Thermochemical Studies and Fluidized Bed Combustion of Low Grade Pakistani Coal Blends

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Abstract: Pyrolysis behavior of low grade Pakistani coals was done using thermo gravimetric analyzer or TGA. The effect of changing the rate of heating was analyzed at for the pyrolysis process. The particle size was also varied and its effect was also investigated. Kinetic parameters were determined for different heating rates. This research also investigated the combustion behavior of low grade coals, from Balochistan like Duki and Chamalung, in a Circulating Fluidized Bed (CFB) riser. This is perhaps the first local practical experience of evaluating combustion performance of local coal blends in a CFB. The effects of varying the primary air and feed rate on emissions were analyzed. The experiments were carried out in a hot CFB installed at NFC-IET, Multan. The experiments showed that the temperature rose to about 900 ℃ at the top of the CFB in quick time. The temperature dependence on combustion and emission were also identified.

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1. Introduction

Coal is currently being used as a major source for producing electricity. Pakistan bears one of the biggest coal reserves of the world which amounts to about major coal reserve in the world which amounts to about 185 billion tones. The coal reserves are widely distributed throughout Pakistan. Most of the coal reserves in Pakistan are low in grade . In order to burn these coal efficiently, new and innovative technologies are required. **(Hussain et al., 2006)**. Due to increasing oil prices and energy crises in Pakistan, the demand for coal utilization is getting higher. In order to burn these low grade coals efficiently, new techniques are being developed worldwide.

The projected coal demand in Asia is a buoyant one, with most countries like Korea, Hong Kong, Philippines, Malaysia, India and Thailand reporting increasing use of coal. Even major coal producing countries like Indonesia and China are projected to face shortage and their capacity for export is expected to be largely curtailed, with production barely matching local demand. In the background of this regional development, Pakistan is projected for steep increase in coal use in the next decade with the construction of more cement plants and several large coal fired power stations. The focus of this projection is to harness the attractive coal deposits in Pakistan which have not been utilized yet.The Duki coal field is located in Loralai district. The total reserves of the Duki coal field are about 13 million tons. The Chamalung mountain range is situated about 45 Kms. north of Kohlu, Tehsil Duki of Balochistan province in Pakistan. The details of coal reserves in Balochistan are shown in Table 1.

Table 1: Information about Balochistan coals

Name of Coal Field	Area of Coal Field Sq. Km	Seam Thickness in Meters			Estimated coal reserves (million ton)
		Max	Min	Avg.	
Duki	100	1.0	0.3	0.5	13
Chamalung	120	1.0	0.3	0.5	N.A

Pyrolysis analysis of the low grade Thar Coal was done using TGA. A number of parameters like temperature, rate of heating and particle size and shape feed rate can greatly affect the devolatilization behavior. TGA offers a quantitative understanding of the pyrolysis process under well controlled laboratory conditions. TGA results have provided adequate data in determining the rate of slow pyrolysis process but the analysis of fast pyrolysis process is beyond the range of this ordinary laboratory instrument. Fast pyrolysis, in general took advantages of chemical pathways which are neither predictable nor possible using conventional thermal techniques. The TGA data was used to identify the characteristics and the kinetics of the reaction of the pyrolysis devolatization with respect to temperature and time.

2.Thermo-gravimetric Studies of Coals

Pyrolysis behavior of fuels can be used as an initial to understand the gasification or combustion processes of that particular fuel **(Abdullah et al., 2010).**It is also important to calculate the kinetic parameters (i.e., activation energy, frequency factor and reaction order) for quantifying the thermochemical behavior **(Al-Abdoulhadi et al., 2011,Bridgwater, A.V., 2011.).** The TGA was heated from 25-900 ℃ for different heating rates. The weight of the sample wasmonitored constantly with respect to time and temperature.

2.1 Determination of Kinetic Parameters

In order to determine the kinetic parameters, a number of researchers have identified various methods **(Guo et al., 2001, Grammelis et al., 2009).**

The Arrhenius equation is written as follows

$$\frac{d\alpha}{dt} = Ae^{-E/RT}(1-\alpha)^n \qquad (1)$$

In the above equation we represent, A (min–1) as the frequency factor, E (J/mol) activation energy, R (J/mol K) universal gas constant, T (K) absolute temperature, n is the order of reaction, t is the time, and α is the fraction of reactant decomposed at time t (min).

Where;

$$\alpha = \frac{w_\circ - w}{w_\circ - w_f} \qquad (2)$$

wo, w, wf represents the are the initial, actual and final weights (mg) of the sample, respectively.

At a constant heating rate β:

$$\beta = \frac{dT}{dt} \qquad (3)$$

By rearranging terms, we get:

$$\ln\left[\frac{1-(1-\alpha)^{1-n}}{T^2(1-n)}\right] = \ln\left[\frac{AR}{\beta E}\right] - \frac{E}{RT} \quad (for\ n \neq 1) \qquad (4)$$

For n=1,

$$\ln\left[-\frac{\ln(1-\alpha)}{T^2}\right] = \ln\left[\frac{AR}{\beta E}\right] - \frac{E}{RT} \quad (for\ n=1) \qquad (5)$$

$$\ln\left[-\frac{\ln(1-\alpha)}{T^2}\right]\ versus\ \frac{1}{T} \quad (for\ n=1) \qquad (6)$$

Will give a straight line of slope –E/R for the proper value of n

2.2 TGA and Kinetics Results

Figure 1 and Figure 2 identify the behavior of the residual weight fractions of coal powder of mesh size 60 undergoing pyrolysis for heating rates varying from 5-50 ℃. A significant weight loss was observed indicating the occurrence of the main decomposition.

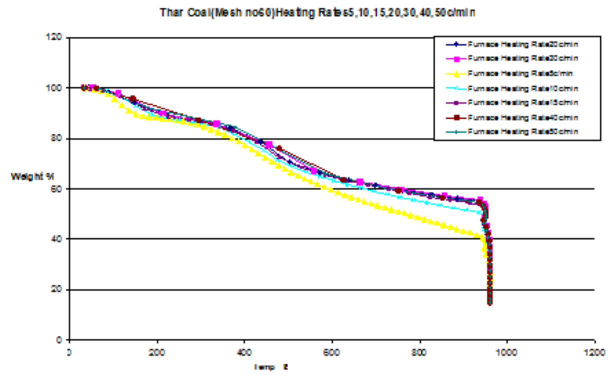

Figure 1: TGA analysis of weight loss (%) for different heating rates for Thar Coal of 60 Mesh Size

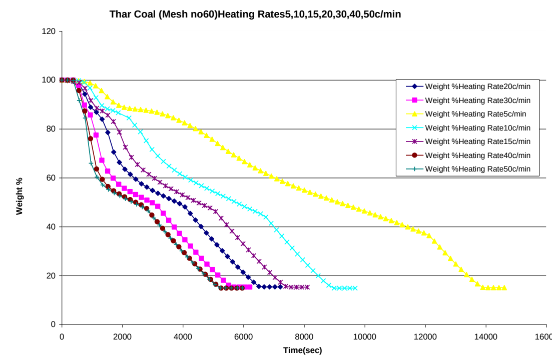

Figure 2: TGA analysis of weight loss (%) as a function of time for different heating rates for Thar Coal of 60 Mesh Size

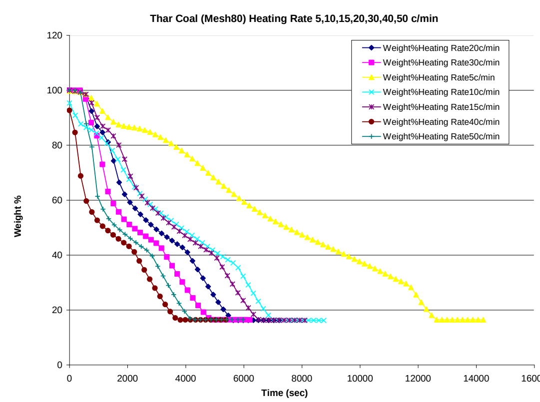

Figure 3: TGA analysis of weight loss (%) as a function of time for different heating rates for Thar Coal of 80 Mesh Size

Figure 3depicts that with increasing heating rate there is a little shift of thermograms. Anincrease in the heating rate results in a faster pyrolytic reaction.The heating rates influence the shape of the TGA curve. When a sample decomposes then the vapour pressure of the gaseous products exceeds the ambient partial pressure. At lower heating rates the sample temperature is more uniform and diffusion of the product gases can occur through the sample but when the heating rate is increased then such free diffusion is inhibited and decomposition temperature is increased. Also, at lower heating rates the decomposition atmosphere is more uniform and the decomposition reaction is completed within a narrower temperature interval. Figure 4 shows that the pyrolysis is pure reaction kinetics controlled**(Mehrabian et al., 2012**).Figure 4 shows that smaller the size of feed stock faster the thermal conversion.The heating rate has influence on the the maximum rate of pyrolysis **(Munir et al.,2009)**.

The lignite coal was used for the present study which has a high aromatic contents.

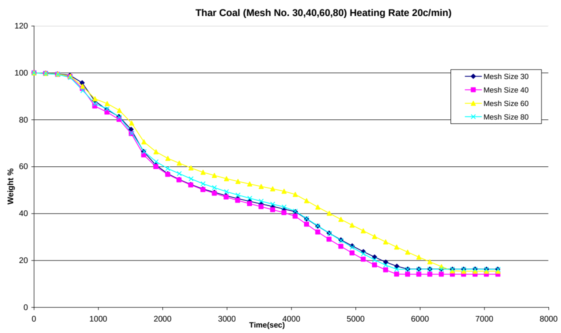

Figure 4:TGA analysis of weight loss (%) as a function of time for different heating rates for Thar Coal of Mesh Size from 30-80

Using the TGA analyses, the kinetic parameterswere estimated with high correlation coefficients (all above 0.94) and listed in Table 2. The effect of heating rate was found to be more pronounced on the activation energy as compared to the frequency factor **(Naik et al., 2010).**

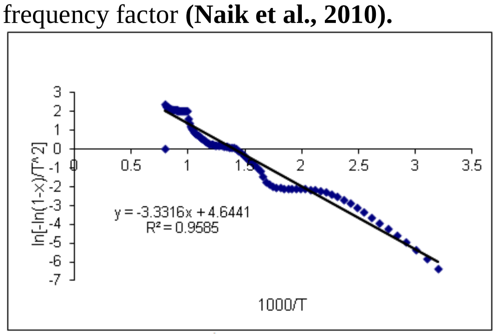

Figure 5: Kinetic plot for a typical heating rate

Table 2: Kinetic Parameters for the pyrolysis of Thar Coal of 60 mesh size

Heating Rate	Activation Energy (kJ/mole)	Frequency Factor (min^{-1})
5 °C/min	**80.16**	**6.8×10^3**
50 °C/min	**102.01**	**6.2×10^4**

3. Combustion Studies of Low Grade Coals:

This is perhaps the first practical experience of evaluating combustion performance of Duki coal in a CFB. The effects of varying the primary air and feed rate have also been analysed and their influence on emissions has been established. The experiments were carried out in a hot CFB installed at NFC-IET, Multan. The system was developed by a grant from Government of Pakistan in line with developing a Coal Research Centre at the NFC-IET Multan. The experimental apparatus comprised of a circulating fluidized bed (CFB) type experimental combustor, dust collector, coal feeder, blower and control panel. A schematic diagram of the test rig is shown in Figure 6.

Figure 6: Photograph of CFB test rig

The proximate and ultimate analyses of the coals are shown in Table 3.

Table 3: Proximate and Ultimate Analysis of Duki coal

Proximate Analysis of Duki Coal			
Moisture	Volatile matter	Fixed Carbon	Ash
11.79	33.06	31.42	24.18

Ultimate Analysis of Duki Coal						
%C	%H	%N	%S	%Ash	%O	GCV
50.00	5.53	1.40	7.16	24.18	11.73	9743 Btu/lb

The fluidized bed was formed by supplying primary air and increasing the in-furnace temperature. The thermo gravimetric analysis (TGA) was used for the pre-set temperatures. The flue gas sampling, for a particular combustion condition, was done three times and average value was taken. At the predefined temperatures, the coal feeding was initiated and the furnace temperature and the gas composition were analyzed. The primary air flow rate of the fluidizing air was kept constant, after the temperatures had stabilized. The flue gas was analyzed from the sampling port.

The CFB test rig was heated using the external gas fired heater between the temperature range of 450- 550℃. The temperature data was continuously recorded at a regular interval of 05 minutes. It took about 140-160minutes before the temperatures in the CFB furnace reached to its set point and stabilized. The 200-300 microns particles wereeasily pushed by the screw feeder. The temperature of the CFB increased rapidly. This increase in temperature caused the suspension density to increase**(Ryu et al., 2006).**With the increase of primary air flow the CO concentration also increased quickly. Figure 7 shows the emission behavior. A temperature decrease from 709℃ to 680℃ caused the NOx emissions to decrease from 75 ppm to 21 ppm as shown in Figure 7.

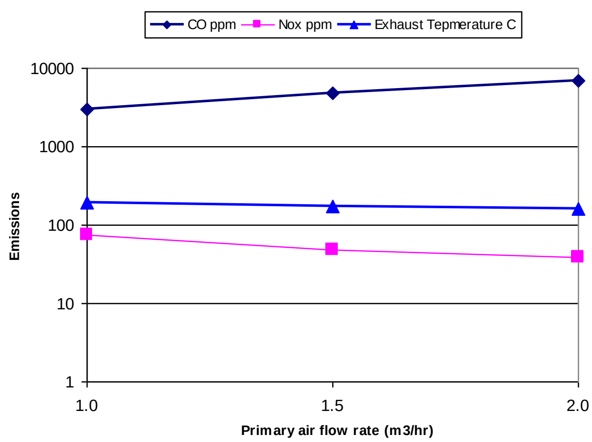

Figure 7: Emission behaviour for particles 212-30 microns

The combustion of 850 microns coal particles under similar condition as that of 600 microns particles has resulted in even lower NOx concentration with the maximum value at 18 ppm. The emissions of the CO are also low. However, the particle size of 850 microns is a bit high for fluidization in our CFB experimental combustor as the combustor temperature at top could reach to only about 740 ℃ and resulted in a lot of tar generation which is not useful for our combustion experiments **(Sarenbo, S., 2009**).

3.3 Co-Firing of Biomasswith Coal

In this study co-firing of bagasse with Duki coal was conducted in the experimental CFB.The influence of bagasse particle size on the combustion performance was also investigated when it was blended with 10% Duki coal. The particle sizes of bagasseconsidered were 425, 600 and 850 microns. The feed rate of bagasse was fixed at a feeder speed of 2 rpm. This corresponds to a low rate of 2.04, 1.08 and 2.53 kg/hr. The primary air flow rate was varied in the CFBC combustor and emission and temperature data were recorded. Figure 8 shows the variation of NOx in the CFBC for different bagasseparticle size blends. Bagasse particle size of 600 microns size gave the minimum emission of NOx as compared o other particle sizes.In this case, the 425 microns particles gave the minimum emissions of NOx and CO, however, the 600 microns particles also showed relatively lower emission values as compared to 850 microns particles.

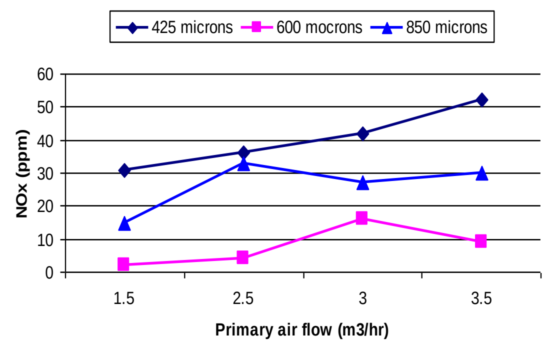

Figure 8 NOx emissionfor various particle sizes

The sulphur emissions were low for various experimental conditions during the experiment, with the SO_2 emissions ranging from 4-12 ppm. The tests were also conducted for Duki coal blends ranging from 10-60%. The influence of coal blending, from 10-60%, was recorded on the combustion performance.

The feed rate of blends was fixed at a feeder speed of 2 rpm. This corresponds to a flow rate of 1.08 kg/hr for various coal blends. The primary air flow rate was varied in the CFBC combustor and emission and temperature data were recorded. A blending ratio of 40% resulted in the maximum CFBC temperature of 950℃.

Figure 9 shows the emission behavior of CO and NOx for various coal blends and it can be inferred that by increasing the blending ratio the CO and NOx emissions decreased. Figure 10 shows that the SO_2 levels increases sharply as the blending ratio increases which ultimately set the limit for coal blending ratio to be adopted in CFB combustors. These figures suggest that a blending ratio of 40% is optimum to obtain a higher CFBC temperature as well as obtaining minimum values of NOx, SO_2 and CO.

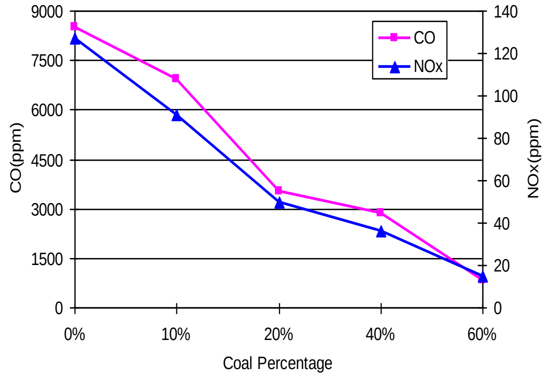

Figure 9 Emission profiles for CO and NOx for various coal blending ratios

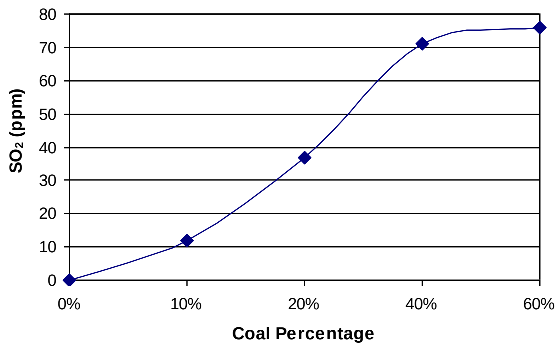

Figure 10: Variation of SO2 as a function of blend percentage

Conclusions:

The thermogravimetric analysis suggests that the pyrolytic temperature and heating rate have significant influenceon devolatization behavior of Thar Coal. Also the thermochemical properties of lowgrade Thar Coal have been understood.Combustionstudies for bagasse and coal blends were also done in a hot circulating fluidized-bed (CFB) test rig.The effects of variation of primary air and feed rate have also been analyzed and their influence on emissions has been established. It was found that NOx and CO deceases with the increase of coal content in the blend. A blending ratio of 40% is found to be optimum to attain a higher CFBC temperature as well as obtaining minimum values of NOx, SO_2 and CO.

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