Relation between atmospheric temperature and bamboo consumption

Fig.11 shows Relation between solar radiation and bamboo consumption. From Fig,11, it is found the if the solar radiation quantity increases, the bamboo consumption quantity will increase too.

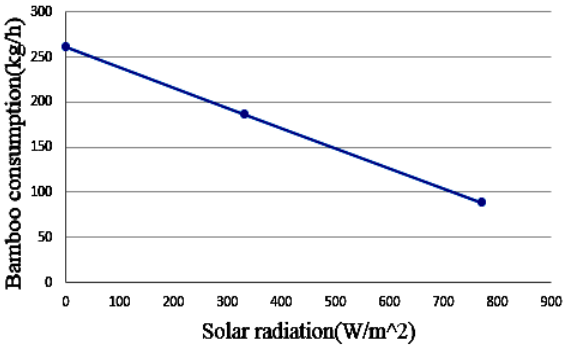


Fig.11 Relation between solar radiation and bamboo consumption

### 4. Conclusion

(1)The lower the temperature-rising ratio, the lower the activation energy, which means the better pyrolysis characteristics;
(2)With the higher atmospheric temperature and solar radiation quantity, the bamboo consumption quantity will become smaller;
(3)When atmospheric temperature is 2 degree centigrade and solar radiation quantity is 0, a boiler whose capacity of the maximum heat energy of 1075kw is necessary.

### 5. References

[1] Y.Li, Y.Toake and Q.Wang, Pyrolysis and combustion process of biomass fuels by TG–DTA/MS analysis, Proceedings of 4th International Symposium on Heat Transfer and Energy Conservation (ISHTEC2012), viewed, TC10-003, CD-ROM