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CO-COMBUSTION OF MUNICIPAL SEWAGE SLUDGE WITH CASTER SEED SHELL IN BUBBLING FLUIDIZED BED COMBUSTOR UNDER OXYGEN-ENRICHED CONDITION: EXPERIMENTAL INVESTIGATION

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Abstract: In India, municipal sewage sludge (MSS) disposal is one of the most complex environmental problems. Incineration is one of the promising technique to undertake this problem which utilized the heating value of the MSS to produce energy and reduced the sludge volume to small-stabilized ash. Generally, MSS having low calorific value and high moisture contents. The co-incineration of MSS with coal or other fuels overcome the problem of burning low calorific MSS. Oxy-fuel fluidized bed combustion technology provides the most favorable environments for the combustion of solid fuels having the moisture content up to 60%, which results in maximum amount of carbon dioxide, which is easy to control. Co-combustion with oxy-fuel fluidized bed has potential for negative CO_2 emission level for power generation. Co-combustion of municipal sewage sludge (MSS) with caster seeds shell (CSS) has been investigated in oxygen-enriched bubbling fluidized bed (BFB) combustor. The tests are performed with two different ratios of MSS/CSS is 25%/75% and 50%/50%. This work extensively investigates the temperature profile, flue gas emission, and the performance of co-combustion MSS with CSS under air-fired and oxy-enriched condition.

1 INTRODUCTION

Due to industrial revolution and urbanization a hue amount of municipal sewage sludge (MSS) is generated in India. Handling of this huge amount of MSS is one of big challenge. To takle such problem and to provide a healthy environment to human being Indian government launch a scheme “Clean India Mission”. To successfully accomplish this goal, India requires to implement or test new advance technologies for energy security, clean environment, and waste management. Four methods generally used for the disposal of MSS are land filling, dumping in sea, used as a fertilizer in agriculture field and incineration under controlled environment. What still these technique has some major issues like (Gupta, Yadav, and Kumar 2015): as land filling takes up a lots of land and contaminates, dumping into sea is harmful, some of MSS products are not suitable for the agriculture, and MSS has low calorific value and high moisture content which make it difficult to burn efficiently. Among these all methods incineration of MSS in a fluidized bed combustor is one of the promising method which gives the advantage of burning low calorific and high moistures MSS under controlled environment. Fuel flexibility is the one of major advantage of the FBC. Incineration of MSS in FBC utilized the heating value of the MSS to produce energy and reduced the sludge volume to small-stabilized ash. Werther et al. (Werther and Ogada 1999) discussed the three groups of thermal processing of sewage sludge like; mono combustion incineration, co-combustion and alternative process. The co-incineration of MSS with coal or other fuels overcome the problem of burning low calorific MSS. Three types of bed are used for combustion are bubbling fluidized bed (BFB), circulating fluidized bed (CFB), and pressurised fluidized bed (PFB). BFB & CFB are used extensively for MSS incineration worldwide where's PFB is under initial stage. Some other advanced combustion technologies like oxy-fired or oxygen-enriched fluidized bed combustor are under developing stage and it can take years to utilize the benefits of this technology(Singh and Kumar 2016). Co-combustion of municipal sewage sludge with biomass under oxygen-enriched or oxy-fired condition has potential to overcome the existing problem and gives some advantages over conventional technologies (Jang et al. 2016).

The main objective of present work is to investigate the combustion and emission characteristics of co-combustion of MSS with biomass in a bubbling fluidized bed combustor under oxygen-enriched (O-E) conditions. Castor seeds shell (CSS) an agriculture waste is used for co-combustion with MSS which is available in surplus quantity in Rajasthan, India ("Biomass Fuel Report Prepared by ABI Energy Consultancy Services Private Limited" 2015). The satisfactory combustion of selected blend will increase the share of renewable energy resource, reduce the problem of MSS disposal and provide some clean energy. A ratio of 25%MSS/75%CSS and 50%MSS/50%CSS is examined in BFB combustor and observations are made of the temperature profile, flue gas emission, and combustion efficiency.

2 METHODOLOGY

2.1 Fuel property:

In this study MSS and CSS (shown in Figure 1) are used for co-combustion. Two different ratio of MSS/CSS investigated are 25%/75% and 50%/50%. MSS used is collected from the sewage treatment plant Bits-pilani, pilani campus, India in dry form and CSS an agriculture waste is collected from the pilani village, India. The CSS is dried into direct sun light for at least 6 hour before use and then used directly. The particles of the CSS are less then 5mm and not require any further treatment. The proximate and ultimate analyses of MSS, CSS and blends are shown in the Table 1. The 25%MSS/75%CSS has the 16.98 MJ/kg gross calorific value (GCV) where's 50%MSS/50%CSS has 13.9 MJ/kg GCV. Sulphur concentration is not found in all blends.

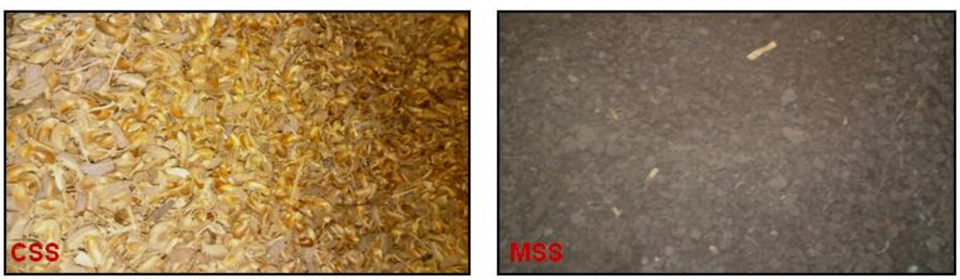

Figure 1: Fuel used for co-combustion (CSS and MSS)

Table 1: Properties of fuel used

	MSS	CSS	25%MSS/75%CSS	50%MSS/50%CSS
Proximate Analysis (Wt.%)				
Moisture	4	8.1	7.075	6.05
Volatile matters	17	69.22	56.166	43.11
Ash	59	8	20.75	33.5
Fixed carbon	20	14.68	16.01	17.34

Ultimate Analysis (Wt. %)				
Carbon	13	40.135	33.35	26.5
Hydrogen	1.8	4.991	4.19	3.35
Nitrogen	1.3	1.104	1.1805	1.2
Sulphur	--	--	--	--
Oxygen	14	30.668	26.5	22.3
GCV (MJ/kg)	7.8	20	16.98	13.9

2.2 Experimental setup and procedure:

The work described in this paper is performed in a 1.8 m long square bubbling fluidized bed combustor made of stainless steel SS310 is shown in Figure 2 a schematic view & in Figure 3 real image of test rig. The test rig consists two cyclones, one heat exchanger, hopper, ID fan, two blowers, data logger, and chimney. Combustor is insulated with ceramic fiberboard with inner side and with glass wool from outer side to minimize the heat loss. Three doors are provided in each zone of combustor as shown in Figure 3. A premixed fuel blend of MSS/CSS at different specified ratio (mass %age) is entered into the splash zone of combustor through hopper and screw feeder arrangement. To control the supply of fuel blend the screw feeder is driven by variable speed stepper motor. Pre-produced Ash in bed is used as a bed material. Primary air and oxygen for fluidization is passed into the bed from bottom of combustor through distributer nozzle. To burn the fuel particle which were transported from the combustor bed or splash zone to freeboard a secondary air or oxygen is supplied into the combustor freeboard though side. Temperature is measured at different location along the height of the combustor by placing 9-thermocouple on combustor at suitable height. LPG is used to initiate the combustion process. The port "S" in the freeboard is used to take measurement of gas concentration by employing "testo 350" portable gas analyser having pump volumetric flow rate 1 l/min (controlled), standard litre ±0.1l/min . The net thermal capacity of this system is below 20 kW. The combustor is made of stainless steel (SS310) to resist with higher temperature.

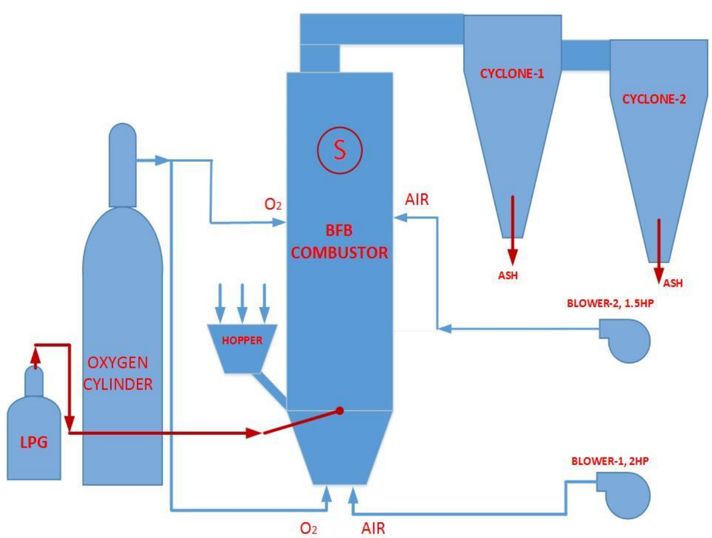

Figure 2: Experimental Setup

Figure 3: Actual picture of Bubbling Fluidized Bed Unit

Table 2: Experimental Setup Description

Plant Type	20 kW Bubbling fluidized bed combustor
Auxiliary systems	Gas supply system, solid feeding, gas analyzer, internal heat exchanger, ID fan. Cyclone
Test Conducting Option	Oxygen-Enriched (O-E) combustion mode, Air-Fired (A-F) combustion mode
Combustor Material	Stainless steel
Combustor Dimensions	1.8 m long square Combustor
Fuel Used:	Municipal Sewage Sludge (MSS), CSS (Caster Seed Shell)
Bed material	Ash
Reactant Gas	Air, O_2
Instrument	Thermocouple, Data Logger, “Testo 350” professional portable gas analyzer

2.3 Performance measure

Combustion efficiency measure of how efficiently energy from the fuel is converted into useful energy. Here the combustion efficiency is calculated by the following equation

$$\textit{Combustion efficiency}, \quad \eta_C = 100 - S_L \qquad (1)$$

Flue gas passing out of the stack is calculated by "Siegert" formula as follows(Kumar and Singh 2016) ;

$$S_L = k_S \times \left[\left(T_{fg} - T_a \right) / CO_2 \right] \qquad (2)$$

The Siegert constant value for 25%MSS/75%CSS is 0.46 and for 50%MSS/50%CSS is 0.49.

(S_L- Stack loss, k_s-"Siegert" Constant, T_{fg}- Flue gas temperature in ^oC, T_a - ambient air temperature)

3 RESULTS AND DISCUSSIONS

Tests are performed for 25%MSS/75%CSS and for 50%MSS/50%CSS in a 20kW bubbling fluidized bed combustor under A-F and O-E condition when steady state is reached to investigate the effect of MSS on the performance of a fluidized combustor and gas emission. The steady state is reached within 5 to 6 hours of operation. The oxygen is enhanced up to 8-10% for O-E conditions and a constant fuel feed rate of approximately 6 kg/hr for 25%MSS/75%CSS and 4 kg/hr for 50%MSS/50%CSS was maintained throughout each experiment.

3.1 Temperature profile & flue gas emission:

Both fuel blends are burned inside the combustor smoothly and efficiently. Temperature is recorded for the combustor bed, splash zone and freeboard along the height by employing thermocouple and data logger. Figure 4 shows the temperature variation along the height of combustor for both blends of MSS/CSS under both A-E and O-E conditions. Combustion for both the fuel blends is even and transition from the A-E to O-E is smooth. It observes that the maximum fuel blend is burned in the splash zone and freeboard for both fuels. This is because the density of fuel is low and fuel burn above the bed in splash zone and freeboard. A similar trend of temperature variation is observed for all cases. The maximum temperature in combustor is observed in the splash zone because most of the fuel burnt above the bed in splash zone and freeboard. Remaining fuel is burned in the freeboard. Combustion is improved inside the combustor under O-E condition when extra amount of primary oxygen introduced to bed through distributor and secondary oxygen to splash zone. Under O-E condition combustion is smooth and burning is improved in the freeboard. 50%MSS/50%CSS under O-E condition has the highest combustor temperature than others cases, because density of 50%MSS/50%CSS is more than 25%MSS/75%CSS, secondly under O-E condition extra amount of oxygen is available for complete combustion.

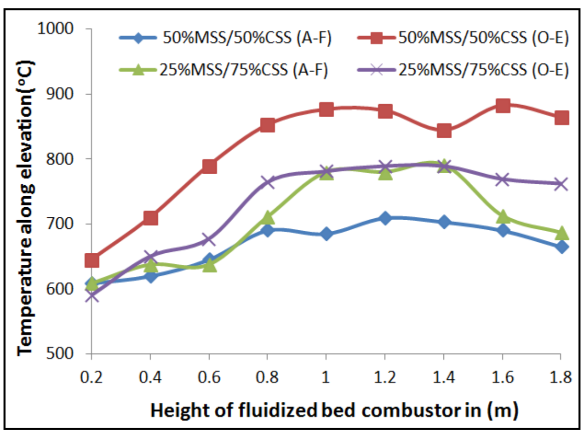

Figure 4: Temperature variation along height of combustor for both A-E and O-E condition.

3.2 Flue gas emission

The species concentration of gas emission is measured in the freeboard by using "testo 350" professional portable gas analyzer, when steady state is reached by. In Figure 5 CO concentration for MSS/CS under both A-E and O-E condition is shown. Under O-E condition combustion is improved and became more stable as the oxygen content is higher. It observed that the amount of carbon monoxide decreases with increase in oxygen concentration. There is no any remarkable difference was observed in CO concentration for both fuel blends.

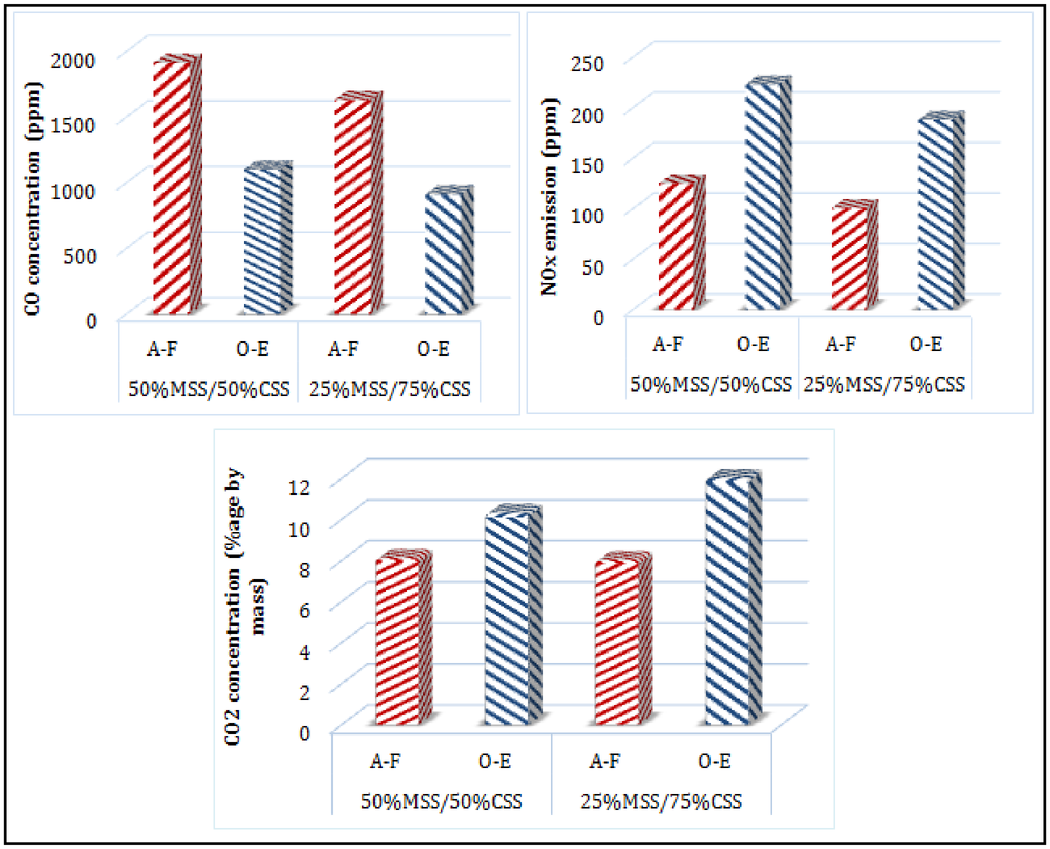

Figure 5: Gaseas emission under A-F and O-E condition

NOx concentration for both ratio of MSS/CS under steady-state A-E and O-E condition is shown in Figure 5. Generally, NO x production depends on nitrogen contents in fuels and it increases with increase in temperature. From Table 1 it observed very little amount nitrogen content for both fuel blends and hence NOx emission here much depend on temperature increase. With increase in oxygen concentration inside combustor, the combustion rate is increased which further increases the temperature and hence NOx increases. Maximum NOx emission was observed for 50%MSS/50%CSS under O-E condition.

CO_2 concentration by mass %age for both A-E and O-E condition is given in Figure 5. CO_2 concentration in emitted gases is increased with oxygen enhancement in the combustor, which is responsible for increase in combustion rate. In this work, maximum CO2 is observed for 25%MSS/75%CSS under O-E condition.

3.3 Combustion efficiency

Figure 6 shows gives combustion efficiency for both fuel blend under different condition, A-E and O-E and it observed that the combustion efficiency increases as the oxygen concentration is increased inside the combustor because the rate of the fuel oxidation is proportional to power of oxygen concentration. A maximum possible combustion efficiency of 96 % is achieved for 25%MSS/75%CSS under O-E condition.

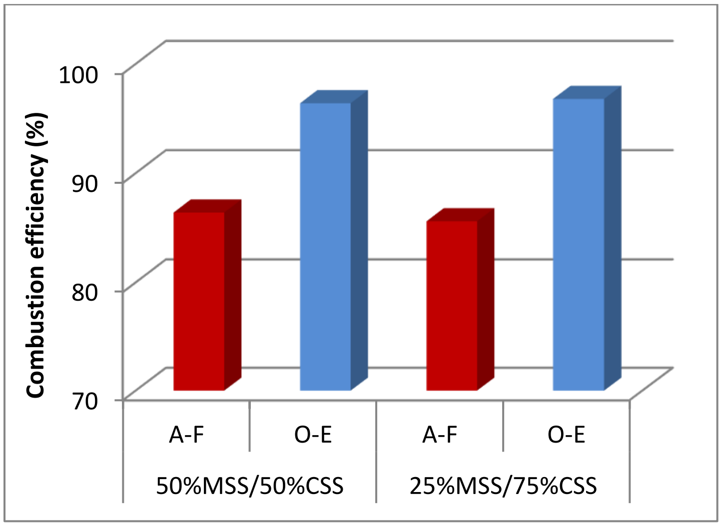

Figure 6: Combustion efficiency for 50%MSS/50%CSS and 25%MSS/75%CSS under A-E and O-E condition.

4 CONCLUSION

An experimental study of an oxygen-enriched (O-E) bubbling fluidized bed combustor has been carried out for co-combustion of MSS with CSS (for two ratio 25%MSS/75%CSS and 50%MSS/50%CSS) to examine the combustor zone temperature, emission, combustor performance under air-fired and oxy-fired condition. The following points are concluded from the above study.

1. MSS as a co-fuel burned successfully with CSS base fuel under bubbling fluidized bed combustor and the burnout of the blend is improved under O-E condition.

2. With the increase in oxygen concentration in supply gas combustion rate increases and the concentration of CO reduces and NOx concentration increases. The CO_2 concentration in flue gases is increased as a result of oxygen enhancement in supply gas.

3. The combustion inside the combustor was smooth. A maximum possible combustion efficiency of 96.5 % was achieved under O-E conditions for 25%MSS/75%CSS.

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