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Thermogravimetric assessment of combustion characteristics of blends of a coal with different biomass chars

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ABSTRACT

In connection to future energy demand and fossil fuel crisis particularly in India, biomass is gaining its importance for possible use as co-fuel. In India varieties of biomass products are available which do have tremendous potentiality for co-combustion with pulverized coal. Based on the emerging need, detailed investigations are felt necessary to examine the compatibility of different kind of biomass with coal and to select suitable blend composition(s) before utilizing those biomass products in utility operation as co-fuels. This study elaborates the lab scale findings of combustion experiments in DSC–TGA apparatus with a typical Indian coal, two biomass samples and low temperature biomass chars (300 and 450 °C) as well as with 'blends of low temperature chars and coal'. Conventional TGA parameters, activation energy and ignition index of different blends were estimated which provided elaborate information on their basic combustion features. Results of non-isothermal combustion studies in general depict that blends containing less than 50% biomass char are better performing as compared those with higher biomass char content. Lowering of activation energy and improvement of reactivity in major combustion zone were also observed in the coal/biomass-char blends. Improvement of ignition index of the blends of coal with 300 °C chars over expected weighted mean values was noticed. Such attempts may help to identify appropriate biomass-type, blend proportion for a given coal and to derive some specific advantages with respect to particular combustion practice.

1. Introduction

Power generations from coal/biomass blends are increasingly gaining importance as a renewable energy source resulting in reduction of CO_2 emissions. As a matter of fact co-firing and co-gasification of fossil fuels and biomass (saw dust, rice husk, coconut coir, straw, corn-cob etc.) are presently being considered because partial replacement of precious fossil fuel is possible in such cases, which give extensive support to the growth of power sector in developing countries like India. Biomass co-combustion also represents a low cost, sustainable, renewable energy option that promises reduction in net CO_2, SO_x and often NO_x emissions and also in the anaerobic release of CH_4, NH_3, H_2S, amides, volatile organic acids, mercaptants, esters, and other chemicals leading to several societal benefits [1–7].

Though many technical issues are yet to be resolved, co-combustion is possibly the best energy option for the power producers from time now on. Actually strictures in respect of GHG emission and scenario of fossil fuel depletion strengthened the foundation of the rationality for co-combustion. Biomass fuels have sometimes been reported to have peculiar combustion features particularly when they are subjected to thermal shock [8]. Biomass fuels having much volatile matter content, may find their possible utilization in co-firing with low volatile coals. As compared to coal, biomass fuels contain higher volatile matter with higher oxygen content and as such possibility of easy release of volatile matter in a combustor is more. All these characteristics of biomass have been found to have large influence on the burn out time of blends of coal and biomass [8–11].

In Indian context use of saw dust and rice husk in power generation is very important particularly in the rural areas where plenty of availability of such materials exists. Co-firing of biomass with coal may also be an option to promote decentralized power generation policy for economic growth of rural sector. Moreover, this is a fact that non coking coals which are mined in India do have high ash and low to medium volatile matters. Therefore, apart from the saving of precious fossil fuel gainful utilization of those coals are also possible in case those are co-fired with biomass.

It has been observed that in co-combustion with fossil fuel, use of biomass chars may be a preferred option instead of raw biomass [12,13]. It has been reported by Kastanaki et. al. [12] that biomass chars obtained after partial devolatilization are more reactive than those obtained from coals. Biomass chars were found to have porous and highly disordered carbon structure and belong to the class of most

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reactive carbon materials. The porosity within the chars causes more accessibility of the reactive gas to active sites resulting in the very good combustion reactivity.

TGA (Thermogravimetric analysis) has been extensively used by several researchers for investigation on basic combustion property of solid fuels. While a number of studies on biomass combustion with TGA have been reported, very few number of TGA studies are available in literature concerning co-firing of coal and biomass and studies on 'coal–biomass char' blends are even less [13–17]. On the other hand, very few studies on kinetics of co-combustion have been reported [12,18,19] wherein those with coal–biomass char blends are very rare [12].

Under the above scenario it is felt that co-combustion of high ash Indian coal and different categories of biomass needs further investigations and extensive basic studies for their possible application in bigger scales. In the present study the concept of using biomass chars in place of raw biomass have been implemented. The use of char prepared at predefined temperature may help to maintain desired heat value of the fuel and appropriate fuel ratio (FC/VM). This paper presents the combustion characteristics (obtained from studies in simultaneous TG–DSC apparatus) of a medium volatile high ash Indian coal, saw dust, rice husk and their chars prepared at two different temperatures and their blends. Two different blend combinations of coal and biomass char (prepared at 300 °C and 450 °C) were selected and attempts were taken to evaluate combustion behavior of different blends of varying compositions by using simultaneous TG–DSC apparatus. Activation energies for combustion of coal, chars (300 °C, 450 °C) and of different coal–char blends under identical condition were evaluated using single step first order reaction model to examine the effect of blending on resulted activation energy. Moreover, in this paper it has been examined whether char blend kinetics can be predicted from the kinetic parameters for char/coal combustion. Calculated rate curves for the blends based on DTG profiles of char and coal were considered in this study to see the deviation of the experimentally observed rate curve from the respective calculated curve. Here, trends of burning characteristics of the blends have also been examined with respect to conventional DSC–TGA parameters [20], ignition index [21], etc. Such studies may help to identify suitable blend combination as well as blend composition particularly in respect of co-combustion.

2. Experimental

2.1. Coal selection and sample preparation

For this study one medium volatile coal and two numbers of biomass samples (saw dust and rice husk) were chosen as constituents for sample preparation. The coal sample was crushed to −3 mm size at first and subsequently crushed to −212 µm size. Saw dust (SD) and Rice husk (RH) samples were locally collected from saw and rice mill and were sun dried and equilibrated under laboratory condition to reduce moisture content. Each of the biomass samples was pyrolysed at 300 °C and 450 °C to obtain two different char samples. Char samples were pulverized to −212 µm size. Blend combinations were prepared using each of those low temperature chars and coal. Biomass char was used in the blend instead of raw biomass because of the following reasons:

(a) it makes grinding easy and therefore requires less energy for grinding.
(b) volatile matter (VM) may be adjusted to a desired level in accordance with the VM level of the coal to maintain appropriate range of fuel ratio required for satisfactory combustion performance.
(c) heat value of char (on unit mass of char) is more than that of biomass (on unit mass of biomass): that is, heat value of fuel may be improved through low temperature pyrolysis.

Sawdust (SD) and rice husk (RH) chars were blended with single coal to prepare different binary blends with varying proportion of coal:biomass. Coal:sawdust char ratios in different blend compositions have been selected as 90:10, 80:20, 70:30, 50:50, and 30:70 which have been designated as CSD1,CSD2, CSD3, CSD4 and CSD5 respectively. For coal–rice husk char combination, coal:rice husk char compositions were taken in the ratios of 90:10, 80:20, 70:30, 60:40, and 30:70 which have been designated as CRH1, CRH2, CRH3, CRH4 and CRH5 respectively. All the blend samples, coal sample and char samples were further ground to −75 µm size for studying the combustion characteristics.

Table 1
Proximate analysis (wt.%, air dried basis), Ultimate analysis (wt.%, daf basis) and GCV (daf basis) of coal, sawdust and their blends.

Sl. No.	M	A	VM	FC	C	H	N	S	O	GCV kcal/kg	Fuel Ratio
Coal	3.9	47.5	21.7	26.9	76.5	4.9	1.38	0.31	16.8	6708	1.24
SD Raw	7.4	8.4	69.5	14.7	42.9	3.2	0.12	0.05	53.8	2531	0.21
SD 300	4.7	8.6	29.4	57.3	72.0	2.7	0.14	0.06	25.2	5711	1.95
SD 450	4.6	11.4	17.1	66.9	84.6	3.1	0.15	0.06	12.0	7352	3.91
CSD1–300	4.0	43.6	22.5	29.9	75.8	4.6	1.17	0.27	18.2	6608	1.29
CSD2–300	4.1	39.7	23.2	33.0	75.1	4.2	1.00	0.23	19.4	6509	1.35
CSD3–300	4.1	35.8	24.0	36.0	74.6	3.9	0.84	0.20	20.4	6409	1.41
CSD4–300	4.3	28.1	25.6	42.1	73.6	3.5	0.58	0.15	22.2	6210	1.55
CSD5–300	4.5	20.3	27.1	48.2	72.9	3.1	0.38	0.11	23.6	6010	1.69
CSD1–450	4.0	43.9	21.2	30.9	77.8	4.6	1.18	0.27	16.1	6772	1.37
CSD2–450	4.0	40.3	20.8	34.9	79.0	4.4	1.01	0.23	15.4	6837	1.51
CSD3–450	4.1	36.7	20.3	38.9	80.0	4.2	0.86	0.20	14.8	6901	1.68
CSD4–450	4.3	29.5	19.4	46.9	81.7	3.8	0.60	0.15	13.8	7030	2.08
CSD5–450	4.4	22.2	18.5	54.9	83.0	3.5	0.40	0.11	13.0	7159	2.62

Table 2
Proximate analysis (wt.%, air dried basis), Ultimate analysis (wt.%, daf basis) and GCV (daf basis) of coal, rice husk and their blends.

Sl. No.	M	A	VM	FC	C	H	N	S	O	GCV kcal/kg	Fuel Ratio
Coal	3.9	47.5	21.7	26.9	76.5	4.9	1.38	0.31	16.8	6708	1.24
RH Raw	10.9	15.4	58.6	15.1	47.9	6.8	0.29	0.04	45.0	4462	0.26
RH 300	5.5	32.2	28.1	34.1	69.9	5.8	0.35	0.06	23.9	6644	1.22
RH 450	3.9	42.8	14.0	39.3	77.7	5.6	0.41	0.08	16.2	7493	2.81
CRH1–300	4.1	46.0	22.3	27.6	75.7	5.0	1.25	0.28	17.7	6701	1.24
CRH2–300	4.2	44.4	23.0	28.3	74.9	5.1	1.13	0.25	18.6	6695	1.23
CRH3–300	4.4	42.9	23.6	29.1	74.2	5.2	1.02	0.22	19.3	6689	1.23
CRH4–300	4.5	41.4	24.3	29.8	73.5	5.3	0.91	0.20	20.1	6682	1.23
CRH5–300	5.0	36.8	26.2	31.9	71.5	5.6	0.61	0.13	20.2	6663	1.22
CRH1–450	3.9	47.0	20.9	28.1	76.7	5.0	1.27	0.28	16.8	6786	1.40
CRH2–450	3.9	46.6	20.2	29.4	76.8	5.1	1.17	0.26	16.7	6865	1.55
CRH3–450	3.9	46.1	19.4	30.6	76.9	5.2	1.07	0.23	16.6	6943	1.71
CRH4–450	3.9	45.6	18.6	31.9	77.0	5.2	0.97	0.21	16.6	7022	1.87
CRH5–450	3.9	44.2	16.3	35.6	77.4	5.4	0.68	0.14	16.4	7258	2.18

Table 3
Combustion parameters of coal, saw dust and their blends.

Sample	Ti (°C)	DSC (°C)	DTG (°C)	R_{max} (%/min)	BOT (°C)	log A (S^{-1})	Eact (kJ/mol)	Correlation coefficient	Di $*10^3$
Coal	359.2	423.0	419.5	6.18	487.2	7.5376	132.3827	0.9991	4.66
SD Raw	243.0	421.8	417.3	10.4	448.6	0.1586	32.7678	0.9909	–
SD 300	285.5	419.6	414.5	7.54	482.0	3.1316	74.0066	0.9974	7.31
SD 450	330.7	423.3	387.2	9.27	473.0	6.5574	117.2414	0.9997	8.27
CSD1–300	334.4	401.3	397.9	8.68	488.2	6.4678	116.6786	0.9980	7.4
CSD2–300	324.5	401.3	399.3	8.28	486.8	6.0200	110.6603	0.9983	7.25
CSD3–300	319.5	412.2	406.8	7.18	489.0	5.4089	103.4286	0.9990	6.31
CSD4–300	304.6	401.5	397.2	10.5	481.3	5.2342	99.5035	0.9986	9.99
CSD5–300	293.3	390.9	387.1	10.86	477.1	4.5853	90.7541	0.9994	11.05
CSD1–450	341.6	421.8	418.7	5.94	503.8	5.8828	111.6275	0.9988	4.71
CSD2–450	336.5	418	408.3	7.22	504.2	5.8212	110.1338	0.9982	6.01
CSD3–450	336.0	407.1	403.8	6.93	495.7	5.5335	106.4713	0.9990	5.81
CSD4–450	335.4	407.5	401.4	6.74	489.5	5.8294	109.9404	0.9996	5.68
CSD5–450	330.9	424.4	417.7	8.82	479.2	7.0679	125.2719	0.9999	7.31