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Experimental Study on Suppression of Agglomeration of Particles in Fluidized Bed Combustion of Biomass.

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Abstract- Fluidized Bed Combustion (FBC) is one of the most promising energy conversion options available today. The use of biomass fuels in FBC is becoming more important because of the environmental benefits associated with these fuels and processes. However, severe bed agglomeration and de-fluidization have been reported due to the special ash forming constituents of some biomass fuels. The alkali compounds from biomass ash have tendency to accumulate especially in a bed with sand particles. For typical cases of FBC of straw, wood and sewage sludge, the experimental results on fluidized bed particle agglomeration are presented and feasible ways for agglomeration abatement are critically assessed.

I. INTRODUCTION

The use of biomass fuels in FBC is becoming more important because of the environmental benefits associated with these fuels and processes. FBC of biomass is complicated often by agglomeration of particles within the bed. Problems in FBC [1] of biomass (straw, grass, rice hulls, wood chips, sewage sludge, etc.) are often caused by higher content of "free" alkali (alkali, water soluble salts) compounds and their interaction with "inert" fluidized bed particles [2 - 7] . The low temperature melting point of ash constituents and their higher volatility can induce particle agglomeration, defluidization in the fluidized bed and further problems, like fouling and corrosion in boiler heat extraction tubing system [6, 7]. The minimum fluidization velocity U_{mf} as function of temperature is normally slightly decreasing with increasing temperature (over 600°C). Due to sintering and sticking of particles, the U_{mf} is increasing sharply from some definite characteristic ("initial sintering") temperature [1,5]. The initial sintering temperature of particles within the bed is in a close relation with phase and melting behavior of biomass ash [5, 8]. Methods for reduction of particle agglomeration tendencies are various: pre-treatment (e.g. water leaching) of biomass to reduce content of water soluble alkali salts (esp. potassium), change of fluidized bed particles, periodic exchange of spend fluidized bed material, combustion of bi-multi fuel briquettes, co-combustion of biomass with suitable kind of coal, lower combustion temperature, higher gas velocity etc.

II. BIOMASS FOR FBC

Three typical kinds of biomass for firing have been chosen: straw, mixed wood chips and paper mill sewage sludge. The basic data from proximate and chemical ultimate analysis of the three biomass materials are collected in Table I. Ash composition of the biomass materials studied is given in Table II.

TABLE I
ANALYSIS OF WHEAT STRAW, WOOD CHIPS AND SEWAGE SLUDGE.

Proximate analysis	Wheat straw	Wood Chips	Dried sewage sludge
Volatile	66	76	65
Fixed carbon	16.3	16.4	12
Ash	6.6	0.31	15.3
Moisture	7.4	5.2	2.4
Ultimate analysis			
C	47.5	50.0	52.3
H	6.7	5.2	4.6
N	1.12	0.21	1.02
0	---	---	--
S	0.21	0.0 2	--
Heating value (KJ/kg)	15700	17400	16500

TABLE II
ASH COMPOSITION OF BIOMASS STUDIED.

Ash constituents	Straw ash	Wood ash	Sewage sludge ash
SiO_2	37.6	44	16.4
$A1_2O_3$	0.93	6.5	---
Fe_2O_3	0.92	4.1	11.1
CaO	9.5	26	----
MgO	2.2	4.4	17.23
Na_2O	0.40	0.63	35.7
K_2O	27.3	14.3	----
SO_3	3.1	----	15.7
P_2O_5	4.3	5.2	---

Sewage sludge from a paper mill (cellulose production) characterized by higher Al and (SO_4) content had origin in mechanic and mechanic-chemical cleaning process of waste water. Such sewage sludge is characterized by higher content of hydrated aluminium oxide. The content of sulphate in the sludge is from the wood processing in cellulose production (Na_2SO, CaSOx and MgSO,). Thermo gravimetric (TG) analysis of the sewage sludge gave information on devolatilization (mainly in the range of temperatures 200 - 700°C). Differential thermal analysis has approximated beginning of burning to be about 300 - 320°C. The significant endo-effect in temperature range 750 - 900°C can be coupled with salt decomposition and/or melting. The beginning of straw ash melting is, according to DT-analysis, at temperatures about 750-770°C. From the point of view of melting tendencies, the wood ash was relatively the most stable (up to temperatures over 800°C). The size of biomass particles used for feeding to the fluidized bed were: straw (briquette): 1-5 mm , wood chips: 0.5-5 mm , dried sewage sludge:0.4-0.8 mm (0.5-2 mm).

II. EXPERIMENTAL APPARATUS

Feasible experiments on FBC of the biomass materials and agglomeration studies have been performed in a pilot scale unit with cylindrical reactor (ED = 85 mm) made of heat resistant steel. Perforated steel plate with holes (Dh = 0.8 mm) was used as air distributor. The height of the steel tube above the distributor was 500 mm. The reactor was equipped with electrical preheating of inlet gas and with auxiliary electrical heating and temperature control. The scheme of the experimental facility with feeding is shown in “Fig. 1”.

Feeding device enabled dosing of variable charges of biomass, from 20mg to 800 mg/charge, Sand particles (Dp = 0.2 - 0.3 or 0.3 - 0.5 mm) served as the "inert" material in the fluidized bed. Height of the fluidized bed at incipient fluidization was about 80 mm.

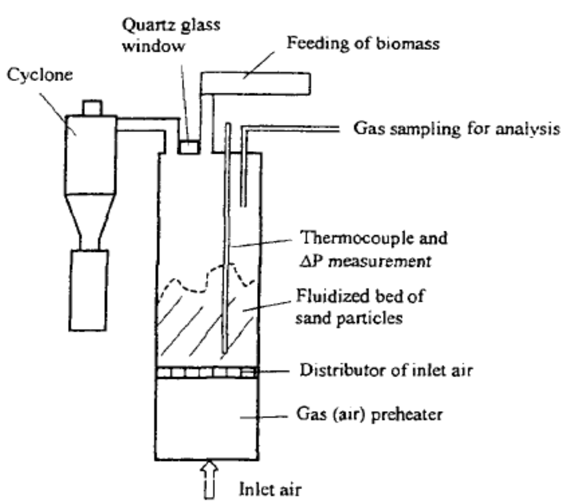

Fig. 1. The experimental unit for biomass burning and agglomeration

The linear gas velocity within the reactor was about 100 and 200 mm/s for two sand size fractions (2-2.5*U_{mf}) . The range of temperatures 700- 900^{0}C has been chosen for the experiments. The behaviour of fluidized bed and particle agglomeration has been observed by means of the quartz glass window in the lid of the reactor. The state of defluidization has been determined from pressure drop ΔP of the bed and pressure fluctuations.

III. RESULTS AND DISCUSSION

A. Influence of operating parameters on agglomeration

In the case of straw and sewage sludge combustion all experiments on FBC with sand as the bed material finished with agglomeration and defluidization. The time needed for defluidization has been observed to by influenced mainly by operating, fluidized bed temperature, slightly by air velocity and sand particle size within the bed. The typical results for straw are given in “Fig. 2”.

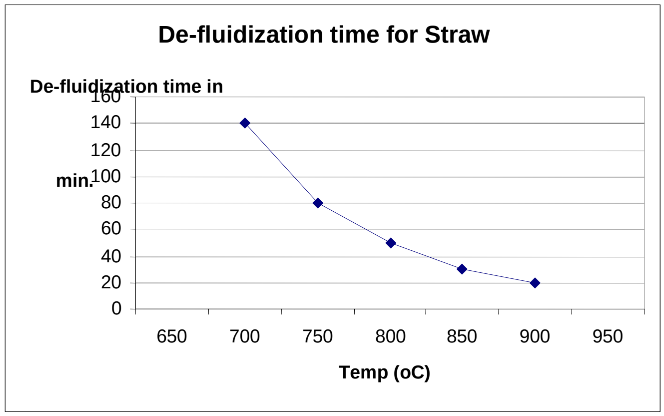

Fig. 2. Influence of FBC temperature on time needed for

Ash components	1.Sand (mass %)	2.Ceramsite (mass %)	3.Lignite ash
SiO_2	97	73	44
$A1_2O_3$	0 .8	11	33
Fe_2O_3	-	13	11
CaO	0 .10	2.4	2.4
MgO	-	2	1
Na_2O + K_2O	-	2	3

defluidization

Temperatures of FBC about 900°C have led practically always to fast development of particle agglomeration with fast development of defluidization. Better behavior of the fluidized bed has been observed for wood chips combustion. The temperatures below 800 - 820°C were relatively safe for longer combustion tests. Nevertheless even in the case of wood FBC the agglomeration initiated after longer time at temperatures about 850°C. Concentration of oxygen in flue gas was between 6 and 8 vol. %.

B. Influence of bed material on the defluidization

Three fluidized bed material have been tested: sand, ceramsite and lignite ash with higher content of Al_2O_3. The chemical composition of the materials is given in Table III.

TABLE III

APPROXIMATE CHEMICAL COMPOSITION OF THE BED MATERIALS (1, 2, and 3.) TESTED

The results from tests with the three fluidized bed materials for FB temperature 850°C are shown in "Fig. 3". The tests are confirmed, that ceramic materials containing higher Al_2O_3 concentrations are suitable as "inert" bed material for biomass combustion.

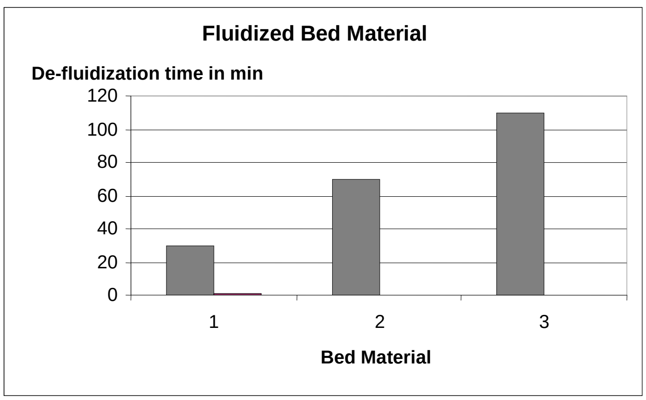

Fig. 3. Influence of fluidized bed material on defluidization time (t = 850°C)

C. Influence of co-firing coal and biomass (straw, sewage sludge and wood)

Define abbreviations and acronyms the first time they are used in the text, even if they have been defined in the abstract. Abbreviations such as MITIJ, SI, MKS, CGS, ac, dc, and rms do not have to be defined. Do not use abbreviations in the title unless they are unavoidable.

Combustion of bi-multi fuel briquettes, Co-firing of biomass with coal is another option for mitigation the agglomeration tendencies in the fluidized bed. Especially high ash coals with higher content of alumina in ash are capable to improve fluidized bed behavior. The sub bituminous coal used in our case has 25 % of ash. The ash contains higher amount of SiO_2 and Al_2O_3 (about 40 mass %) and low content of alkali metals (below mass 3%). The experimental results on co-firing paper mill sludge with 40 mass % of coal are in "Fig 4".

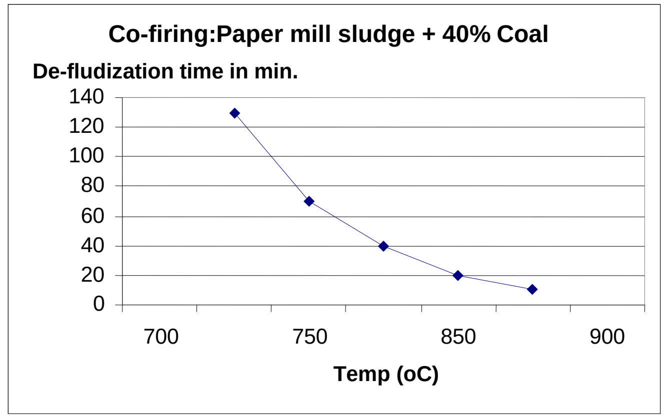

Fig. 4. co-firing paper mill sludge with 40 mass % of coal

The co-firing is now well proved method of abatement the problems with particle agglomeration in biomass combustion.

D. Composition of fly ash and bottom ash - partition of alkali metals

During fluidized bed combustion of biomass the comminution phenomena (fragmentation, attrition) together with carbon elutriation and in situ reactions and partition of various metals, chlorine and sulfur play a significant role in initiation of eutectic mixture formation and initiation of the agglomeration process. An example of comparison of composition of fly ash and bottom ash in FBC of the paper mill sewage sludge is given in Table IV.

TABLE IV
PARTITION OF ALKALI METALS AND Al BETWEEN FLY ASH AND BOTTOM ASH AND COMPARISON WITH "AVERAGE" ASH COMPOSITION FROM FIXED BED COMBUSTION OF THE SLUDGE IN MUFFLE FURNACE.

Content	Muffle furnace	FBC –fly ash	FBC –bottom ash
Ash from sludge II	10.3%	3 -5%	4 -6%
Al content in ash	26	30-33	20-22
(Na + K)in ash	12.1	5 -6.3	20-23
$(SO_4)^2$	19.2	9.0	28

The $A1_2O_3$ from fly ash was totally soluble in diluted sulfuric acid unlike the Al_2O_3 from bottom ash agglomerates in FBC of the sludge.

E. Influence of water leaching (straw, wood) on content of water soluble alkalies

Pretreatment, esp. leaching of biomass (with water, diluted acids etc.) can significantly reduce content of alkali metals (Na + K) and partly reduce content of Ca and Mg in biomass. The water leaching can be efficient in the case of straw, grass and "softer" biomass. Application of leaching for reduction of alkalies in wood is less successful (Table V.). The efficiency of the water leaching depends on disintegration of biomass, duration end intensity of leaching, rinsing, pressing, dewatering, drying etc. The leaching process of biomass with involved drying can be, of course, economically unacceptable.

TABLE V.
COMPARISON OF REMOVAL EFFICIENCIES OF ALKALIES AND CHLORINE FROM STRAW AND WOOD..

Component	Straw		Wood	
	unleached	leached	unleached	leached
Ash	7	5	0.35	0.30
K_2O	1.8	0.63	0.07	0.051
Na_2O	0.5	0 24	---	----
CaO	0.55	0.36	0.07	0.06
Cl	1.4	0.3	---	---

IV. CONCLUSION

FBC of biomass is complicated by "in bed" particle agglomeration, which can cause after some time of running full defluidization.

In the case of FBC of only biomass (without any accompanying fuel) three factors are significant for mitigation of problems:

Choice of suitable inert particulate material (e.g. alumina based or SiO_2-Al_2O_3 rich coal ash), choice of relatively lower combustion temperature (practically about 800°C) and frequent exchange of spent bed material containing agglomerated and alkali enriched particles.

In case of possible co-firing (e.g. with coal) the agglomeration can be controlled by blending coal/biomass ratio and by choice of a coal with suitable ash composition. The severity of agglomeration problems in FBC of straw, dried paper mill sludge and wood are different - in order: straw « paper mill sewage sludge » wood.

In practical cases of FBC of biomass, choice of suitable "inert" particulate bed material, sound and safe ratio of biomass/coal in co-combustion and temperatures below 850°C are the most practical methods, how to avoid problems with agglomeration and defluidization.

When co-combusted with coal, agglomeration can be effectively prevented. The in-bed ash compositions in both cases are alerted towards higher melting temperatures and the reason may be that the coal ash will act as a physical and/or chemical absorbent for the fluxing elements in the biomass ashes.

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