Preliminary Investigation on Combustion Characteristics of Rice Husk in FBC

W. Permchart, and S. Tanatvanit

***Abstract*—**The experimental results on combustion of rice husk in a conical fluidized bed combustor (referred to as the conical FBC) using silica sand as the bed material are presented in this paper. The effects of excess combustion air and combustor loading as well as the sand bed height on the combustion pattern in FBC were investigated. Temperatures and gas concentrations (CO and NO) along over the combustor height as well as in the flue gas downstream from the ash collecting cyclone were measured. The results showed that the axial temperature profiles in FBC were explicitly affected by the combustor loading whereas the excess air and bed height were found to have minor influences on the temperature pattern. Meanwhile, the combustor loading and the excess air significantly affected the axial CO and NO concentration profiles; however, these profiles were almost independent of the bed height. The combustion and thermal efficiencies for this FBC were quantified for different operating conditions.

***Keywords*—**Temperature, Combustor loading, Excess air, Bed height.

I. Introduction

RICE husk is one of the most viable biomass fuels in Thailand, which has been considered as important alternative energy source to fossil fuels. In 2007, the available supply of rice husk in the country was estimated to be 1,646 ktoe (or 4.83 million tons); meanwhile, simply 63.4% of this biomass residue was utilized as the fuel (or alternatively) in industrial and residential sectors [1]. These figures indicate a great power generation potential of the utilization of rice husk as an alternative fuel.

Generally, rice husk, in particular, can be efficiently fired in fluidized bed combustion systems. Over the decades, a number of research works aimed at studying of biomass combustion in fluidized bed systems have been carried out in Thailand. Most of them were conducted experimentally on the laboratory scaled combustors [2] – [5]; meanwhile, some research works were devoted to modeling study [6], [7].

However, the combustion process of biomass is still far from being well understood. Some problems associated with effects of fuel properties and operating conditions (i.e. excess air and bed height) on the combustion pattern and efficiency must be studied. Taking into consideration a great potential of biomass fuel utilization for power generation, another important aspect, the environmental impact of biomass combustion, should be considered as well.

This study was aimed at experimental study of rice husk combustion in the conical FBC. The effects of operating conditions (i.e. excess of combustion air and combustor loading) as well as bed height on combustion process, specifically, on formation and reduction of major gaseous pollutants (NO and CO) in the conical FBC, were the focus of this research work.

II. Materials and Methods

A. Experimental Set-up

The conical FBC consisted of two parts: 1) a conical part (bottom part) of 1-m high with cone angle of 20^0, and 2) a cylindrical part (top part) of 2-m high and 0.9-m inner diameter. The outer walls of the combustor were insulated with 50-mm-thick ceramic fiber. The schematic diagram of the experimental set-up is shown in Fig. 1.

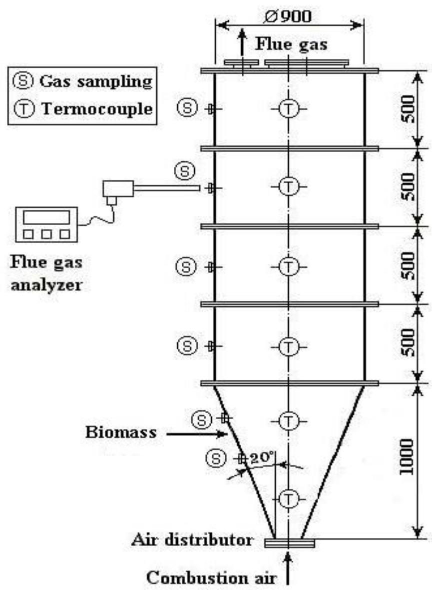

Fig. 1 Schematic diagram of the experimental set-up

Combustion air was supplied into the combustor by a blower through the nozzle stand pipes with bubbling caps,

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which was used as the air distributor of the FBC. Rice husk with 10.3% moisture content was supplied over the bed. The tests were conducted for two feed rates of 37.3 and 82.4 kg/hr; meanwhile, the excess air was provided in the range of about 20 – 120 %.

Silica sand of about 0.3–0.5 mm in diameter was used as the inert bed material to ensure effective fluidization and therefore stable fuel ignition and combustion in the bed [8]. The tests were conducted for two static bed heights: of 20 and 40 cm. During the tests, the bed material was changed every 60 hours in order to avoid agglomeration of the bed material [9].

Thermocouples were fixed at the combustor walls for providing measurement of temperatures along FBC height. A flue gas analyzer was used to measure the gas concentrations (CO, CO_2, O_2 and NO) in flue gas which was sampled through the special holes in the combustor body and at the outlet of the ash collecting cyclone (see Fig. 1).

Additionally, fly ash was sampled for analyzing the unburned carbon content. Based on the analyses of heat losses owing to two factors, the unburned carbon in fly ash and the incomplete combustion (based on CO content in flue gas), the combustion efficiency for the conical FBC was estimated for each test run.

B. Analyses of Rice Husk and Chemical Composition of Sand Used in the Tests

Table I shows the proximate and ultimate analyses of the tested rice husk and the chemical composition of sand used in the conical FBC as the inert bed material.

TABLE I
PROXIMATE AND ULTIMATE ANALYSES OF RICE HUSK AND CHEMICAL COMPOSITION OF SAND

	Rice husk	Bed material
Proximate Analysis		
Moisture (wt.%)	10.30	
LHV (MJ/kg)	12.32	
Ultimate Analysis		
C	37.90	
H	4.82	
O	34.90	
N	0.43	
S	0.17	
Ash	21.78	
Chemical Composition (wt.%)		
SiO_2		89.90
Al_2O_3		7.80
Fe_2O_3		1.20
CaO		0.05
MgO		0.05
K_2O		0.90
Na_2O		0.10

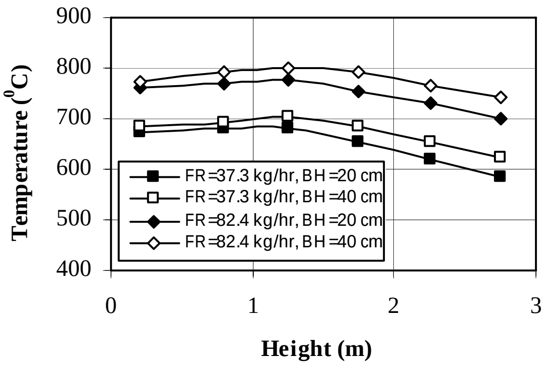


Fig. 2 Effects of the combustor loading and bed height on the axial temperature profiles in the conical FBC for the tests conducted at quasi-identical EA of 59-63%

III. RESULTS AND DISCUSSION

A. Axial Temperature Profiles in the Conical FBC

Fig. 2 shows the axial temperature profiles in the conical FBC along the combustor height when firing rice husk at the combustor loading (FR) of 37.3 and 82.4 kg/hr for 20- and 40-cm of bed heights (BH) obtained for identical values of excess air (EA) of 59-63%.

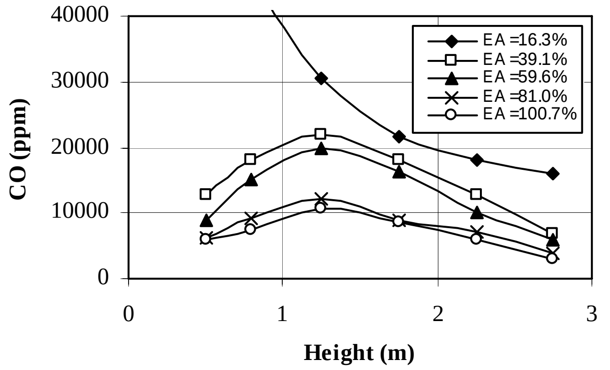
As seen, the temperature profiles in the conical FBC are quite uniform and explicitly affected by the combustor loading whereas the sand bed height is found to have minor influences on the temperature pattern .Changes in EA weakly affected the temperatures in the freeboard of the combustor whereas the temperatures in the bed region remained almost unchanged for various EA.

B. Axial Gas Concentration Profiles in the Conical FBC

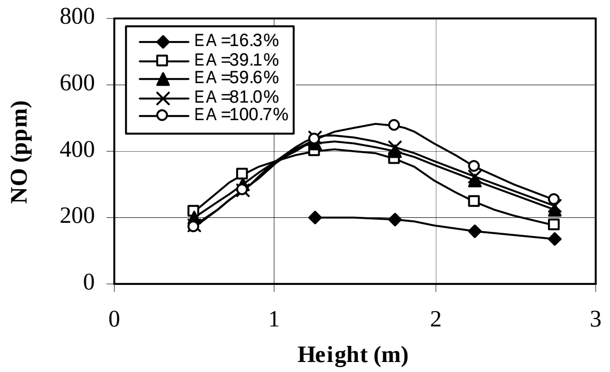
The axial gas concentration profiles for CO and NO in the conical FBC are shown in Fig. 3 for firing rice husk at FR = 82.4 kg/hr and BH = 20 cm for different values of EA varied from 16.3 to 100.7%.

As seen in Fig. 3*a* and 3*b*, CO and NO profiles possess the maximum values, CO_{max} and NO_{max}, which are located at the top of the fluidized bed region and significantly affected by EA. The strongest effects of EA were observed at the relatively low EA (lower than 60%), especially on the CO profiles. In some tests, CO_{max} exceeded 40000 ppm (i.e. the upper limit of flue gas analyzer for this gas) because of high devolatilization rate of the fuel followed by oxidation of carbon-based components to CO [8]. In the freeboard region, CO concentration was decreased because oxidation of carbon monoxide by OH radicals and oxygen.

Unlike CO profiles, NO concentrations were increased with an increasing in EA. NO formed in the combustor from fuel-nitrogen through: 1) combustion of the nitrogenous species released with volatile matter (i.e. HCN and NH_3), and 2) oxidation of nitrogen retained in the char [10], [11].

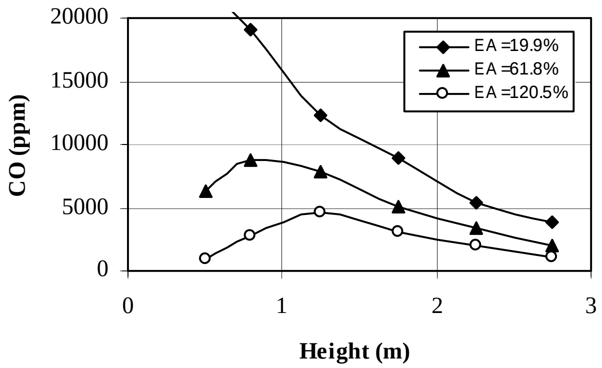


(a)

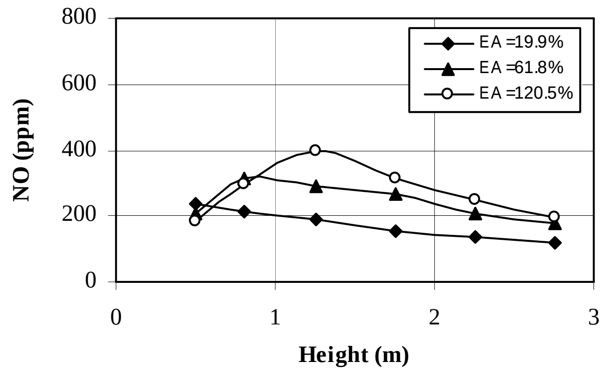


(b)

Fig. 3 Axial gas concentration profiles for CO (*a*) and NO (*b*) in the conical FBC firing rice husk at FR=82.4 kg/hr and BH=20 cm for different values of EA



(a)



(b)

Fig. 4 Axial gas concentration profiles for CO (*a*) and NO (*b*) in the conical FBC firing rice husk at FR=37.3 kg/hr and BH=20 cm for different values of EA

In the freeboard region, NO was reduced through its reaction with NH_3 as well as due to reactions of NO with carbon and CO on the char surface [10] – [12].

Fig. 4 shows the CO and NO profiles for firing rice husk at the reduced load, namely, at FR = 37.3 kg/hr and BH = 20 cm for different values of EA. As may be seen from comparison of these profiles in Fig. 3 and Fig. 4, the formation and reductions rates of CO and NO, as well as CO and NO emissions from the conical FBC, were noticeably diminished at the reduced combustor loading.

The CO emission at reduced loads becomes lower because of increase in the residence time of reactants, whereas the NO emission reduction is explained by the temperature lowering whilst the fuel feed rate is reduced. The noticeable influence of the excess air and relatively weak effect of temperature on the axial NO profiles indicate the fuel-NO mechanism of the NO formation in combustion of rice husk in the conical FBC.

As seen in Fig. 3 and 4, the locations of CO_{max} and NO_{max} divide conventionally the combustor volume into formation (lower) and reduction (upper) regions for these pollutants. These locations, as well as the values of CO_{max} and NO_{max} were affected by operating conditions in the combustor, especially by the excess air.

C. *Efficiencies of the Conical FBC*

Table II shows the heat losses as well as combustion efficiency of the conical FBC during the tests at FR = 82.4 kg/hr and BH = 20 cm for difference values of EA. The heat losses owing to incomplete combustion (Q_{ic}) and unburned carbon (Q_{uc}) were estimated by [13]. These losses are affected by the excess air leading to the maximum in the combustion efficiency determined with the use of their values.

As seen in Table II, the heat loss with unburned carbon is elevated for the case of firing rice husk compared with other biomass fuels, e.g. sawdust [2]. This can be explained by the high ash content in rice husk (see Table I) as well as by the large size of the fuel particles (of 2.4 × 8 mm on average).

TABLE II
COMBUSTION EFFICIENCIES FOR THE CONICAL FBC FIRING RICE HUSK

EA (vol.%)	FR (kg/hr)	Qic (%)	Quc (%)	Efficiency (%)
16.3	82.4	4.29	12.47	83.24
59.6	82.4	0.53	13.15	86.32
100.7	82.4	0.34	18.35	81.31

IV. CONCLUSION

As found in the work, the axial temperature profiles in the conical FBC were explicitly affected by the fuel feed rate whereas the excess air and bed height were found to have minor influences on the temperature pattern.

Both CO and NO axial profiles possessed the maximum. The fuel feed rate and the excess air significantly affected the formation and reduction processes of both CO and NO. However, CO and NO axial profiles were almost independent of the bed height.

The combustion efficiency of the conical FBC firing rice husk was found to be in the range of 81 to 86% under different operating conditions. The thermal efficiency of the combustor was somewhat lower (by 2.4–2.8%) than the combustion efficiency for the respective test runs.

TABLE III
LISTS OF SYMBOLS AND ABBREVIATIONS

Abbreviation	Full Meaning
toe	Ton of Oil Equivalent
BH	Bed Height
EA	Excess Air
FBC	Fluidized Bed Combustor
FR	Combustor Loading
LHV	Lower Heating Value
Q_{ic}	Heat loss owing to incomplete combustion
Q_{uc}	Heat loss with unburned carbon in ash

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