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Studies in an atmospheric bubbling fluidized-bed combustor of 10 MW power plant based on rice husk

Ravi Inder Singh [a,*], S.K. Mohapatra [b], D. Gangacharyulu [c]

[a] Department of Mechanical Engineering, Guru Nanak Dev Engineering College, Ludhiana, Punjab 141 006, India
[b] Department of Mechanical Engineering, Thapar University, Patiala, Punjab, India
[c] Department of Chemical Engineering, Thapar University, Patiala, Punjab, India

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ABSTRACT

In this paper an experience, environmental assessment, a model for exit gas composition, agglomeration problem and a model for solid population balance of 10 MW power plant at Jalkheri, Distt. Fatehgarh Sahib, Punjab, India based on rice husk has been discussed. Three phase multistage mathematical model for exit gas composition of rice husk in fluidized bed has been derived. The model is based on three-phase theory of fluidization and material balance for shrinking rice husk particles and it is similar to model developed by Kunii and Levenspiel. The burning of rice husk is assumed to take place according to single film theory. The model has been used to predict the exit gas composition particularly O_2, CO_2 and N_2. The agglomeration problem of above plant which is main reason for defluidization of bed has also been discussed. SEM of ash agglomerates has been done. Ash samples taken from the above 10 MW power plant at Jalkheri has been quantitatively analyzed. Finally solid population model has been formed to calculate bed carbon load and carbon utilization efficiency. Above two models are experimentally correlated with the data collected from the above 10 MW power plant at Jalkheri, Distt. Fatehgarh Sahib, Punjab, India which uses rice husk as a fuel input (at the time of study). All the results from the model for rice husk are coming with in permissible limits.

1. Introduction

With growing population and depletion of fossil fuels, there is an urgent need to effectively tap the non-conventional and renewable energy sources. Among the various alternatives biomass holds a special promise owing to its inherent ability to store solar energy and is the only renewable source of carbon and host of the other chemicals. Rice husk is an important biomass that is found throughout the world. Fluidized-bed combustion process seems to be suitable technology for converting it into thermal energy and power generation. Rice husk corresponding to a heating value of 15 MJ/kg [30]. India alone gives 22 million tonnes [30] of rice husk per year which if used effectively can be used for power generation and other purposes. Fluidized-bed combustion (FBC) is one of the most promising energy conversion options available today. FBC combines high efficiency combustion of low-grade fuels viz., high ash coal, coal washery rejects and middling, wood and other biomass of agri-waste and municipality waste.

In the last decade, a large number of rice-husk based power plants have been developed. The study will help the engineer in optimizing the operating conditions of commercial plants. The study will help an engineer to predict hydrodynamic parameters, exit gas composition, carbon utilization efficiency, bed carbon load, and causes of agglomeration leading to defluidization of the bed of commercial operated rice husk fluidized-bed power plants.

The project activity of Jalkheri Power Plant leads to GHG on-site emissions in the form of CO_2 from combustion of biomass that will be consumed by plant species, representing a cyclic process of carbon sequestration. Since the biomass contains only negligible quantities of other elements like nitrogen, sulphur, etc. release of other GHG's are considered as negligible.

Although, a lot of study on fluidized-bed rice husk combustors is done in past but due to the complicated nature of fluidized-bed behavior, study for a specific system may not represent properly other systems that differ in design and operating features. Besides most of the study is correlated with the experimental results obtained from laboratory scale FBC units. In this work a three-phase mathematical model for exit gas composition and solid population balance for shrinking particles in an atmospheric bubbling fluidized-bed combustor using rice husk has been developed including some features neglected or simplified in the previous studies. Biomass being neutral fuel, no project emissions is considered so our exit gas model is quite useful which results in CO_2, O_2 and N_2 mainly. In commercial installations, the occurrence of agglomeration is still one of the main reasons for unscheduled

* Corresponding author. Tel.: +91 9815960327.
E-mail address: ravis021@yahoo.com (R.I. Singh).

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Nomenclature

A_t	cross-sectional area of the bed (cm^2)
A_b	cross-sectional area occupied by the bubbles (cm^2)
A_{cw}	cross-sectional area occupied by cloud-wake phase (cm^2)
C_{e_n}	nth stage emulsion phase oxygen concentration (g mol/cm^3)
C_0	inlet oxygen molar concentration (g mol/cm^3)
C_p	oxygen concentration in the particular phase (g mol/cm^3)
C_s	carbon concentration in the bed (g mol/cm^3)
C_{b_n}	nth stage oxygen concentration in the bubble phase (g mol/cm^3)
C_{cw_n}	nth stage oxygen concentration in the cloud-wake phase (g mol/cm^3)
d_p	diameter of rice husk particles (cm)
D_g	diffusivity of gas (cm^2/s)
D_b	diameter of bubble (cm)
Exair	excess air
FMTH	stoichiometric air feed rate to the combustor (g mol/s)
FME	actual air feed rate to the combustor (g mol/s)
f_{cw}	fraction of cloud-wake phase in the bed
F_0	total carbon feed rate (g/s)
F_1	carry over rate (g/s)
F_2	fly ash (air heater and ESP hopper) (g/s)
F_3	total carbon in carry over rate (g/s)
F_4	actual carbon in fly ash (air heater and ESP hopper) (g/s)
F_5	carbon lost due to unburnt rice husk (g/s)
g	acceleration due to gravity (cm/s^2)
H_{mf}	height of bed at minimum fluidization (cm)
K_s	intrinsic chemical reaction rate constant (cm/s)
K_g	mass transfer coefficient (cm/s)
K	effective reaction rate constant (cm/s)
$k_{shrk} = \frac{dd_p}{dt}$	shrinkage rate of rice husk particles (g/s)
$(K_{bc})_b$	gas interchange coefficient from bubble to cloud-wake phase (s^{-1})
$(K_{ce})_b$	gas interchange coefficient from cloud-wake to emulsion phase (s^{-1})
$K^*(d_p)$	elutriation rate constant (g/cm^2 s)
$K(d_p)$	elutriation constant (s^{-1})
N	number of g mole of oxygen
N_D	number of holes in distributor
M_c	molecular mass of carbon
P_{av}	average pressure in the combustor (atm)
$P_b(d_p)$	char size distribution in the bed (cm^{-1})
$P_1(d_p)$	size distribution of overflow rate (cm^{-1})
R	gas constant
Sh	Sherwood number
T_b	absolute bed temperature (K)
U_o	superficial gas velocity (cm/s)
U_{mf}	minimum fluidization velocity/emulsion phase gas velocity (cm/s)
u_{br}	single bubble velocity (cm/s)
u_b	average absolute velocity of crowd of bubbles (cm/s)
Z	bed height (cm)
Z_{n-1}	bed height at $(n-1)$th stage (cm)
Z_n	bed height at nth stage (cm)
U_{cw}	velocity of gas through cloud-wake phase (cm/s)
U_b	velocity of gas through bubble phase (cm/s)
W_c	bed carbon load (g)
$W_{rice\ husk}$	feed rate of rice husk (g/s)
XC, XH, XS, XO, XW	carbon, hydrogen, sulfur, oxygen, and moisture weight percentages, respectively
XVM	weight fraction of volatile matter in the rice husk
XFC	weight fraction of fixed carbon in the rice husk
AFBC	atmospheric fluidized-bed combustor
PSEB	Punjab State Electricity Board
NSML	Nahar Spinning Mill Limited, Ludhiana, Punjab, India
AMV	actual measured value
ESP	electrostatic precipitator
GHG	green house gases

Greek symbols

ε_{mf}	voidage in the bed at minimum fluidization
ρ_p	density of rice husk particles
ρ_g	density of gas
μ_g	viscosity of gas
ε_b	volume fraction of bubbles in the bed

outrages. It damages the image of FBC installations by reducing reliability of electricity production from rice husk and in addition, it negatively influences the investments in future fluidized-bed combustion projects. Our finding will also help to explain the reasons of defluidization of fluidized bed at Jalkheri Power Plant.

1.1. Literature survey (Combustion of biomass/rice husk and modeling of fluidized bed reactors)

The first attempt to model fluidized-bed combustors was presented by Yagi and Kunii [45], who did not consider, however, the presence of the bubble phase. A big impulse to fluidized-bed combustion modeling was given in the 70s and 80s. Since then a great amount of models has been presented in literature as reviewed by La Nauze [24] and Adanez and Abanades [1]. Most models apply the two-phase theory of fluidization [12] in order to characterize bubbling bed fluid dynamics. A limited number of models assume the presence of three phases. Reddy and Mohapatra [36] developed a mathematical model using three-phase theory of fluidization and results are validated with commercial power plant of 10 MW capacity using coal washery rejects.

Combustion of biomass [14] in fluidized beds is becoming more and more attractive as a result of the constantly increasing price of fossil fuels, the presence of high quantities of biomass to be disposed of and global warming issues. Fluidized-bed technology usually is the best choice, or sometimes the only choice, to convert biomass to energy due to its fuel flexibility and the possibility to achieve an efficient and clean operation. Extensive experimental investigation has been carried out to date on the feasibility and performance of biomass combustion and gasification in fluidized beds. Even if a great amount of operating data has been collected so far, detailed comprehension of the basic mechanisms taking place during conversion in fluidized beds of biomass is still lacking. Usually biomass is treated just like fossil fuels in spite of the great differences and variability of chemical and physical properties. Biomass usually have a much higher moisture and volatile content, a more porous and fragile structure, often anisotropic, a lower density and a much higher intrinsic reactivity. While basic phenomena in fluidized-bed combustion and gasification of these fuels are the same as those for fossil fuels, differences arise because of the different chemical and physical properties of these fuels that determine the greater or smaller relevance of the various phenomena. Drying time is usually longer due to the higher moisture content of these fuels and results in small delay of the subsequent devolatilization, but in general has a limited influence on overall performance. The high-volatile content of biomass leads to longer