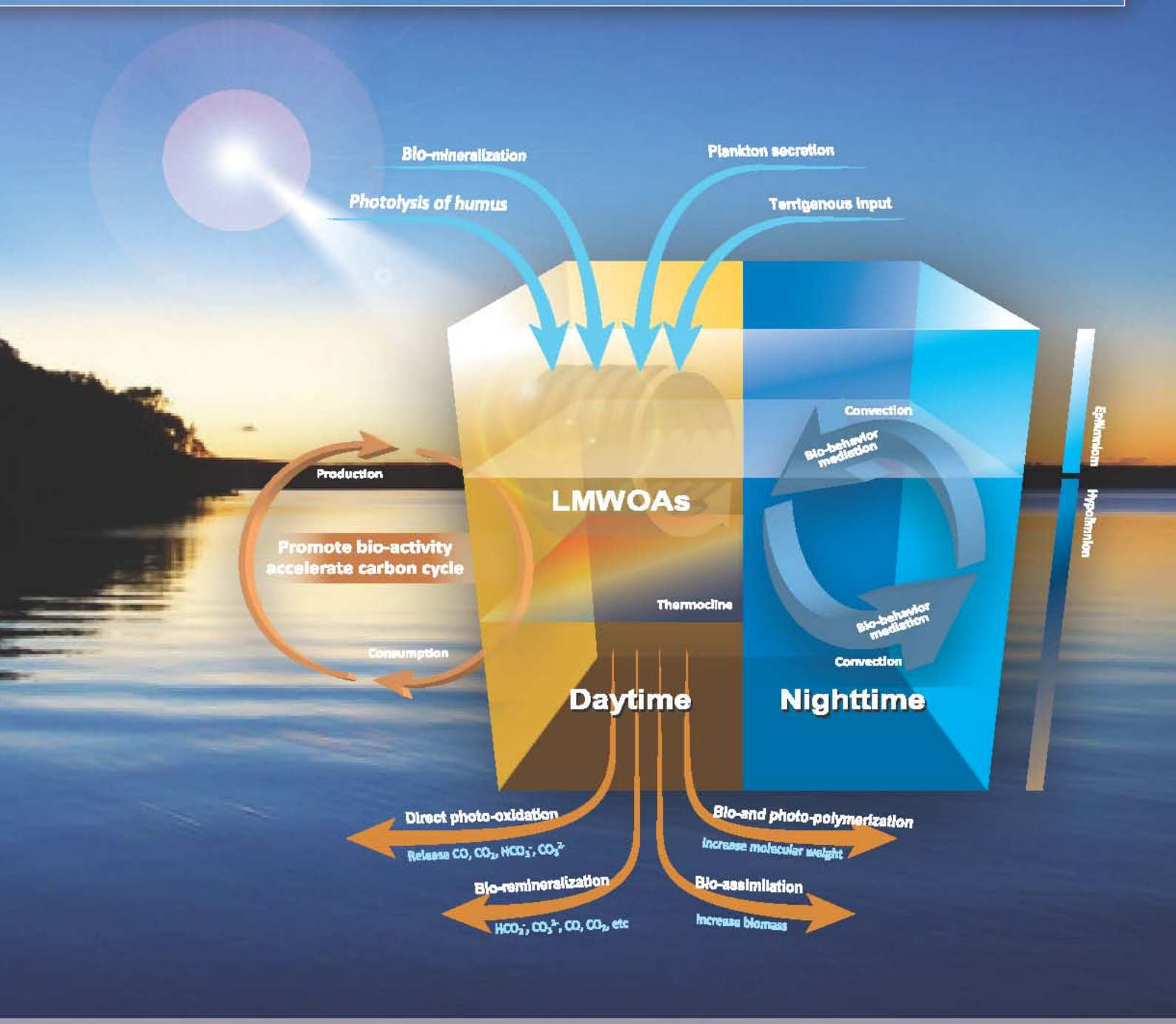
JES

JOURNAL OF ENVIRONMENTAL SCIENCES

ISSN 1001-0742
CN 11-2629/X

February 1, 2013 Volume 25 Number 2
www.jesc.ac.cn



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Research Center for Eco-Environmental Sciences
Chinese Academy of Sciences

ISSN 1001–0742 **Journal of Environmental Sciences** Vol. 25 No. 2 2013

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Serial parameter: CN 11-2629/X*1989*m*184*en*P*24*2013-2

Available online at www.sciencedirect.com
ScienceDirect
Journal of Environmental Sciences 2013, 25(2) 335–339
JOURNAL OF ENVIRONMENTAL SCIENCES
ISSN 1001-0742
CN 11-2629/X
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Pollutant emission characteristics of rice husk combustion in a vortexing fluidized bed incinerator

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Received 12 May 2012; revised 25 June 2012; accepted 27 June 2012

Abstract

Rice husk with high volatile content was burned in a pilot scale vortexing fluidized bed incinerator. The fluidized bed incinerator was constructed of 6 mm stainless steel with 0.45 m in diameter and 5 m in height. The emission characteristics of CO, NO, and SO_2 were studied. The effects of operating parameters, such as primary air flow rate, secondary air flow rate, and excess air ratio on the pollutant emissions were also investigated. The results show that a large proportion of combustion occurs at the bed surface and the freeboard zone. The SO_2 concentration in the flue gas decreases with increasing excess air ratio, while the NO*x* concentration shows reverse trend. The flow rate of secondary air has a significant impact on the CO emission. For a fixed primary air flowrate, CO emission decreases with the secondary air flowrate. For a fixed excess air ratio, CO emission decreases with the ratio of secondary to primary air flow. The minimum CO emission of 72 ppm is attained at the operating condition of 40% excess air ratio and 0.6 partition air ratio. The NO*x* and SO_2 concentrations in the flue gas at this condition are 159 and 36 ppm, which conform to the EPA regulation of Taiwan.

Key words: incineration; rice husk; vortexing; fluidized bed; pollutant emission

DOI: 10.1016/S1001-0742(12)60054-0

Introduction

Rice is the most important agricultural crop in Asia. Rice husk is generated in large quantity as a byproduct in the rice milling industry; with a lower heating value (LHV) of 14.1 kJ/kg, it can be a potential energy resource. At present, stove fired and grate fired furnaces are the most popular ways in rice husk combustion. However, its high volatile content makes it difficult to incinerate in conventional grate-type furnaces (Bhattacharya and Wu, 1989). Finding an economical and environmentally friendly solution to dispose this waste is needed as a renewable energy resource and for the sake of environmental protection.

Among different combustion methods, fluidized bed incineration has the advantage of its ability in treating wastes of varying properties at a lower operation temperature (Deng et al., 2009), which makes it a suitable technology for recovering heat energy from rice husk. High combustion efficiency was attained in pilot-scale fluidized bed incinerators or combustors in many studies (Albina, 2003; Armesto et al., 2002; Kaewklum and Kuprianov, 2008). Permchart (2004) studied the combustion of rice husk in a fluidized bed combustor and results show the maximum combustion efficiency of 86% was attained for excess air of about 60%. Staged combustion mode has been used in the fluidized-bed combustion to increase the combustion efficiency. Higher combustion efficiency can be achieved if part (slightly more than that required for char combustion) of the total air is supplied as the primary air and the remainder is supplied as the secondary air above the bed. Rice husks were fed to the fluidized bed, heated rapidly, and released volatile matters which are mostly burned in the freeboard. The amount of fine particles decreases as the primary air decreases (Bhattacharya and Wu, 1989). Fang et al. (2004) reported that secondary air can improve the combustion efficiency and the proper air split 7:3 are reasonable for rice husk combustion in a circulating fluidized bed.

Boateng et al. (1992) investigated the combustion features of rice hull char in a bench-scale fluidized-bed reactor, and the burnout time were traced at different temperatures. Liu et al. (1995) indicated that rice husk pore volume and specific surface area reach maximum at approximately 850°C, and the values decrease when temperature exceeds 900°C. Rice husk ash contains about

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90% silicon by weight. The ash from low temperature combustion is mostly made of amorphous silica, but ash from higher temperature combustion contains mostly crystalline silica. The carbon does not combust well even in pure oxygen at temperatures as high as 1200°C because carbon-silica bonds are strong and stable (Ganesh et al., 1992). Therefore, high temperature does not guarantee high combustion efficiency for rice husk.

Because the rice husk is light and it is easier to be carried up to splash zone to combust, the concept of vortexing fluidized bed incinerator (VFBI) is to create a vortex by blowing the second air tangentially into the freeboard to increase the combustion intensity, and the turndown capability. This system improved the combustion performance of BFB incinerator (Chyang et al., 2008; Qian et al., 2011). VFB combustor has been used for coal combustion studies for many years, but few focused on biomass incineration. Meanwhile, the reports about pollutant emission characteristics of rice husk combustion in VFBI are few. The main pollutant emissions are CO, NOx, and SO_2. Most researchers thought that NOx from the biomass combustion was primarily formed from fuel-N (Eldabbagh et al., 2005; Gayan et al., 2004). However, the mechanisms of formation and reduction of NOx in VFBI is complex. The main purpose of this research is to study the characteristics of pollutant emissions in rice husk combustion using VFBI, and the proper operating condition of VFBI is also investigated.

1 Materials and methods

1.1 Apparatus

All the experiments were conducted in a pilot scale VFBI system which includes a vortexing fluidized bed incinerator with a windbox, feeding system, air supply system, and flue gas treatment system. The process flowchart of the VFBI system used in this study is shown in **Fig. 1**.

The fuel stored in two hoppers fell directly through the screw feeders, air lock, and water-cooled chute into the fluidized bed incinerator. The feeding spot is located 0.45 m above the distributor. The primary air was supplied by a 15-hp roots blower and the secondary air was supplied by a 7.5 hp turbo blower to create the swirling effect in the freeboard. The VFBI of 5.75 m height with an inner diameter of 0.45 m was constructed of 6 mm thickness stainless steel covered with ceramic fiber of 150 mm thickness to reduce heat loss. A perforated plate of 6 mm thick stainless steel with 442 holes of 2.9 mm diameter was used as the gas distributor (open-area-ratio was 1.84%). Four equally spaced secondary air injection nozzles with inside diameters of 12 mm were installed tangentially at a level of 1.3 m above the distributor. Four heat exchange tubes of 31.75 mm O.D. and 1.0 m in length were installed in the freeboard at a level of 1.75–2.75 m above the distributor for preheating the secondary air. The configuration of the VFBI used in this study is shown in **Fig. 2**.

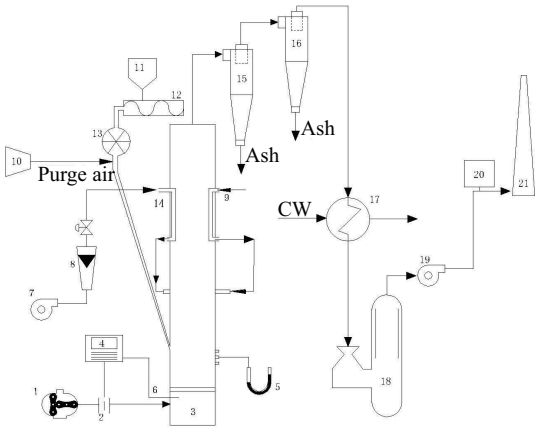

Fig. 1 Flow diagram of the experimental system of vortexing fluidized bed incinerator (VFBI). (1) roots blower; (2) orifice meter; (3) windbox; (4) recorder; (5) manometer; (6) thermocouple; (7) turbo blower; (8) rotameter; (9) secondary air; (10) compressor; (11) hopper; (12) screw feeder; (13) air lock; (14) secondary air preheater; (15) primary cyclone; (16) secondary cyclone; (17) shell and tube heat exchanger; (18) venturi scrubber; (19) induced fan; (20) flue gas detector; (21) stack.

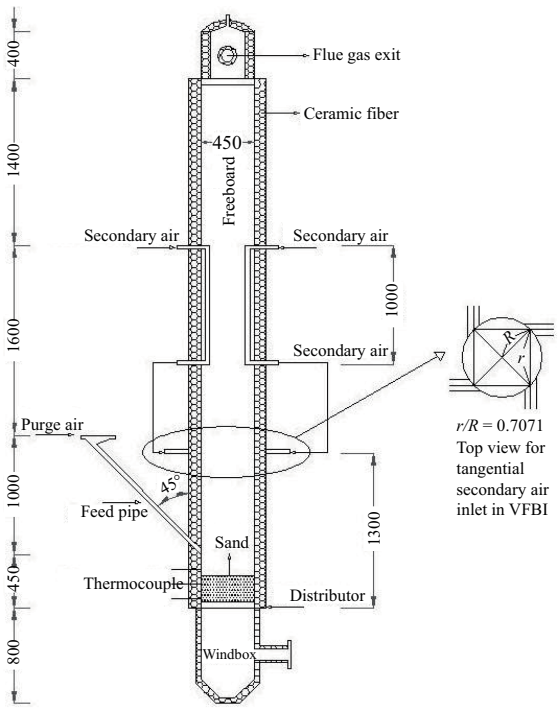

Fig. 2 Configuration of VFBI.

Flue gas leaving the incinerator went through two cyclones arranged in series for the primary cleaning. Ash and unburned char discharged from each cyclone into a sealed vessel was collected for removal or analysis. After the cyclones, the flue gas entered a venture scrubber after going through a shell-and-tube heat exchanger. Finally, the flue gas was discharged via a stack.

The temperature and pressure drops within the VFBI were measured with K type thermocouples and the manometers connected to the pressure taps located near the

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wall of the incinerator, respectively. The bed temperature was controlled by injecting water into the bed. The flue gases were sampled at six locations: 0.45 m (the bed surface), 1.8 m (within the freeboard), 2.3 m (also within the freeboard), and 4.6 m (the outlet of the VFBI) above the distributor, a point between the incinerator outlet and the first cyclone inlet, and a point at the outlet of ID Fan.

For a given operating condition, when the temperature profiles in the incinerator and the concentration of oxygen in flue gas were kept constant, it was considered as steady state combustion. Once the steady state conditions were established, the flue gas was sampled for analysis from the six sample points. The components in the flue gas, such as CO, NO*x*, SO_2 and O_2 were analyzed by an ECOM-S gas analyzer. In the preliminary test of this study, we measured the N_2O concentration by an MTI-M200 micro gas chromatograph (GC) and found that its value is almost lower than 5 ppm. Therefore, we did not discuss the N_2O emission concentration in this manuscript. The pollutant concentration emission concentrations reported in this study were all corrected to 10% residual oxygen on a dry basis.

1.2 Fuels and working conditions

Rice husk was used as the feeding material. The feeding rate was kept at 130,000 kcal/hr in this study. The proximate and ultimate analyses of rice husk are listed in **Table 1**. Silica sand was employed as the bed material. The mean size of the silica sand was 0.863 mm in diameter. Working conditions for experiments are as follows: primary air flow rate (Q_p) 1.7–2.5 Nm^3/min; secondary air flow rate (Q_s) 0–1.9 Nm^3/min; stoichiometric air (Q_g) 2.1 Nm^3/min; excess air ratio 9.5%–100%; feeding rate 41.6 kg/hr; bed material silica sand; bed weight 60 kg; density 2500 kg/m^3; mean diameter 0.863 mm; U_{mf} at 800°C is 0.258 m/sec; U/U_{mf} at 800°C is 2.72–4.0.

During this test, when we discuss the effect of parameters under multi variables, the other parameters are kept fixed.

2 Results and discussion

2.1 Temperature distribution

Figure 3 shows the typical temperature distribution profiles within the VFBI in the axial direction at various excess air ratios. In this study, over-bed feeding system was employed and the secondary air was preheated. The primary airflow rate was kept at stoichiometric air of 2.1 Nm^3/min. The excess air ratio was adjusted by changing the secondary air flow rate.

As shown in this figure, the bed temperature was almost independent of excess air ratio. It can be explained that the flow rate of primary air is constant. Meanwhile, it implies that the effect of the secondary air on the combustion within the bed zone is negligible. Due to the high

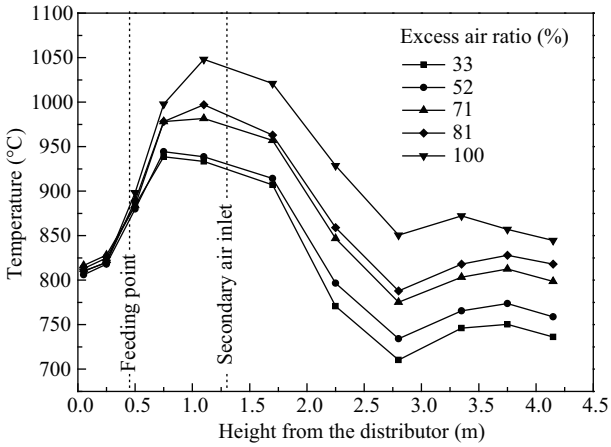

Fig. 3 Temperature distribution with various excess air air ratios. Q_p: 2.1 Nm^3/min, Q_s: 0.49–1.9 Nm^3/min, Q_g: 0.2 Nm^3/min.

volatile content of rice husk, the temperature above the bed surface is higher than that in the bed. The maximum temperature within the incinerator occurs within 0.1–0.6 m below the secondary air injection points or 0.3–0.6 m above the feeding point. It can be attributed to the combustion behavior of volatile matters and char captured by the swirling flow created by the tangentially injected secondary air. Because the swirling effect was enhanced by the increasing excess air ratio, more rice husk or char was captured. Therefore, the maximum of each temperature profile increases with the excess air ratio. The phenomenon that the temperature within the freeboard at level 1.75–2.75 m dropping abruptly can be attributed to the heat exchange tubes installed in this section. The freeboard temperature at the level above 2.75 m from the distributor increases with the distance from the distributor. It implies that the unburned matter is combusted in this region and the heat generated from combustion is greater than the heat loss from the incinerator to the surrounding. At the top of the incinerator, the temperature declines because the heat generated is less than the heat loss.

2.2 CO emission

The effect of secondary air flow rate on the CO emission at various primary air flow rates is shown in **Fig. 4**. The CO emissions decrease with increasing the secondary air flow rate, while the effect of the primary air flow rate on the CO emission is not obvious. The reasons are as follows. Firstly, the combustion fraction in the bed zone is smaller than that of bed surface and freeboard zone due to the lower density and fixed carbon of rice husk. The primary air flow rate ranges from 1.7 to 2.3 Nm^3/min, the corresponding superficial velocities are 2.7–3.65 times minimum fluidizing velocity. Therefore, the combustion behavior in the bed zone stays almost unchanged within this narrow superficial velocity range. Secondly, more and more rice husk and its unburned char are carried back to the bed surface as the excess air increases. This prolongs the residence time of the fuel particles in the incinerator,

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Table 1 Proximate and ultimate analysis of rice husk

Ultimate analysis (%)					Proximate analysis (%)				LHV (kJ/kg)
C_{ad}	H_{ad}	O_{ad}	N_{ad}	S_{ad}	M_{ad}	V_{ad}	FC_{ad}	A_{ad}	LHV_c
45.01	5.83	48.08	0.93	0.15	10.58	59.95	16.24	13.23	13114.75

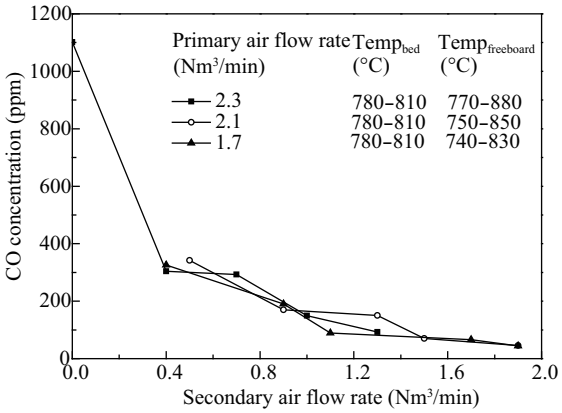

Fig. 4 Effect of secondary air flow rate on CO emission at various primary air flow.

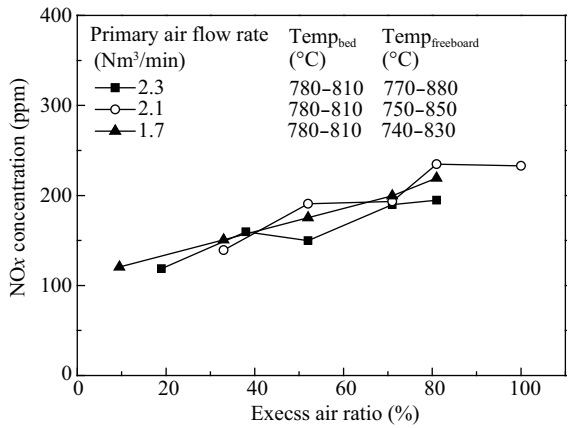

Fig. 5 Effect of excess air ratio on the NO*x* emission at various primary air flow rates.

which is conducive to the complete combustion of rice husk. Thirdly, the bed surface and freeboard temperatures increases with the secondary air flow rate (**Fig. 3**), resulting in decreasing the CO concentration.

It can be seen that the CO emission is extremely high without the secondary air. In this condition, the excess air ratio is 9.5%. Without the swirling effect generated by the secondary air, rice husk is easier to be carried up to the freeboard zone, even out of the incinerator due to its lower density. As seen in **Fig. 3**, the mean freeboard temperatures are about 100–200°C lower than that of the bed surface, which is against the complete combustion of rice husk, resulting in higher CO emission. Meanwhile, the effect of the secondary air flow rate on the CO emission is minimal when the excess air ratio is over 80%, indicating the secondary air's accelerating effect mitigated at higher excess ratios. Therefore, the optimum operation condition for fluidized bed incineration of rice husk is low fluidizing velocity and high ratio of secondary air injection over bed. The advantage of low fluidizing velocity is it can prolong the rice husk residence time within the dense zone and the advantage of high secondary ratio is it can accelerate the combustion in the freeboard zone.

2.3 NO emission

Fluidized bed incinerator has lower NO*x* emission compared with other incinerators; this can be attributed to the lower operating temperature (700–900°C) which significantly limit the emission of thermal NO*x* and prompt NO*x*. However, fuel NO*x* is the main content in the NO*x* emission.

Figure 5 shows the effect of excess air ratio on NO*x* emission at various primary air flow rates. NO*x* emission concentration increases with the increasing excess oxygen ratio. This primary because freeboard temperature increases from about 750°C to 850°C when the excess air ratio increases from 33% to 100% (**Fig. 3**), and thus improves the combustion efficiency, resulting in decreasing the CO concentration, which reduce the chance of a NO reduction reaction with CO:

$$2NO + 2CO \longrightarrow 2CO_2 + N_2 \quad (1)$$

Meanwhile, at lower freeboard temperature, low excess air ratio (< 40%) leads to a higher CO emission concentration which prompts Reaction (1), resulting in the reduction of the NO concentrations. This is in agreement with the result by Okasha et al. (2007) and Zhu and Lee (2005).

To investigate the relationship between CO and NO in rice husk combustion using fluidized-bed incinerator, the mean CO and NO emission concentrations are correlated for all the operating parameters as shown in **Fig. 6**. This figure shows that the mean NO concentration at the incinerator exit decreases with the increasing CO concentration. This is in agreement with the results from previous studies (Chyang et al., 2007). As seen in this figure, the maximum NO*x* concentration emission is lower than 250 ppm, which is in conformity to the regulation of Taiwan.

2.4 SO_2 emission

Figure 7 shows the effect of excess air ratio on SO_2 emission at various primary air flow rates. SO_2 emission decreases slightly with the rising excess air ratio. For a certain excess air ratio, the effect of the primary air on the SO_2 is not significant. The maximum SO_2 concentration emission is below 80 ppm, and the mean SO_2 emission at optimal operating condition is lower than 25 ppm, which are both in conformity to the regulation of Taiwan. Due to the very low sulfur content in rice husk, the SO_2 emission

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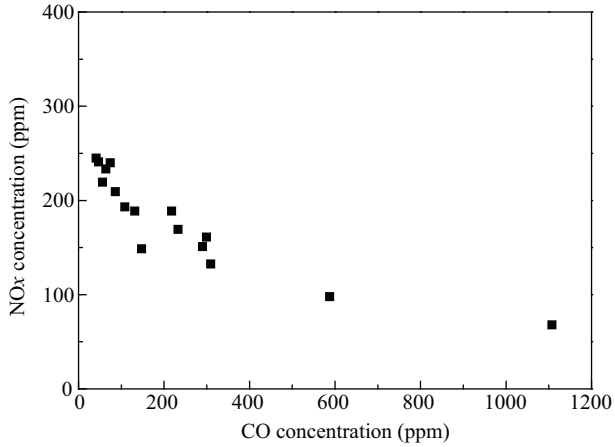

Fig. 6 Relationship between concentration of CO and NO*x*.

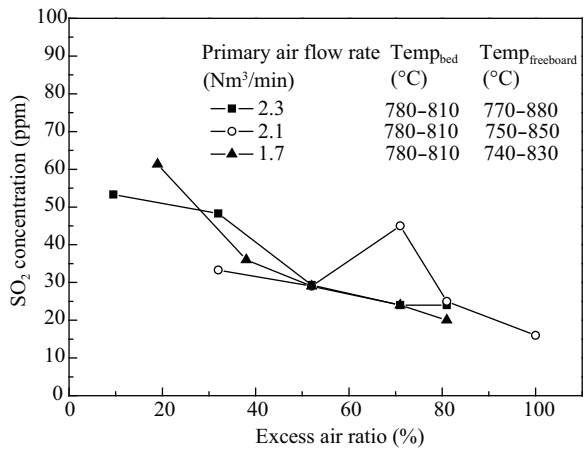

Fig. 7 Effect of excess air ratio on the SO_2 concentration.

concentration from rice husk incineration is negligible. There is no need for desulfurizer like CaO when rice husk is burned in a fluidized bed incinerator.

3 Conclusions

The maximum temperature within the incinerator is observed at the bed surface due to the high volatile content of rice husk. The SO_2 emissions from all the test runs in this study are below 80 ppm due to the low sulfur content in rice husk. NO*x* emissions increase with excess air ratio. For a given primary air flow rate, CO emissions decrease with rising secondary air flow rates. Under fluidization state, the CO emissions decrease as the partition ratio of primary air decrease for a given total air flow rate. The optimum operation condition for rice husk in fluidized bed incineration is low fluidizing velocity and high secondary air injected over bed.

References

Albina D O, 2003. Combustion of rice husk in a multiple-spouted fluidized bed. *Energy Sources*, 25(9): 893–904.

Armesto L, Bahillo A, Veijonen K, Cabanillas A, Otero J, 2002. Combustion behaviour of rice husk in a bubbling fluidised bed. *Biomass and Bioenergy*, 23(3): 171–179.

Bhattacharya S C, Wu W Z, 1989. Fluidized bed combustion of rice husk for disposal and energy recovery. *Energy from Biomass and Wastes*, 12(2): 591–601.

Boateng A A, Fan L T, Walawender W P, Chee C S, Chern S M, 1992. Kinetics of rice hull char burnout in a bench-scale fluidized-bed reactor. *Chemical Engineering Communications*, 113(1): 117–131.

Chyang C S, Qian F P, Lin Y C, Yang S H, 2008. NO and N_2O emission characteristics from a pilot scale vortexing fluidized bed combustor firing different fuels. *Energy & Fuels*, 22(2): 1004–1011.

Chyang C, Wu K, Lin C, 2007. Emission of nitrogen oxides in a vortexing fluidized bed combustor. *Fuel*, 86(1-2): 234–243.

Deng W Y, Yan J H, Li X D, Wang F, Chi Y, Lu S Y, 2009. Emission characteristics of dioxins, furans and polycyclic aromatic hydrocarbons during fluidized-bed combustion of sewage sludge. *Journal of Environmental Sciences*, 21(12): 1747–1752.

Eldabbagh F, Ramesh A, Hawari J, Hutny W, Kozinski J A, 2005. Particle-metal interactions during combustion of pulp and paper biomass in a fluidized bed combustor. *Combustion and Flame*, 142(3): 249–257.

Fang M, Yang L, Chen G, Shi Z, Luo Z, Cen K, 2004. Experimental study on rice husk combustion in a circulating fluidized bed. *Fuel Processing Technology*, 85(11): 1273–1282.

Ganesh A, Dutt Grover P, lyer P V R, 1992. Combustion and gasification characteristics of rice husk. *Fuel*, 71(8): 889–894.

Gayan P, Adanez J, de Diego L F, García-Labiano F, Cabanillas A, Bahillo A et al., 2004. Circulating fluidised bed co-combustion of coal and biomass. *Fuel*, 83(3): 277–286.

Kaewklum R, Kuprianov V I, 2008. Theoretical and experimental study on hydrodynamic characteristics of fluidization in air-sand conical beds. *Chemical Engineering Science*, 63(6): 1471–1479.

Liu H, Lin Z, Liu D, Wu W, 1995. Combustion characteristics of rice husk in fluidized beds. In: Proceedings of the 13th International Conference on Fluidized Bed Combustion (Heinschel K J, ed.). ASME, New York, Orlando, FL. 615–618.

Okasha F, 2007. Staged combustion of rice straw in a fluidized bed. *Experimental Thermal and Fluid Science*, 32(1): 52–59.

Permchart W, Kouprianov V I, 2004. Emission performance and combustion efficiency of a conical fluidized-bed combustor firing various biomass fuels. *Bioresource Technology*, 92(1): 83–91.

Qian F P, Chyang C S, Huang K S, Tso J, 2011. Combustion and NO emission of high nitrogen content biomass in a pilot-scale vortexing fluidized bed combustor. *Bioresource Technology*, 102(2): 1892–1898.

Zhu S, Lee S W, 2005. Co-combustion performance of poultry wastes and natural gas in the advanced Swirling Fluidized Bed Combustor (SFBC). *Waste Management*, 25(5): 511–518.

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Journal of Environmental Sciences (Established in 1989)
Vol. 25 No. 2 2013

Supervised by	Chinese Academy of Sciences	**Published by**	Science Press, Beijing, China
Sponsored by	Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences		Elsevier Limited, The Netherlands
		Distributed by	
Edited by	Editorial Office of Journal of Environmental Sciences	Domestic	Science Press, 16 Donghuangchenggen North Street, Beijing 100717, China
	P. O. Box 2871, Beijing 100085, China		Local Post Offices through China
	Tel: 86-10-62920553; http://www.jesc.ac.cn	Foreign	Elsevier Limited
	E-mail: jesc@263.net, jesc@rcees.ac.cn		http://www.elsevier.com/locate/jes
Editor-in-chief	Hongxiao Tang	**Printed by**	Beijing Beilin Printing House, 100083, China

CN 11-2629/X **Domestic postcode: 2-580** **Domestic price per issue RMB ¥ 110.00**

ISSN 1001-0742