Performance of a Pilot-scale Rice Husk Incinerator

Seung J. Park — Associate Professor
Myoung H. Kim — Full-time Lecturer

Department of Agricultural Machinery Engineering
Chonbuk National University
Chonju, Chonbuk 560-756, Republic of Korea

ABSTRACT

This study was conducted to find possible application areas of the by-products generated from the incineration of rice husk. To this end, a pilot-scale rice husk incinerator system was constructed and its performance test was carried. Major findings are summarized as follows.

1. The rice husk incinerator system developed in this study performed satisfactorily in terms of thermal efficiencies. At the optimum operating condition, thermal 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 were quite uniform and crystallization of SiO_2 in the ash was negligible.
2. 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.
3. 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 was an accceptable CO_2 supplier to greenhouses.

Key Words : Rice husk, Combustion, Incinerator, Flue gas, Heat exchanger, Rice husk ash, SiO_2 crystallization

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. Worldwide rice husk production is estimated aproximately 100 million tonnes per annum and in Korea about 0.8 million tonnes was produced in 1995.

Disposal of rice husk is a particularly serious problem because of its bulky nature and high resistance to 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 poutry, 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 combution is crystalline and has low pozzolanic value, controlled incineration at about 500-750°C 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 find possible application areas of the by-products generated from the incineration of rice husk.

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°C for two hours in a muffle furnace. Degree of SiO_2 crystallization in the ash was examined by using X-ray diffraction technique. High level heating value and moisture content was measured by a bomb colorimeter and air-oven method, respectively.

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 conveyor. Ash is removed from the combustion chamber by gavity through a grate made of cast-iron. A link mechanism is provided between grate and 1-hp 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.

An ignition burner (1×10^5 kcal/hr) similar to those used in commercial hot-air grain dryers is located in the lower section of the combustion chamber. Primary and secondary air is supplied to the combustion chamber by a single 1-hp 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 (control temp.) was assigned to the main and sub plot, respectively, with two replications.. Three levels of feed rates (10, 15, and 20 kg/hr) were chosen based on preliminary findings where the operating range of feed rate was between 8.5 and 25 kg/hr. Temperature levels employed were 500, 600, and 700°C. These are control values for the temperature at the location near the top of the combustion chamber shown as T_1 in Fig. 1. This temperature was used to adjust the location of burning surface in the chamber through ash removal where the grate openning/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 effeciency and crystallization analysis. Tempeatures 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 ash and organic matter content of the discharged ash was determined by combustion at 600°C for two hours in a muffle furnace, energy conversion efficiency of the rice husk was calculated from the following equations.

$$\text{Conversion efficiency of discharged ash,}\quad E_{cd} = \frac{\dfrac{W_{cd}}{C_a} - W_{sd}}{\dfrac{W_{cd}}{C_a} - W_{cd}}$$

$$\text{Conversion efficiency of elutriated ash,}\quad E_{ce} = \frac{\dfrac{W_{ce}}{C_a} - W_{se}}{\dfrac{W_{ce}}{C_a} - W_{ce}}$$

$$\text{Conversion efficiency of rice husk,}\quad E_{ct} = f_d \cdot E_{cd} + f_e \cdot E_{ce}$$

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.

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°C. The ash becomes darker as combustion temperature increases as reported by Anuradha (1992). This could be due to the conversion of white SiO_2 component into black SiO at elevated combustion temperatures.

B. Combustion characteristics of the incinerator system

i) 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 the amount of NO_x in the flue gas increases sharply above 1000°C and SiO_2 in the ash becomes crystallized at temperaturs above 900°C. NO_x level in the atmosphere is one of the parameters monitored by the environmental 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°C except at the flue gas outlet. Husk of Dongjin variety gave higher temperatures because of its higher heating value. Location T_7, which is 30 cm 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 in chamber temperatures with time. The incinerator reached steady-state five to six hours after the ignition. Large temperature variations in T_7-T_8 and T_5-T_6 could be explained by their location which is very next to the burning surface thus exposed directly to the flame.

ii) 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/hr, 500°C), 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/hr) was combined with higher combustion temperature settings of 600 and 700°C, 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.

Only 0.5% of the total ash from the incinerator was elutriated with the flue gas and its conversion efficiency was 95%. Amount of excess air had a slight effect on the combustion temperature variation only.

iii) Flue gas analysis

Table 4 shows pollutants concentration in the flue gas for two combustion conditions. 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 could be used as a CO_2 supplier to the greenhouses.

iv) Crystallization of discharged ash

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

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 rice husk was combusted below 750°C, SiO_2 in the resulting ash was mainly amorphous.
2. The rice husk incinerator system developed in this study performed satisfactorily in terms of thermal efficiencies. At the optimum operating condition, thermal 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 was an accceptable CO_2 supplier to greenhouses.

REFERENCES

1. Anuradha Ganesh, Prem Dutt Grovert and P.V. Ramachandra Lyer. 1992. Combustion and gasfication characteristics of rice husk. Fuel. v.71:889-894
2. Beagle, E.C. 1978. FAO Agricultural service bulletin.
3. Davidson, J.F. 1989. Fludised combustion: a review of papers on fundamentals and new ideas. J. of the Institute of Energy __: pp.178-186
4. Haxo, Jr, H.E. and P.K. Mehta. 1974. Ground Rice-Hull Ash as a Filler for Rubber. Rubber chemistry and technology. v.48:271-288
5. Malhotra, V.M. 1993. Fly Ash, Slag, Silica Fume, and Rice-Husk Ash in Concrete: A Riview. Concrete International. pp.23-28
6. Nazma Ikram and M. Akhter. 1988. X-ray diffraction analysis of silicon prepared from rice husk ash. Journal of Materials Science. v.23:2379-2381
7. Park, S.J. 1988. Development of a Hot Water Boiler System with a Rice Hull Furnace. Ph.D. Dissertation. Seoul National University. Suwon, Korea

Table 1. Properties of rice husk used for experiment

Property / Variety	Moisture content(%) (wet basis)	Ash content(%) (wet basis)	High level heating value (kcal/kg)	Bulk density (kg/m^3)
Dongjin	12.08	13.15	3660.5	Husk : 105
Keywha	10.16	13.50	3429.4	Ash : 67

Table 2. Specifications of pilot-scale incinerator system

Incinerator	**Dimension** unit: mm
Exterior	1100 Φ × 2100
Combustion chamber	600 Φ × 1500
Rice husk feeding screw conveyor	100 Φ, Pitch 70
Cyclones	480 Φ (Standard type)
Ignition burner	100,000 kcal/h
Hot water boiler	
Connecting pipe	22 Φ
Water tank	2000 liter
Heat exchanger (cylindrical annulus type)	D_i = 640 Φ, D_o = 840 Φ, H = 1500

Table 3. Analysis of experimental results at each treatment

Treatments: Rice husk feedrate (kg/h)	Treatments: Control Temperature (℃)	Conversion efficiency(%)	Heat exchanger efficiency(%)	System efficiency(%)	Remarks
10	500	96	53	50.9	· Variety : Dongjin · Excess air : 100%. · 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	

Table 4. Air 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
Standard (Incinerator, Boiler)	600			200	300

No	Name	Capacity
1	Ricehusk combustor	10-30kg/h
2	Ricehusk tank	300kg
3	Hot water tank	2000ℓ
4	Ricehusk feeding cyclone	10m³/min
5	Ash collection cyclone	10m³/min
6	Bag filter	10m³/min

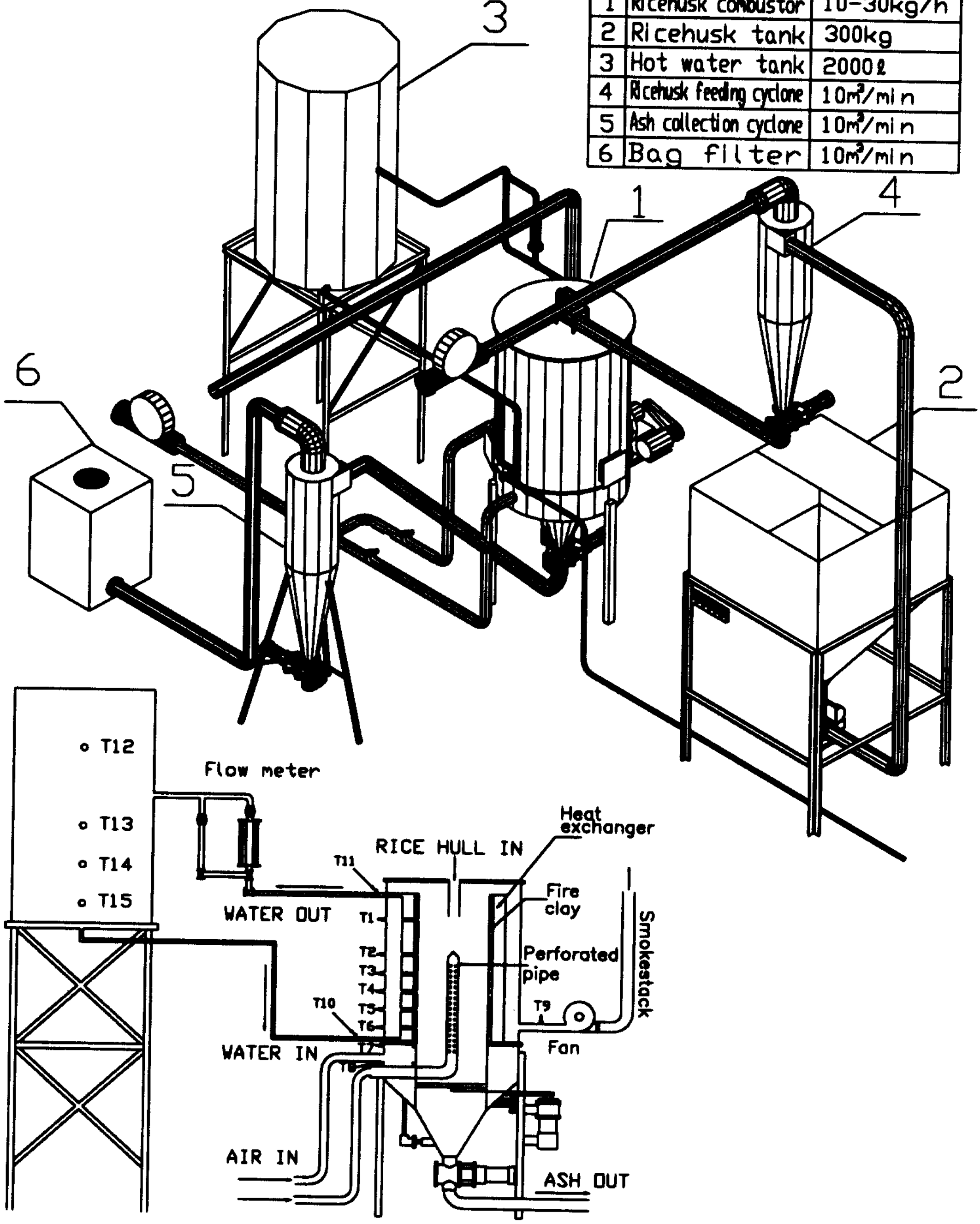

Fig. 1 The view of pilot-scale incinerator and locations of temperature measurements

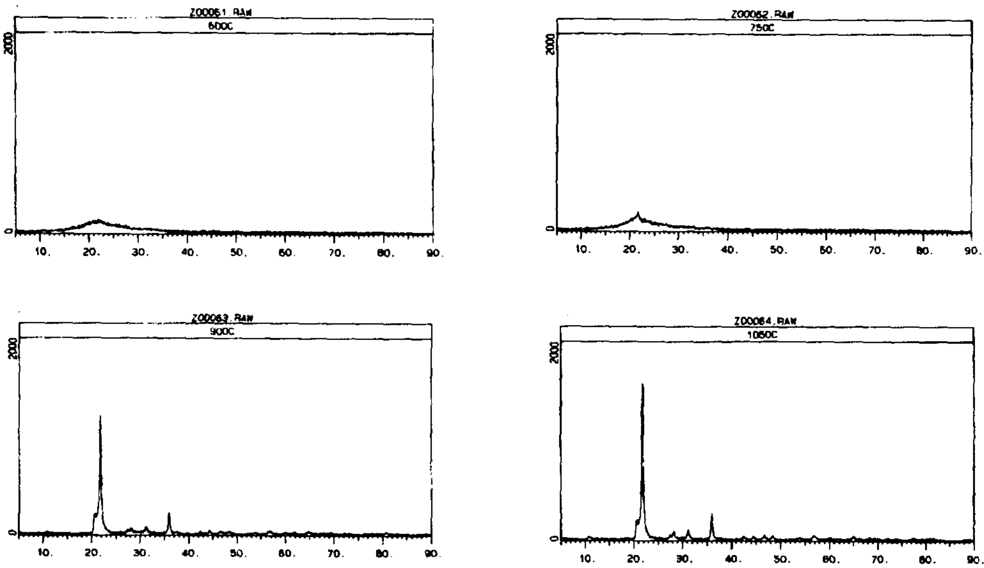

Fig. 2. X-ray diffraction patterns of rice husk ash at different combustion temperature of muffle furnace. (variety: Dongjin)

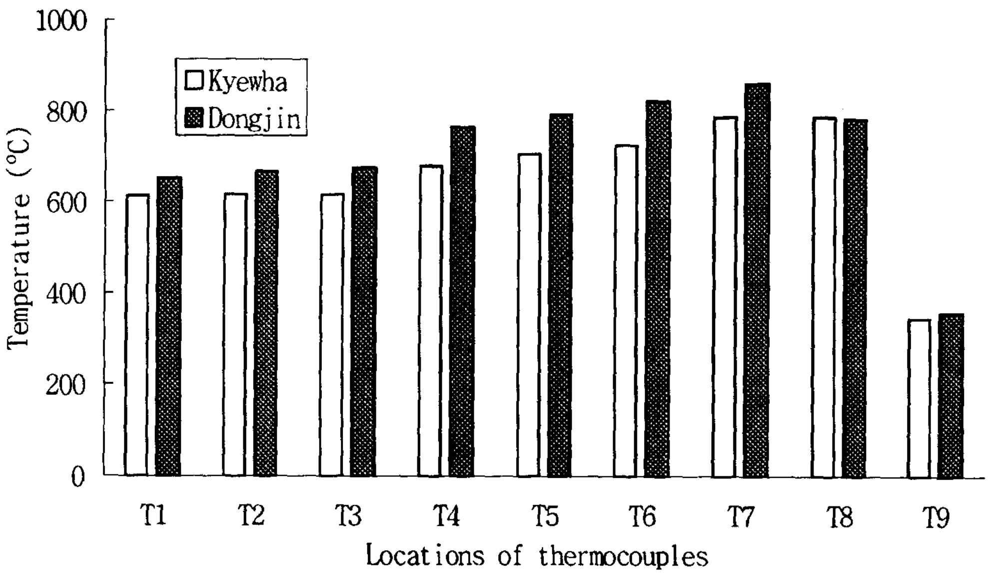

Fig. 3. Comparison of mean temperature distribution in the combustion chamber with variety (Husk feedrate : 13kg/h, Control temp.:620℃)

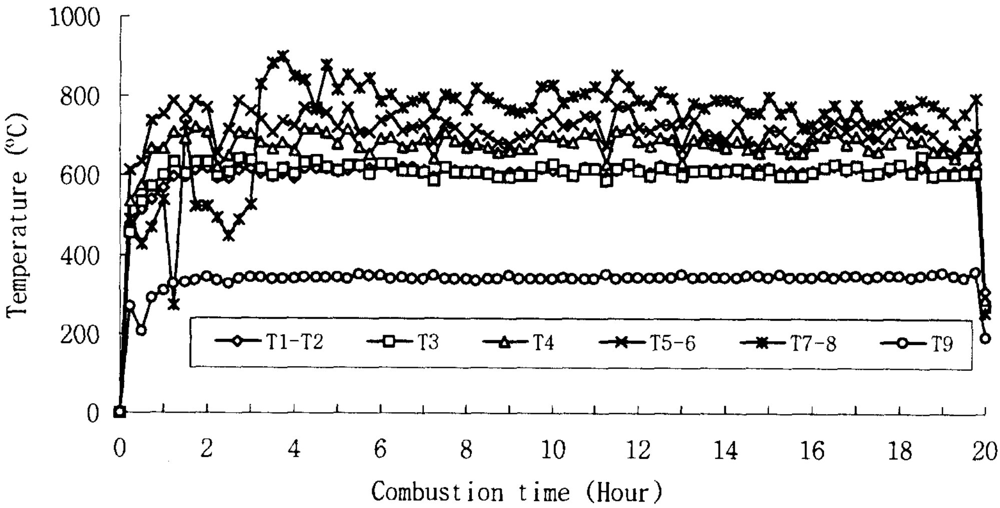

Fig. 4. Temperature changes in the combustion chamber with time from beginning of the incinerator operation
(Variety:Donjin, Husk feedrate: 13kg/h, Control temp.:620℃)

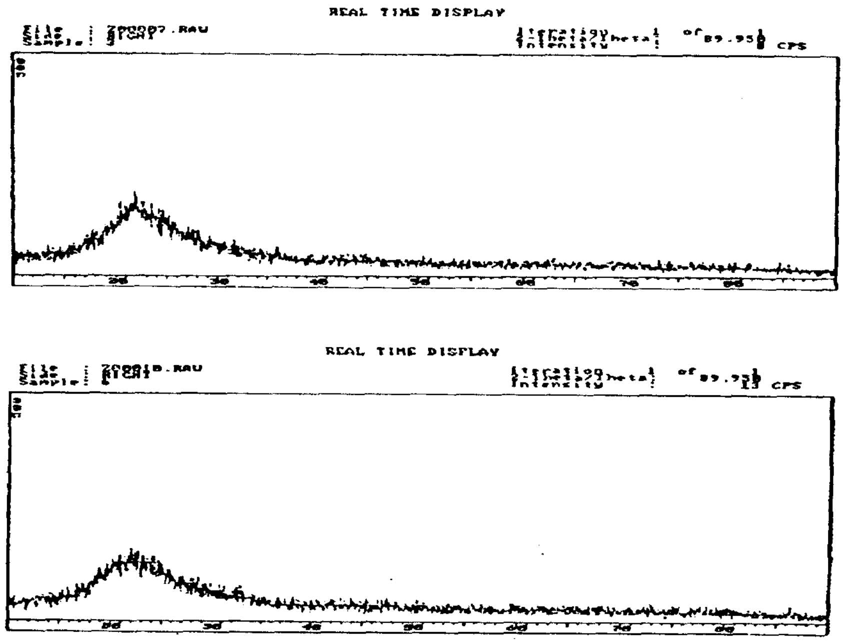

Fig. 5. X-ray diffraction patterns of rice husk ash
(a): 20kg/h of rice husk feedrate, 700℃ of control temperature
(b): 15kg/h of rice husk feedrate, 600℃ of control temperature