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파이로트 규모 왕겨 燒却爐의 性能에 관한 연구

Performance of a Pilot-scale Rice Husk Incinerator

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摘 要

왕겨 재를 분쇄하여 콘크리트 混和용 재료로 이용하려는 연구의 일환으로서, 파이로트 規模의 多目的 왕겨 燒却爐를 設計, 製作하고 그 性能을 分析하였다. 왕겨 燃燒時의 熱에너지는 回收하여 원예施設의 煖房이나 콘크리트의 高溫 養生水로써 이용하고자 熱交換裝置를 제작하여 왕겨 燒却爐시스템에 장착하였고, 排煙가스내의 이산화탄소가 시설원예 作物의 光合成에 이용될 수 있는지 排煙가스의 造成을 조사하였다. 분쇄된 왕겨 재의 콘크리트 混和材로서의 적합성은, 燃燒 灰分의 성분 중 SiO_2 의 結晶化 상태를 分析함으로써 判斷하였다. 연구결과를 要約하면 다음과 같다.

1. 왕겨 灰分의 SiO_2 結晶化는 燃燒온도 750℃ 이하에서는 거의 발생하지 않는 것으로 분석되었다.
2. 燒却爐의 작동은 매우 만족스러웠으며 最適 작동조건은 왕겨供給率 15kg/h, 制御온도 600℃로 分析되었다. 最適 작동조건에서, 왕겨燃燒率은 97%, 熱交換機 效率은 59.5%, 전체 시스템의 熱效率은 57.7% 로서 양호하였으며, 灰分의 SiO_2 結晶化도 거의 발생하지 않아 生成된 왕겨 灰分은 훌륭한 콘크리트 混和材로 판단되었다.
3. 燒却爐내 溫度分布는 대체로 均一하였으며, 排煙가스내의 大氣오염물질 중, 질소酸化物과 황酸化物 함량은 許容기준치보다 매우 낮았으나 일산화탄소 함량은 許容기준값 부근으로 나타나 排煙가스를 직접 원예시설 내에 공급하기 위해서는 약간의 연소실 구조 개선이 필요하다고 판단되었다.

주요용어 (Key Words): 왕겨(Rice Husk), 왕겨 소각로(Rice Husk Incinerator), 실리카 결정화(SiO_2 Crystallization), 콘크리트용 혼화재(Supplementary Cementing Materials), 연소 가스(Flue Gas)

1. Introduction

The production of rice, one of the major food crops in the world, also produces significant amount of waste materials-namely, rice husk and straw. World-wide rice husk production is estimated approximately 100 million tonnes per annum and in Korea about 0.8 milion tonnes was produced in 1995.

Disposal of rice husk is a particularly serious problem because of its bulky nature and high resistance to

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degradation. Efforts over the past years to utilize rice husk have resulted in minor success, mostly as low-value applications in the agricultural sector, because of its unfavorable characteristics such as abrasiveness, poor nutritive value, low bulk density, and high ash content (Beagle, 1978; Haxo and Mehta, 1974). Some of the major uses for rice husk now in practice are litter and bedding material for animals and poultry, roughage in animal feeds, pesticide carrier, filter media, and pressing aids.

One of the interesting uses of rice husk comes from material science. Manufacturing portland cement is a highly energy-intensive process. Considerable efforts are being made to find substitutes, so called supplementary cementing materials, in order to replace part of the cement in concrete (Malhotra, 1993). Low calcium fly ash and blast-furnace slag have been on the market for a long time, whereas high calcium fly ash, condensed silica fume, and rice husk ash are relatively new. As ash produced by uncontrolled combustion is crystalline and has low pozzolanic value, controlled incineration at about 500～750℃ is favored to make the ash highly pozzolanic and better supplementary cementing material. The objectives of this study are therefore:

1. To construct a pilot-scale rice husk incinerator system for the production of amorphous ash as supplementary cementing materials.
2. To analyze the performance of a pilot-scale rice husk incinerator system.
3. To find possible application areas of the by-products generated from the incineration of rice husk.

2. Materials and Methods

Rice husks of Dongjin and Kyewha variety were obtained after 1995 harvest season and used in this study. Table 1 shows their moisture and ash content, heating value, and bulk density. Ash content was determined after combustion at 600℃ for two hours in a muffle furnace. Degree of SiO_2 crystallization in the ash was examined by using X-ray diffraction (X-ray diffractometer, Rigaku, Japan) technique. The high level heating value and moisture content was measured by a bomb calorimeter and air-oven method, respectively.

Table 1 Properties of rice husk used for experiment

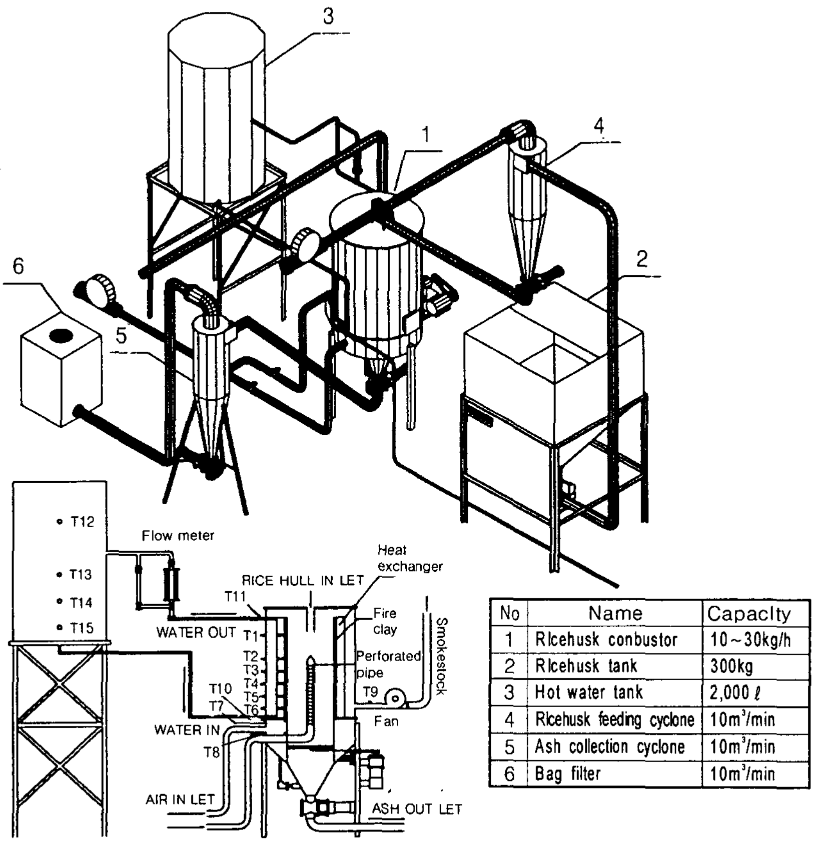
Property / Variety	Moisture content (%) (wet basis)	Ash content (%) (wet basis)	High level heating value (kJ/kg)	Bulk density (kg/m^3)
Dongjin	12.08	13.15	15,330	Husk : 105 Ash : 67
Keywha	10.16	13.50	14,360	

A) Construction of incinerator system

Configuration and specification of the pilot-scale rice husk incinerator system developed in this study is shown in Fig. 1 and Table 2, respectively. The incinerator is a 10:1 scale-up version of previous one (Park, 1988) with some modifications. Husk transportation to and ash discharge from the furnace is done pneumatically by cyclones and centrifugal fans. After being collected in the cyclone, husk is fed uniformly into the incinerator by a screw feeder. Ash is removed from the combustion chamber by gravity through a grate made of cast-iron. A link mechanism is provided between grate and brake motor in order to open or close the grate intermittently. On-off control of the motor is done automatically based on the temperature inside the combustion chamber.

Table 2 Specification of a pilot-scale incinerator system

Incinerator	Dimension (unit: mm)
Overall dimension	Φ1100 × 2100
Combustion chamber	Φ600 × 1500
Husk feeding screw feeder	Φ100, Pitch 70
Cyclones	Φ480 (Standard type)
Ignition burner	100,000 kcal/h
Hot water boiler	
Connecting pipe	Φ22
Water tank	2,000 liter
Heat exchanger (cylindrical annulus type)	$D_i = \Phi 640$, $D_o = \Phi 840$, H = 1500



No	Name	Capacity
1	Ricehusk conbustor	10~30kg/h
2	Ricehusk tank	300kg
3	Hot water tank	2,000 ℓ
4	Ricehusk feeding cyclone	10m³/min
5	Ash collection cyclone	10m³/min
6	Bag filter	10m³/min

Fig. 1 The view of pilot-scale incinerator and locations of temperature measurements.

An ignition burner (1×10^5 kcal/h) similar to those used in commercial hot-air grain dryers is located under the grate. Primary and secondary air is supplied to the combustion chamber by a centrifugal fan. Air supply was adjusted to maintain the excess air in the range of 100~200% and the ratio between primary and secondary air was 1.0. Thermal energy from combustion is recovered by water circulating through a loop consisting of 2000 *l* water tank, pump, and a cylindrical annulus heat exchanger which surrounds the exterior of combustion chamber.

B) Performance test

A split-plot design was employed to study the performance of the rice husk incinerator. Husk feed rate and combustion chamber temperature was assigned to the main and sub plot, respectively, with two replications. Three levels of feed rates (10, 15, and 20 kg/h) were chosen based on preliminary findings where the operating range of feed rate was between 8.5 and 25 kg/h. Temperature levels employed were 500, 600, and 700℃. These are target values for the temperature at the location near the top of the combustion chamber shown as T1 in Fig. 1. Control of this temperature is achieved by adjusting the location of burning surface in the chamber through ash removal where the grate opening/closing is manipulated by a motor.

After the incinerator is given enough time to reach a steady-state, various measurements were made. Ash discharged was collected for two hours and sampled for energy conversion efficiency and crystallization analysis. Temperatures at 15 locations throughout the system (Fig. 1) were measured by K-type thermocouples for two hours at 15 min. interval. At the same time, flow rate of circulating water was measured by a rotameter. A portable gas analyzer (Enerac 2000E) was used to measure CO, CO_2, SO_x, and NO_x concentration of the flue gas. Volumetric flow rate of the air supply to the combustion chamber was determined from cross-sectional area of pipe and average velocity measured by a hot-wire anemometer.

After inorganic and organic matter content of the discharged ash was determined by combustion at 600℃ for two hours in a muffle furnace, energy conversion efficiency of the rice husk was calculated from the following equations.

Conversion efficiency of discharged ash,

$$E_{cd} = \frac{\dfrac{W_{cd}}{C_a} - W_{sd}}{\dfrac{W_{cd}}{C_a} - W_{cd}}$$

Conversion efficiency of elutriated ash,

$$E_{ce} = \frac{\dfrac{W_{ce}}{C_a} - W_{se}}{\dfrac{W_{ce}}{C_a} - W_{ce}}$$

Conversion efficiency of rice husk,

$$E_{ct} = f_d \cdot E_{cd} + f_e \cdot E_{ce}$$

where, W_{sd}, W_{se} : initial weight of discharged and elutriated ash sample, respectively, W_{cd}, W_{ce} : final weight of discharged and elutriated ash sample, respectively, C_a : ash content of rice husk (dry basis, decimal), f_d, f_e : weight fraction of discharged and elutriated ash ($f_d + f_e = 1.0$). Heat exchanger efficiency was defined (Park, 1988) as the ratio of thermal energy transferred to the circulating water to thermal energy generated by rice husk combustion in the incinerator. The overall thermal efficiency of the incinerator system is defined and calculated as follow.

$$E_s = E_{ct} \times E_e$$

where, E_s : overall thermal efficiency of the system, E_{ct} : thermal conversion efficiency of rice husk, E_e : heat exchanger efficiency.

3. Results and Discussion

A) Physicochemical properties of sample rice husk

Fig. 2. shows X-ray diffraction patterns of the rice husk ash obtained from combustion in a muffle furnace at various temperatures. Crystallization of SiO_2 in the ash becomes noticeable when the combustion temperature exceeds 900℃. The ash becomes darker as combustion temperature increases as reported by Anuradha (1992). This could be due to a structural change such as the conversion of white SiO_2 component into black SiO or combining carbon with the silica at elevated combustion temperatures.

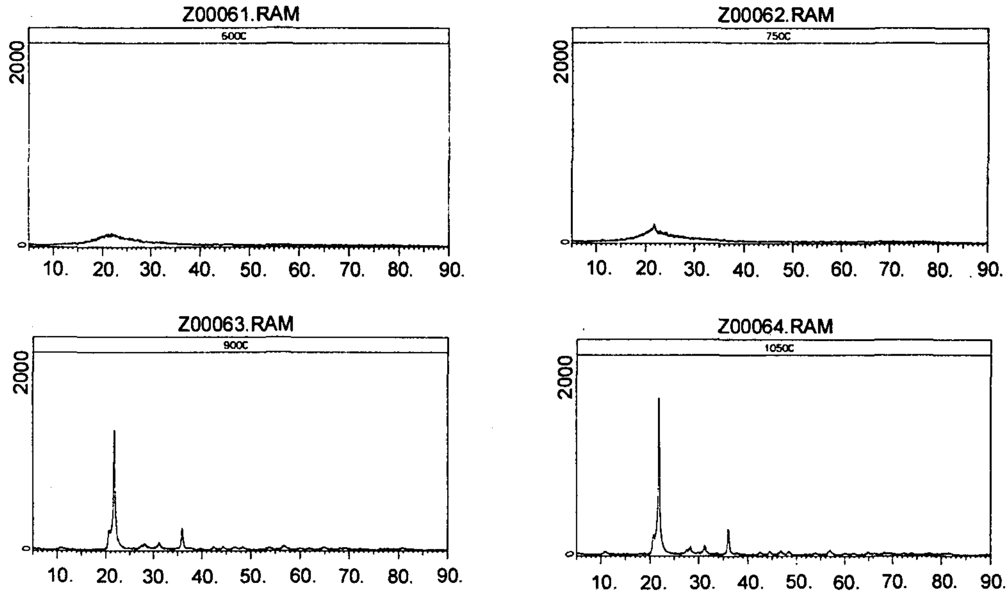


Fig. 2 X-ray diffraction patterns of rice husk ash at different combustion temperatures of muffle furnace (variety: Dongjin).

B) Combustion characteristics of the incinerator system

(1) *Temperature distribution in the combustion chamber*

For the present study, attempts have been made to maintain temperatures in the combustion chamber as low as possible since it is well known the amount of NO_x in the flue gas increases sharply above 1,000℃ and SiO_2 in the ash becomes crystallized at temperatures above 900℃. NO_x level in the atmos-

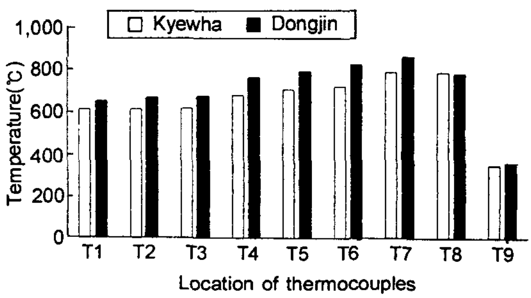


Fig. 3 Temperature distribution in the combustion chamber with variety (Husk feedrate: 15 kg/h, Control temp.: 600℃).

phere is one of the parameters monitored and strictly regulated by the environmental protection agencies on regular basis. Crystallized ash is not only difficult to grind but also poor supplementary cementing materials.

A typical temperature distribution in the combustion chamber is shown in Fig. 3. indicating all temperatures are uniformly maintained below 900℃ except at the flue gas outlet. Husk of Dongjin variety gave slightly higher temperatures because of its higher heating value. Location T7, which is 30cm above the bottom of the combustion chamber, matches the burning surface and was the hottest point. From there, the temperatures decrease as climbing up the chamber. Fig. 4. shows the change of chamber temperatures with time. The incinerator reached steady-state in five to six hours after the ignition. Large temperature variations in T7~T8 and T5~T6 could be explained by their location which is very next to the burning surface thus exposed directly to the flame.

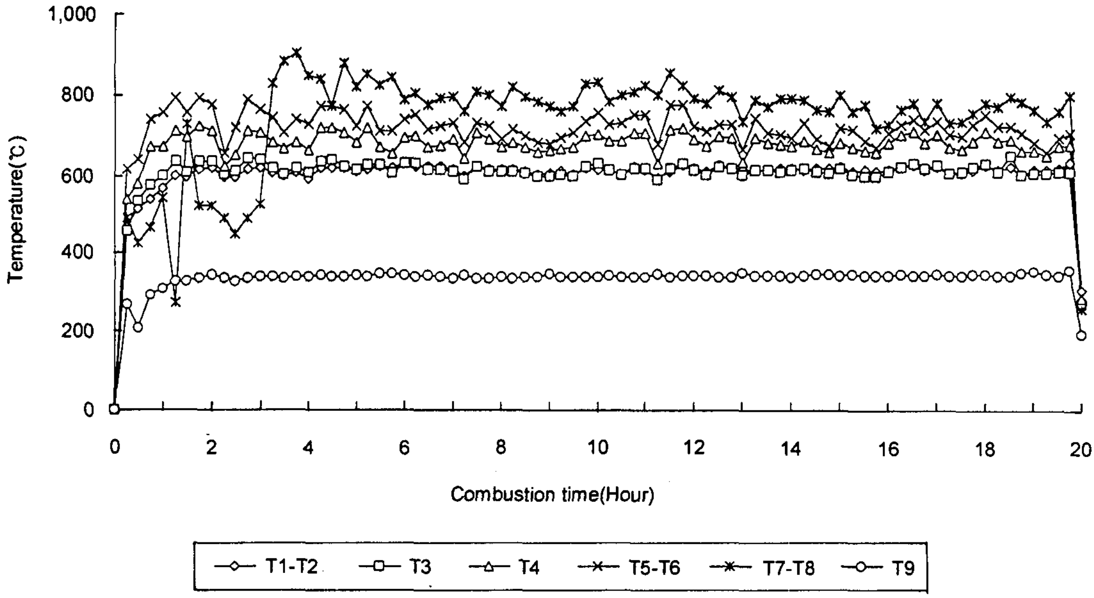


Fig. 4 Temperature changes in the combustion chamber with time (Variety: Dongjin, Husk feedrate: 15 kg/h, Control temp.: 600℃).

(2) *Thermal efficiency of the system*

Analysis on the thermal efficiencies of the system was summarized in Table 3. Under high feed rate combined with low combustion temperature condition (20 kg/h, 500℃), rice husk showed the lowest thermal conversion efficiency of 87% and the heat exchanger efficiency was also the worst. This is so because the grate should be frequently opened to maintain the chamber temperature low and then the rice husk was forced to discharge although the combustion was not completed yet. On the other hand, when small feed rate (10 kg/h) was combined with higher combustion temperature settings of 600℃ and 700℃, it was hard to achieve continuous combustion because of improper air supply up to the burning surface positioned now higher than normal. Except those particular conditions, combustion was satisfactory. The thermal conversion efficiency of rice husk, overall thermal efficiency, and the heat exchanger efficiency was in the range of 93~99%, 47~58%, and 50~60%, respectively. The flowrate of water circulating through the heat exchanger was adjusted to about 2m^3/h for all test conditions and the average temperature difference of water △T between inlet and outlet of the heat exchanger measured about 10℃, 15℃, and 20℃ for the rice husk feedrate of 10 kg/h, 15 kg/h, and 20 kg/h, respectively.

Table 3 Analysis of experimental results at each treatment

Treatments		Conversion efficiency (%)	Heat exchanger efficiency (%)	System efficiency (%)	Remarks
Rice husk feedrate (kg/h)	Control Temperature (℃)				
10	500	96	53	50.9	· Variety: Dongjin · Excess air: 100% · Circulating water flowrate: about 2 m^3/h · Percent of elutriated ash: 0.5% · Conversion efficiency of elutriated ash: 95%
	600	98	—	—	
	700	97	—	—	
15	500	93	50.5	46.9	
	600	97	59.5	57.7	
	700	99	50.3	49.6	
20	500	87	43.8	38.0	
	600	94	54.3	51.2	
	700	94	53.2	49.9	

Only 0.5% of the total ash from the incinerator was elutriated with the flue gas and its conversion efficiency was 95%. For the range of 100~200%, the amount of excess air had a slight effect on the combustion temperature variation only.

(3) *Flue gas analysis*

Table 4 shows pollutants concentration in the flue gas for two combustion conditions. The legal limit of pollutants concentration is also included for the purpose of comparison. The measurements were made at least five times after 48 hours of continuous operation. Keeping the combustion chamber temperature low to prevent SiO_2 crystallization resulted in a higher CO concentration in the flue gas which was sometimes over the legal limit. It seems that under this condition combustible gas given off from the husk was unable to finish up the combustion. Davidson (1989) also reported similar finding in a fluidized combustion study. Since this problem could be easily fixed by minor changes in chamber design and other pollutants were well below the legal limit, the flue gas from the incinerator has a potential to be used as a CO_2 supplier to the greenhouses. As far as NO_x and SO_x in the flue gas concerned, there are some research results indicating their harmful effect on plant growth. But a test with algae showed that direct supply of the rice husk incinerator flue gas had no appreciable effect on their normal growth (Chun et al., 1996). The sensitivity of plants to NO_x and SO_x might depend on the plant type as well as the concentration of these gases.

(4) *Crystallization of discharged ash*

Rice husk ash discharged from the incinerator has little degree of crystallization as indicted by X-ray diffraction analysis results (Fig. 5). This is similar to the X-ray diffraction patterns reported by Nazma (1988) at combustion temperature of 600℃. Most of SiO_2 being amorphous, the rice husk ash seems to have potential as a supplementary cementing material.

Table 4 Pollutants concentration in the flue gas of pilot-scale incinerator

Treatment \ Pollutants	CO (PPM)	CO_2 (%)	NO (PPM)	NO_2 (PPM)	SO_2 (PPM)
Control temp. : 600℃ Husk feedrate : 15 kg/h	500 ~ 650	5.7 ~ 8.7	40 ~ 47	50 ~ 70	40 ~ 52
Control temp. : 700℃ Husk feedrate : 20 kg/h	429 ~ 570	5.9 ~ 8.9	60 ~ 85	30 ~ 60	10 ~ 50
Government Standard (for incinerator, boiler)	600			200	300

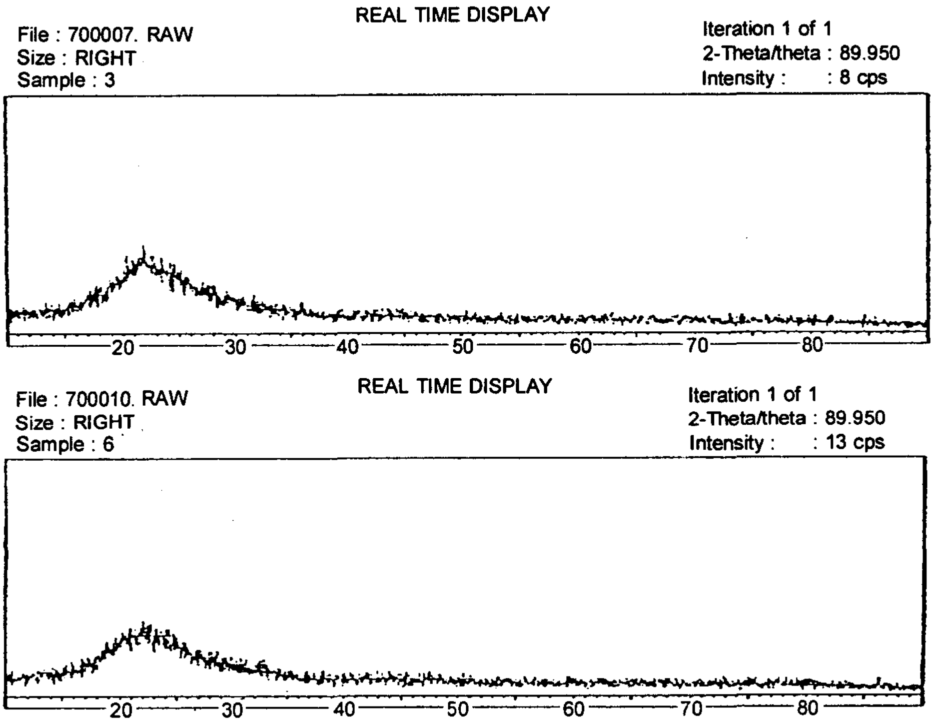


Fig. 5 X-ray diffraction patterns of rice husk ash for.
① rice husk feedrate of 20 kg/h; control temp. of 700℃ (above)
② rice husk feedrate of 15 kg/h; control temp. of 600℃ (below).

4. Conclusions

This study was conducted to find possible application areas of the by-products generated from a pilot-scale rice husk incinerator. Major findings are summarized as follows:

1. When combustion of rice husk was made above 900℃ in the muffle furnace, SiO_2 in the resulting ash was mainly crystalline.

2. The rice husk incinerator system developed in this study performed satisfactorily in terms of thermal efficiencies. At the optimum operating condition, ther-

mal conversion efficiency and heat exchanger efficiency was 97% and 60%, respectively, while overall thermal efficiency of the system was 58%. Under all conditions tested, temperatures in the combustion chamber was quite uniform and crystallization of SiO_2 in the ash was negligible.

3. NO_x and SO_x content in the flue gas was well below the legal limit but the CO concentration was around the legal limit.

4. Thermal energy from combustion was successfully recovered by a heat exchanger to provide hot water; ash was found a good supplementary cementing material; and the flue gas also had a potential as an acceptable CO_2 supplier to greenhouses if minor change in combustion chamber design would be made.

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