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Assessment of the rice husk lean-combustion in a bubbling fluidized bed for the production of amorphous silica-rich ash

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ABSTRACT

Rice husk lean-combustion in a bubbling and atmospheric fluidized bed reactor (FBR) of 0.3 m diameter with expansion to 0.4 m in the freeboard zone and 3 m height was investigated. Experiment design – response surface methodology (RSM) – is used to evaluate both excess air and normal fluidizing velocity influence (independent and controllable variables), in the combustion efficiency (carbon transformation), bed and freeboard temperature and silica content in the ashes. Hot gases emissions (CO_2, CO and NO_x), crystallographic structure and morphology of the ash are also shown. A cold fluidization study is also presented. The values implemented in the equipment operation, excess air in the range of 40–125% and normal fluidization velocities (0.13–0.15 Nm/s) show that the values near the lower limit, encourage bed temperatures around 750 °C with higher carbon transformation efficiencies around 98%. However, this condition deteriorated the amorphous potential of silica present in the ash. An opposite behavior was evidenced at the upper limit of the excess air. This thermochemical process in this type of reactor shows the technical feasibility to valorize RH producing hot gases and an amorphous siliceous raw material.

1. Introduction

Paddy rice is the third most cultivated product in Colombia after coffee and corn. In Colombia, approximately 2 million tones of dry Paddy rice were produced in 2006 [1]. Rice husk (RH) represents approximately 20% of the gross weight of the grain and its final disposition constitutes a serious environmental problem. Currently only a small fraction of the RH generated is used such as floor covering in stables; for moisture retention in crops, and burned for grain drying in furnaces. The main components of the RH are cellulose and hemicellulose (50%) besides lignin (26%) and organic components (4%), as oils and proteins. The remaining amount includes inorganic materials as SiO_2, Al_2O_3, K_2O, Na_2O, MgO, CaO, Fe_2O_3, MnO, and P_2O_5 [2].

Biomass is an attractive energy source capable to produce heat, power and gaseous or liquid fuel from a thermochemical transformation process (combustion, gasification and/or pyrolysis). RH is a renewable energy source that presents disposal problems and is considered an agricultural residual waste. Atmospheric fluidized bed reactors (FBRs) (bubbling and circulating) are considered as a viable and effective technology for operations involving mass transfer and energy. This technology is an interesting and efficient mechanism in the thermochemical conversion of heterogeneous, low density and irregular/complex shape materials such as RH. Its inherent advantages of fuel flexibility, low temperatures and isothermal operation conditions allow the thermochemical conversion of several agricultural wastes. As one kind of renewable energy source as well as its complex physicochemical characteristics, RH thermochemical conversion in atmospheric FBRs have attracted increasing research and development efforts. Several studies about thermochemical transformation (gasification and combustion) of RH in fluidized bed can be found in the literature (Armesto et al. [3]; Fang et al. [4]; Okasha [5]; Rozainee et al. [6]; Singh et al. [7]; Vélez et al. [8]).

On the other hand, rice husk ash (RHA) is the product of the thermochemical transformation of RH. The conditions of the conversion process (pyrolysis, gasification and/or combustion) establish the physical-chemical characteristics of the final products, including the ash. For the RH, its ash corresponds to 14–25% SiO_2 according to the variety of the rice, climate and soil of the producing area [9,10]. The main component of RHA, which is generated at moderate combustion temperatures, is amorphous silica (SiO_2) in the range of 80–97% [9,11].

The adequate combustion of RH generates hot gases with low levels of pollutants, as carbon monoxide and particulate material.

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Nomenclature

η_c	combustion efficiency (%)
λ	excess air (%)
E_a	energy losses by the residual carbon present in the rice husk ash (kW)
E_f	energy corresponding to rice husk (kW)
E_{fg}	energy losses by the carbon monoxide in flue gases (kW)
T_{Bed}	average temperature (°C)
T_{FB}	freeboard temperature (°C)
Uf_n	normal fluidization velocity (at 273,15 K and 101.3 kPa) (m/s)
$\%SiO_2$	SiO_2 content in the RHA (%)

Abbreviations

FBR	fluidized bed reactor
LOI	losses on ignition (%)
RH	rice husk
RHA	rice husk ash
RS	response surface
RSM	response surface methodology

Conversely, the inadequate combustion yields several pollutants like smoke, acid gases, volatile organic compounds and particulate materials that have significant adverse impacts on human health like silicosis disease.

This work presents some results obtained during the lean-combustion of Colombian RH in a bubbling fluidized bed pilot plant at atmospheric pressure by using an experimental design (response surface methodology, RSM). With this methodology is evaluated the excess air and normal fluidizing velocity influence (independent and controlling variables) in the combustion efficiency (carbon transformation), bed and freeboard temperature and silica content in the RHA. Flue gases emissions (CO_2, CO and NO_x), and RHA characteristics (crystallographic and morphology structure) are also presented. Besides, it is showed a simple cold fluidization study of the RH/sand for selecting the operating range of the fluidization velocity.

2. Materials and methods

2.1. RH

RH was acquired in compacted packages of 70 kg. This Biomass was originated in the Tolima department of Colombia. RH did not suffer any previous processing before being fed in the bubbling FBR. Table 1 presents the ultimate and proximate analyses (dry basis) of the RH used in this research [12].

2.2. FBR facility and technique

The equipment used for the present work (for the cold fluidization study and combustion experiments) is an atmospheric bubbling FBR. Fig. 1 shows a schematic representation of the experimental setup. The reactor is a cylindrical refractory chamber of 0.3 m ID with expansion to 0.4 m in the freeboard zone. The height is 3 m. It also has a hopper for material storage, with an automatic feeding screw system. It has a high-pressure air blower with a thermal differential instrument for air measurement. Finally, it presents a natural gas burner for the bed preheating. More details can be found in Ramírez et al. [12].

Table 1
Ultimate and proximate analyses of RH.

Ultimate analysis	%wt (ar)	Proximate analysis	%wt (ar)
Carbon	36.60	Volatile	57.70
Hydrogen	5.83	Residual humidity	9.30
Nitrogen	3.31	Ash	17.60
Oxygen (by difference)	36.65	Fixed carbon	15.40
Sulfur	0.01	Higher heating value (MJ/kg)	14.61

Gases leaving the reactor pass through a cyclone to separate and to collect the entrained ashes. Temperatures were recorded by seven thermocouples type K placed along the height of the reactor. The temperature signal is collected by a data acquisition system (ADAM 4118). Data were stored in a PC by means of the software Smiles Viewer®. Pressures on bed were measured from U tube manometers. The bed material consists of silica sand with average diameter of 250 μm. The bed height (static state) was 0.4 m in all tests (for cold fluidization and combustion tests). From a simple cold study was identified the appropriate velocities range for the bubbling fluidization of the RH/sand mixture. Table 2 shows the experimental conditions implemented.

RH combustion started with bed preheating. By means of the burner, the FBR was heated up to 400 °C. Once this temperature was reached, RH was fed into the reactor. Stoichiometric combustion condition (air/fuel ratio of 4 Nm^3/kg approx.) was then adjusted to reach quickly a bed average temperature of 700 °C. The RH flow was controlled by means of a variator frequency driver which is coupled to the feeding system. Fluidization velocity was guaranteed using a by-pass valve and the flow meter. The tests were done at different operating conditions. The modified variables were the normalized fluidization velocity and the excess air. Steady conditions were kept along the combustion process. The following variables were measured:

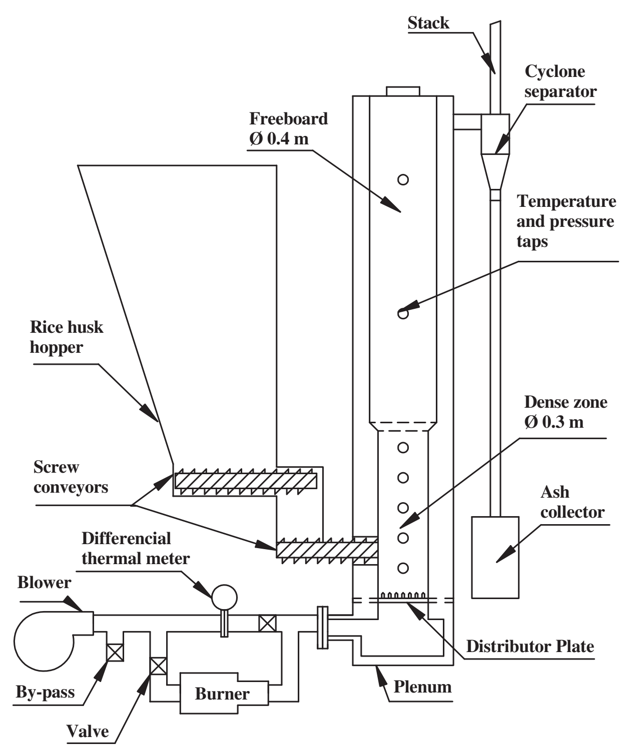

Fig. 1. Schematic of the fluidized bed reactor (FBR).