Co-firing of Brown Coal &Bagasse for Sulfur Reduction

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Abstract-Biomassresources such as bagasse, sawdust, rice husk, wheat husk, coconut etc play the vital role in reducing the concentration of SOx and NOx gases when used in co-combustion mode. This study focused on characterization and emission analysis of coal and coal-biomass blends. The blends of brown coal with bagasse in weight proportion10%(CBg-1), 20%(CBg-2), 30%(CBg-3)respectively were characterized by thermal techniques. Proximate and ultimate analysis of coal, bagasse and coal-bagasse blends was carried out. The study reveals that CBg-1 releases 4.18%, CBg-2 emits 3.65% and CBg-3 contained 2.87% of elemental sulfur. Muffle furnace flue gases analysis depicted that coal-bagasse blends samples CBg-1 releases CO_2, NO_2, NO and SO_2 16.573%, 0.01435%, 0.008237%, 0.4384% respectively. It was concluded that sulfur contents were reduced by addition of biomass, SO_2 and NO_x emissions were reduced, whereas CO_2 emissions were increased. Reduction inSO_x, NO_x and enhancement in CO_2 showed efficient and environmental friendly combustion.

Keywords-Brown Coal, Baggase, Characterization, Sulfur Reduction, Co-Firing, Emission Analysis

I. INTRODUCTION

Pakistan is ranked 7th in terms of coal containing country [i] ranging fromsub-bituminous to brown coal [ii]. These resources mounted to more than 185Billion Ton, from which 175 Billion Ton are located in Thar desert of Sindh province and named Thar coal [ii] which is still unused. Presentaly Lakhra coal power is running with capacity150MW [ii].Although it contains high percentage of sulfur, ranges from 1.2% to 14.8%[i]. Presently, coal covers 5.4% of energy demands in Pakistan [ii].Biomass is a renewable and environment friendly source of energy, which is mainly derived from agricultural, municipal solid waste and animal manure. It can play the vital role in utilizing these low quality coal resources in blend combination for generation of electricity and heat. Countable amount of biomasses are available from these resources; 0.000055 Billion Ton/dayof MSW, 0.000225 Billion tons/day of AR and 0.001 billion tons/day of (AM)animal manure [iii][iv].It is estimated that globally 220 billion tons of dry biomass produced annually by photosynthesis [v, vi]. From these available biomass resources, bagasse is the major source that is commercially being utilized as single source or in blend with coal for energy generation.

Bagasse covers 7% energy demand of these countries [iv]. Pakistan is 5th largest sugarcane producer country in the world and potential of bagasse available is 0.015 billion tons in the year 2012-13[vii][viii].Hence there is the available capacity to generate 2000MW of electric power using bagasse as fuel [ix].

Co-firing of coal and biomass is a cost effective and sustainable option for producing energy. Co-firing reduces NO_x, SO_x and CO and CO_2 emissions [x]. Blending ratio of biomass upto 10 to 30% is optimum for reduction of hazardous pollutants [xi]. Blending ratio of up to 40% of biomass lower the temperature and reduce energy efficiency up to 8% [xii]. Co-firing of coal with biomass eliminate some negative aspects, which frequently occurs during the combustion of biomass alone. Moreover, at high temperature co firing of coal and biomass, chlorine content present in biomass are limited [xiii]. During co-firing combustion properties i.e. overall ash loading, emissions of sulfur oxides and thermal input can be predicted whereas slagging, fouling, burnout, No_x emissions and ignition behavior cannot be estimated [xiv, xv].Aim of this study is to analyse the composition of coal and bagasse blends in various combinations such as 90:10, 80:20 and 70:30 by weight % respectively and to determine the impact of these blending ratio on emission gases..

II. MATERIALS AND METHODS

Coal samples were collected using ASTM D346/D346M-11[XXII] and prepared using ASTM D2013 [xxiii] for Analysis. Bagasse samples were collected using standard representative sampling method. Binding agent (molasses) was obtained from sugar mill. Coal samples were crushed using jaw crusher and gyratory crusher, then passed from sieve analysis to obtain size 208 μm. Bagasse samples were air dried for about10 days in open air. Bagasse samples were crushed using Hammer mill. Bagasse samples were sieved in similar manner and mean size obtained. Finally coal and bagasse samples were stored respectively.

A. Proximate Analysis of Coal and Bagasse

Proximate analyses of samples were carried out according to ASTM D3172 standard [xxiv], Moisture, volatile matter, fixed carbon and ash contents were analyzed.

1) Moisture Content

Moisture contents were analyzed in accordance with ASTM D3173/D3173M-17 [xxvi] using electric oven. 1g of coal in platinum crucible was heated at temperature 110^0C at time 1hour.

Moisture content was determined as follows;

$$M = \frac{(wi - wf) * 100\%}{wi} \quad (1)$$

M = Moisture

W_i = Initial weight of sample

W_f = Final weight of sample

2) Ash Content

Ash contents were analyzed in accordance with the ASTM D3174-12 [xxviii] using muffle furnace. After removal of moisture contents sample was put into muffle furnace for 1hour by raising temperature gradually from 450^0C to 600^0C, then heated at temperature from 600^0C to 700^0C for 1hour. Color of samples from black became yellowish.

Ash content was determined as follows:

$$Ash = \frac{(wi - wf) * 100\%}{wi} \quad (2)$$

W_i = Initial weight of sample

W_f =Final weight of sample

3) Volatile Matter

Volatile matter contents were analyzed using standard ASTM D3175-17 [xxx] in electric oven. 1g of coal sample was heated in electric oven at 900^0C for 7minutes. Bagasse samples were heated at same temperature for 5minutes. The color of samples was changed into black.

Vollatile Matter was determined as follows:

$$Weight\ loss\ \% = \frac{(A - B) * 100}{A} \quad (3)$$

A = weight of sample used (g)

B = weight of sample after heating (g)

$$VM\ \% = C - D \quad (4)$$

VM = Volatile Matter

C = Weight Loss %

D = Moisture %

4)Fixed Carbon

Fixed Carbon present in samples was calculated by following relations;

$$FC = 100 - (M\% + VM\% + Ash\%) \quad (5)$$

FC = Fixed Carbon

B. Ultimate Analysis of Coal and Bagasse

Ultimate analysis of coal, bagasse and coal-bagasse blends were carried out using ASTM D3176 [xxv]. Ultimate analysis includes carbon, hydrogen, nitrogen, oxygen and sulfur contents in an elemental form with or without ash addition. Determination of experimental procedure of each component is given below [xvi].

1) Determination of Carbon and Hydrogen

According to standard ASTM 3178-84 [xxvii], 0.2g of each sample was taken. Samples were combusted in oven in the presence of air (oxygen). Carbon and hydrogen react with oxygen and converted into CO_2 and H_2O respectively. CO_2 and H_2O are absorbed using KOH and $CaCl_2$ respectively in the tubes of known weights. The increase in weights of the tubes is then determined using the following calculations:

C% = increase in weight of KOH *12*100/initial weight of coal sample*44

H% = increase in weight of $CaCl_2$ *2*100/initial weight of coal sample*18

2) Determination of Nitrogen

According to standard ASTM D3179 [xxix], 1 gof each sample was heated with H_2SO_4 and K_2SO_4 in a long necked flask (kjeldhal flask). Potassium sulfate K_2SO_4 act as a catalyst. After the completion of reaction solution was treated with KOH. Ammonia was formed. Ammonia was distilled and absorbed using standard acid solution of known volume. For liberation of ammonia un-dissolved acid was titrated with NaOH.

N% = (volume of acid used*normality14)/ (weight of coal taken*44)

3) Determination of Total Sulfur Content (Eschka method)

1gof each sample was mixed with 3g of Eschka mixture based on ASTM D4239-14e2 [xxxi]. The mixture was heated at 800^0C for one hour. After heating, the mixture was digested in water. The dissolved sulphate was precipitated using barium chloride. The precipitate was filtered and reduced to ashes. The amount of Sulfur was determined gravimetrically.

Note: Eschka mixture was a mixture of magnesium oxide and anhydrous sodium carbonate in the ratio of 2:1.

4) Determination of Ash

The percentage of ash was determined by same method as proximate analysis.

5) Determination of Oxygen

The percentage of oxygen was determined by the formula written below;

O_2% = 100 – (C%+H%+S%+N%+ ash %)

6) Coal-Bagasse Blends

Bagasse was blended with coal at ratio of 10, 20 and 30 respectively. Molasses (binding agent) was added 5% constantand 5% of Sulfur fixation agent $Ca(OH)_2$was addedin the coal-bagasse blends.

Calculation for Single blend

Suppose the composition of coal-bagasse blend 1 (CBg-1). Total weight was 40g.

90% of coal

40*90/100 = 36g of coal

Similarly;10% of bagasse

40*10/100 = 4g of bagasse

36g of coal (90%) was blended with 4g of bagasse (10%), molasses and sulfur fixation agent was added 2g(5%) each. Blend was formed in briquettes formation machine.

In this way three different samples of blends was formed. Namely CBg-1 contains 90%coal and 10% bagasse, CBg-2 contains 80% coal and 20% bagasse and CBg-3 contains 70% coal and 30% Bagasse.Blends were dried and stored.

7) Emissions Analysis of Coal-Biomass Blends

Hazardous emissions such as CO, CO_2, NO, NO_2 and SO_2 were analyzed using muffle furnace (for co-firing) and stack gas analyzer (for emissions). Coal-bagasse blend samples were heated at temperature of 850^{0}C. By co-firing emission were released. The emissions were analyzed from the stack of muffle furnace using stack gas analyzer. Stack gas analyzer has ability to analyze CO, CO_2, NO, NO_2 and SO_2 emissions.

III. Results and Discussion

A. Proximate analysis of Coal and Bagasse samples

As depicted in Fig.1 the coal contains higher percentage of fixed carbon 24.49%) , ash (29.37%) and moisture (17.6%) and lower in volatile matter (28.41%). Whereas bagasse is the highest in volatile matter (76.6%), lowest in fixed carbon (11.1%), moisture (10.4%) and ash (1.9%). The other investigators have reported the Lakhra coal results in specific range of these components i.e fixed carbon in the range 9.80%-38.20%, moisture 9.70%-38.10%, volatile matter 18.30%-38.60% and ash 4.30%-49.00%. While the other research reported similar results for bagasse i.e fixed carbon 11.35%, volatile matter 37.70%, moisture 48.8% and ash 2.15% [xviii]. [xvii] showed fixed carbon 9.80%-38.20%, moisture 9.70%-38.10%, volatile matter 18.30%-38.60% and ash 4.30%-49.00% [xvii].

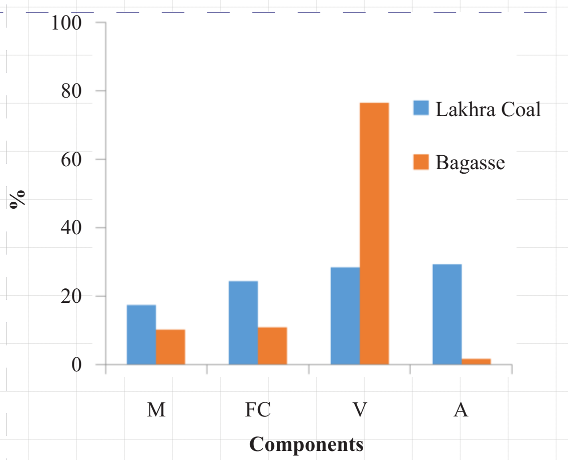

Fig. 1. Proximate analysis of raw materials

B. Ultimate analysis of Coal and Bagasse Samples

Ultimate analysis of coal sample carried out on moisture ash free basis gave carbon content 68.84%, Hydrogen 10.2%, nitrogen 1.42%, Oxygen 14.7% and sulfur 4.2% as shown in Fig. 2.Previous research showed sulfur range of 1.2% to 14.8% [xvii]. Bagasse sample gave 49.84% of carbon, 6% of hydrogen, 0.2% nitrogen, 43.9% of oxygen and 0.06% of sulfur as shown in Fig. 2. [xviii] showed carbon 44.1%, Hydrogen 5.62%, Nitrogen 0.19%, oxygen 44.4%. Basic composition of bagasse varies depending on its source and environmental conditions.

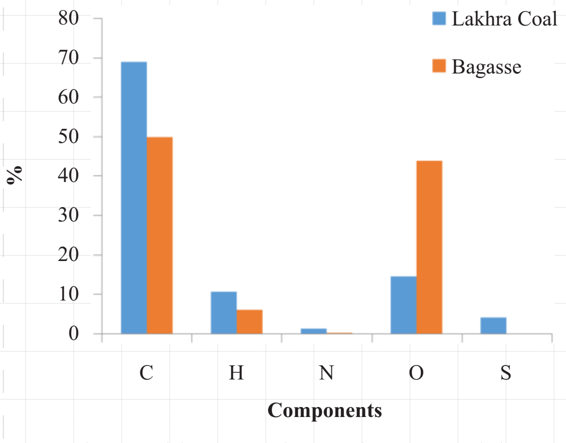

Fig. 2. Ultimate analyses of raw materials

C. Proximate analysis of coal-bagasse blended Samples

The different samples of coal-bagasse blends CBg-1, CBg-2, CBg-3 were analyzed. CBg-1 gave higher moisture 16.91%,fixed carbon 23.15% and higher ash content 26.62%.CBg-3 gave higher volatile matter content 42.94% as shown in Fig. 3.

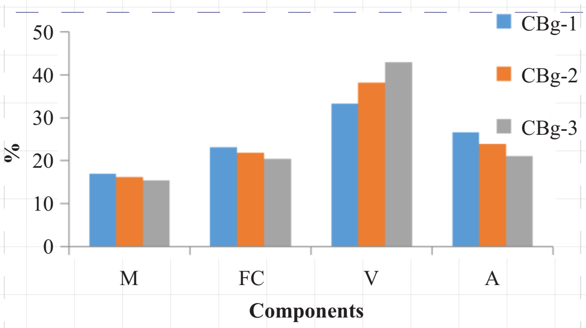

Fig. 3. Proximate analysis of Coal-bagasse blends

D. *Ultimate analysis of coal-bagasse blended Samples*

Ultimate analysis of coal-bagasse blends were carried out CBg-1 gave higher amount of carbon 67.22%, Hydrogen 9.5%, Nitrogen 1.9% and sulfur 4.18%. It was examined that over all percentage of sulfur reduced to 0.05%.Whereas carbon and hydrogen content were increased. CBg-3 sample gave higher amount of oxygen 23.07%.

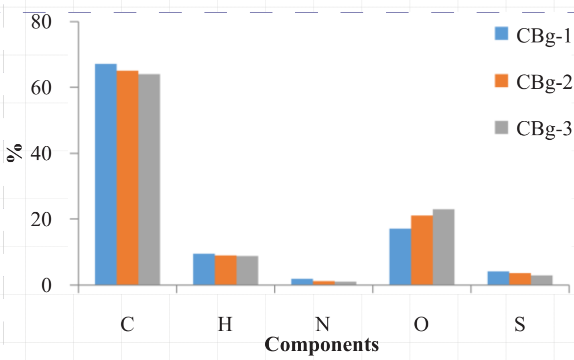

Fig. 4. Ultimate analysis of coal-bagasse blends

E. *Emission Analysis of Coal-bagasse blends*

Emission analysis is part of a combustion process carried out for improving the fuel economy, reduction of undesirable exhaust emissions and for improving the life of fuel burning equipment. Combustion analysis begins with the measurement of flue gas concentrations.

Flue gas emissions were carried out at Petroleum of natural gas Institute of MUET using muffle furnace for co-firing and flue gas analyzer for emissions such as CO_2, CO, NO_2, NO, NO_x, SO_2, and H_2 ,O_2 etc. results were shown in Table I.

TABLE I
EMISSION ANALYSIS OF COAL-BAGASSE BLENDS

Component	O_2 %	NO_2 %	NO %	NO_x %	SO_2 %	H_2 %	CO %	CO_2 %
CBg-1	0.9189	0.01435	0.008327	0.2267	0.4384	2.1064	1.427	16.573
CBg-2	1.0965	0.01246	0.00725	0.1971	0.3844	2.7453	1.9543	15.136
CBg-3	1.2845	0.01065	0.00695	0.176	0.3486	3.1019	2.3658	14.326

1) Emissions of Oxides of Carbon

CO_2 emissions are released based on the carbon content as obtained from the elemental analysis of the coal and the excess air (oxygen) used in the power plants and plant (equipment) efficiency.CO_2 emissions varies by varying the excess air during combustion as well as carbon content in the coal. CO_2 emissions cannot determined/estimated without experimental investigation [xix]. CO emissions released are by product of CO_2. CO emissions released because of incomplete co-firing.

CBg-1 released CO_2 emissions (16.573 %) was the highest percentage of CO_2 emissions, the byproduct CO emissions released were 1.427% which showed lower percentage of CO emissions evolved. CBg-2 samples release CO_2 and CO emissions were 15.136% and 1.9543% respectively and CBg-3 released 14.326% and 2.3658% of CO_2 and CO emissions respectively as shown in Fig. 5. There is release of higher percentage of $CO_2$and lower percentage of CO emissions in samples CBg-1, CBg-2 and CBg-3 showed efficient co-firing.

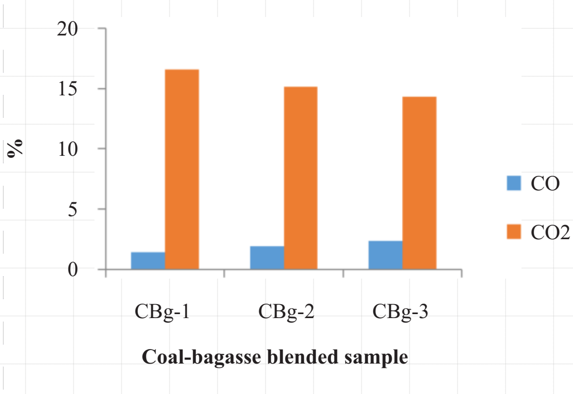

Fig. 5. CO_2 and CO Emission analysis of coal-bagasse blended samples

2) Emissions of Oxides of Nitrogen

Nitrogen oxides NO_x are one of the most important emissions resulting from the combustion of fuels.

Typically Nox emissions released from co-firing are NO, NO_2, N_2O, N_2O_3 and N_2O_5. NO and NO_2 are major NO_x emissions. Nitrogen oxides are environmentally the most harmful. The research has been done for reduction of NO_x emissions. NO_x emissions depend upon presence of nitrogen in the raw material, excess air (oxygen) and co-firing process conditions [xx].

NO_2 emissions released by coal-biomass blends samples CBg-1, CBg-2 and CBg-3 were 0.01435%, 0.01246% and 0.01065% respectively. NOx emissions released were 0.008272 for CBg-1, 0.00725% for CBg-2, 0.00695% for CBg-3 respectively as shown in Fig. 6.

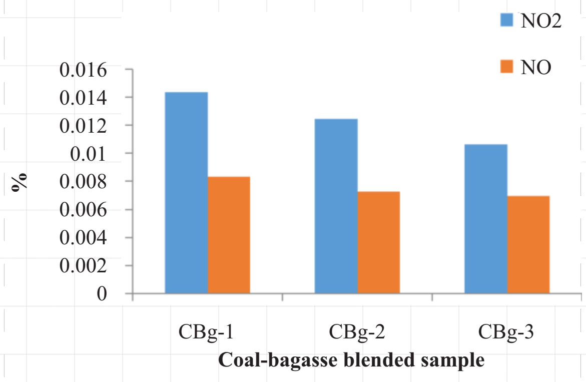

Fig. 6. NO_x Emission analysis of coal-bagasse blended samples

3) Emissions of Oxides of Sulfur

SO_2 emission released depends upon the presence of sulfur content. None of any practical accessory has been found for reduction of SO_2 emissions in the atmosphere [xxi]. It is estimated that all the sulfur present in the coal is converted into SO_2 emissions during co-firing.

Coal-bagasse blends i.e. CBg-1 sample released 0.4384% SO_2, CBg-2 released 0.3844% SO_2 and CBg-3 sample released 0.3486% SO_2 as shown in Fig. 7. Collectively all the SO_2 emissions released were significantly reduced.

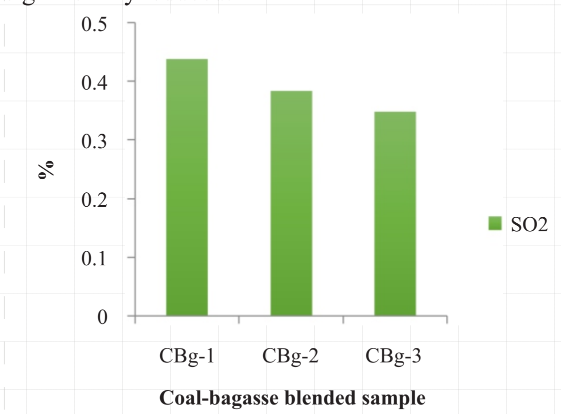

Fig. 7. SO_2 Emission analysis of coal-bagasse blended samples

IV. Conclusion

Lakhra coal contain higher amount of sulfur ranges from 2.0-14%. By addition of bagasse (biomass) in coal basic composition of coal varies, gave lower sulfur content as compared to coal. Sulfur present in the coal converted into SO_2 emissions was reduced. Bagasse (biomass) is a CO_2 neutral fuel. By addition of bagasse to form blends transport, dispose and environment problem of biomass were reduced and Coal dust is become useful. Coal-bagasse blends gave efficient combustion, reduce CO emission. Finally NO_x emissions reduced to significant level were released in very small quantity.

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