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# Coal Fired Power Plant: A Review on Coal Blending and Emission Issues

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**Abstract.** Nuclear power is an undisputedly clean source of energy. However, the Fukushima nuclear power plant accident serves as a reality check to most developed countries that have nuclear power plants to rethink their power strategy due to the huge environmental impact it has if accidents happen. With this scenario, coal will still be relevant in power industry for many years to come. However, getting good quality coal economically has become a challenge. Coal blending practice will help to achieve the objective of getting enough coal for the boiler with correct quality. Optimizing the coal combustion in power plant will improve its efficiency and lead to reduction of greenhouse gases in the flue gas. One of the main objective in the coal combustion research is to develop techniques that help power plant operators utilizes coal cleanly and efficiently. Coal combustion also associated with green house emission or pollutants. CO, CO2, NOx and SO2 are major gases emitted by coal combustion. The operators need to ensure the desired power output is achieved and at the same time, maintaining the strict emission standard at all time. This paper will discuss the pulverized coal combustion and process involved. Coal blending practice among the power plant also will be discussed and reviewed. Further discussion on coal combustion emission and optimization techniques will also be discussed. It can be said that coal blending practice and emission control techniques are essential in ensuring sustainable coal plant operation for years to come.

## INTRODUCTION

### Pulverized Coal Combustion

The coal combustion process consists of several steps. First, as the coal particles are heated during combustion, moisture is driven off the coal particles. Next, the coal particles undergo de-volatilization and the volatile organic constituents are released. The volatile matter is combusted in the gas phase and it can occur prior to and simultaneously with combustion of the char particles. Combustion of the char is a surface reactions where these reactions are for the most part sequential, and the slowest of these will determine the rate of the overall process. The combustion of the volatiles is generally assumed to be a homogenous reaction, although there is possibility of volatile matter burning heterogeneously. The burning of the volatiles is a very fast process that is measured in milliseconds [1].

Char combustion is a much slower process than de-volatilization and therefore determines the times taken for complete combustion in the furnace. Studies have shown that the combustion of the char begins with chemical sorption of oxygen at active sites on char surface and that the decomposition of the resultant surface oxides mainly generates carbon monoxide (CO)[2]. The CO is then oxidized to CO2 in a gaseous boundary zone around char particle. Fresh reaction sites are continuously exposed as the surface oxides decomposed. CO2 then either moves off into the gas stream or is reduced to CO if it impinges on the char. The rate of char combustion is a complicated process, as it is influenced by mass transfer by diffusion through the pores and the surface

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reactions. The diffusion coefficients are strongly dependent on pore diameters and pressure, and the surface reactions is influenced by the formation of activated absorption complexes and their composition [3].

## Coal Blending Practices: Past and Present

The ash fusion characteristics and mineral behavior of three types of coals and blended coals are investigated. The result shows blended ash softening temperature is not linear with parent coal. Some combinations of component coal mineral produce low melting eutectic mineral at high temperature and this cause the averaging of softening temperature of blended coal. The blended ash mineral composition at ash initial deformation temperature is consistent with the ternary system phase diagram Silica Oxide-Aluminum Oxide-Calcium Oxide [4]. Deposition experiments with Australian black coals and its blend were conducted to assess the blend behavior and its potential to form ash deposits. It is found that the blend behavior was not additive. Some blends developed thicker ash deposit layer than the source coal and some other blends shows lower potential to form ash deposits [5]. Slag viscosity and slag indices techniques can be used to characterize the ash deposits but it cannot be used to determine the ash deposition rate. However, thermomechanical analysis technique can be used to predict the thermal behavior of the ash deposits. The test will promote heterogenous ash particle-particle interaction during thermomechanical analysis test [5].

Co-firing between coal and biomass is discussed in [6]. A pH based extraction method is adopted together with chemical equilibrium that determines the speciation of biomass inorganic matter. Classification of inorganics in coal and biomass which are concerns during ash formation, further divided into three main group that represent the bonding of the inorganic to the carbon matrix [6].High temperature thermochemical analysis shows that coal may has buffering effect on biomass alkali metals, thus reducing the release of alkali gases that can cause deposition and corrosion issues during co-firing of coal and biomass [6].

Coal blending optimization can increase the diversity of prepared coal, quality stability and flexibility of production. Coal blending also assist in solving transportation capacity and processing capacity of production equipment. A model of coal blending is developed and it is found that the optimization parameters model are non linear. By using adaptive simulated annealing genetic algorithm, the coal blending parameters were optimized and can provide guidance in the actual production planning [7]. Computational fluid dynamic code to predict coal ash deposition rate and numerical slagging index based on ash fusibility, viscosity and content in coals has been developed. The model has been validated against measurement data on fifteen different coals, including lignite and bituminous coal [8].

The numerical slagging index has successfully predicted the performance of four coal blends that have been investigated. Ash chemistry of the ash, mineral distribution and the ash loading of the coals have significant effect on the rate of ash accumulation in the boilers. The performance of coal blends in not linear from that of parent coals [8]. The combustion character of blending lignite is lower than burning soft coal. Burning lignite effect with lower furnace temperature. The numerical simulation result shows similar outcome with experimental result. Blended lignite also results in high volatile which subsequently the burning time of carbon will be shortened. This promote slag in the furnace [9].

Blending of coal with petroleum coke has proven to be environmentally acceptable. The optimum is with 10% petroleum coke into the coal blend. The blend increases the calorific value of the blend while decreasing inorganic content. The elevated sulfur content cause by the blend is managed by the wet scrubbing technology [10]. Two types of coal; one with high ash viscosity and another with low ash viscosity, are used to investigate the effect of coal blending on ash fusion properties and slag viscosities. The ash fusion temperature of the blended coals are similar due to their similarity of ash content. The ash viscosity of blended coal also much difference at high temperature. Increasing blend composition from low ash viscosity coal result in change of slag type from crystalline to glassy to crystalline slag [11].

Zhundong lignite was blended with Australian bituminous and Indonesian lignite in various blends to investigate the ash sintering and fusion characteristics. The blends were combusted in muffle furnace. The mechanism of ash sintering and fusion are investigated through its mineralogical and morphological changes of the ash at different heat treatment temperatures. Sintering of Zhandong lignite ash was attributed to Sodium and Chlorine bearing minerals whereas fusion of the Zhandong lignite ash was attributed to the eutectics formed between Ca, Al, Fe and S. The addition of 20% of Australian bituminous to the Zhandong lignite coal inhibited ash sintering but promoted ash fusion due to formation of hauyen, gehlenite and nepheline at 1250 Deg C [12].

## Coal Fired Power Plant and Emission Issues

Coal fired power plant are always associated with concern on emissions caused by various parameters such as Carbon Dioxide ($CO_2$), Nitrogen Oxide(NOx), Sulphur Oxide (Sox) and etc. However coal fired power plant will not be replaced by other clean and environmental friendly technology any time soon. Relatively cheap coal price compare with other fuel such as oil and natural gas means coal will still be one of the main source for power.

The development of new formulae to calculate CO2 emission factor for the combustion of coal especially the one utilizing Turkish coal is discussed in [13]. The formulae is developed using easily obtainable coal property data, such as LHV, HHV, VM and FC contents. It is important to know the amount of CO2 release to atmosphere from coal combustion in order to control the possible global warming effect [13].

Fossil fuel combustion release the majority of greenhouse gases (CGGs)[14-15].The largest source of CO2 is the combustion of fossil fuel especially coal for power generation. Precaution measure need to be taken to extract the CO2 released to mitigate the climate change effect. Other pollutants from coal firing are SO2 and NOx, plays important roles for photochemical smog and acid rain. Many techniques have been proposed by the researchers to reduce the emission of these pollutants. However, mostly the methods proposed are not compatible with high combustion efficiency. The paper describes process of coal combustion with oxygen on which separation of Nitrogen from combustion air in advance, in order to get the higher concentration of CO2 in the exhaust gas. With this proposed method, the recovery of CO2 from exhaust gas will become easier and less costly and zero CO2 emission may be materialized [16].

The combustion characteristics of a coal blend such as ignition behavior, burnout, unburned carbon and NOx emission cannot always be predicted as a linear combination of the properties of each component. The paper studies the possible modifications in combustibility behavior, carbon burnout and NO emission produced by blending coal of different origin and rank by means of temperature programmed combustion test in thermogravimetric analyzer along with test in a laminar entrained flow reactor [17].

Sulfur removal technologies in pulverised coal fired boilers with high flame temperature of 1200 - 1600 Deg.C was investigated. The staged desulfurization process combined with air staged combustion pattern, in which sorbents are injected into the primary air field and the upper furnace, to capture SO2 under reducing and oxidizing is found to have effective desulfurization efficiency. Flue gas recirculation was found to have effective desulfurization process under oxygen conditions and can results with a high desulfurization efficiency of about 80% furnaces [18].

The effect of operating condition in pressurised fluidized bed combustion (PFBC) on nitrogen oxide emissions for sub bituminuous coals is described in the journal paper. The two type of coal used are German and Chech coal respectively. The experiment was done by using on a smaller laboratory apparatus or test rig. The result shows that the higher the operating pressure, the lower the NOx concentration. At the same time, the particle size distribution of the coal can cause characteristic change in NOx and N2O emission in PFBC especially at lower combustion temperature [19].

Coal particle size effects the mineralogical properties. Decreasing coal particle size results in mode inherent minerals are of excluded particles having size less than 10 micron. The paper investigates the coal size effect to the particulate matter (PM) emission. It is found that decreasing coal particle size leads to formation of more PM because of the direct transferring of more excluded minerals. Potassium also found to have higher volatility than sodium. Most potassium vaporized and reacted with sulfur, chloride and phosphorous to form PM around 0.1 micron. Sodium in PM is formed by the transferring of melted sodium aluminosilicate into PM around 4 micron [20].

The effect of air staging in NOx reduction for bituminuous coal firing is discussed. The result shows that air staging improved NOx emission from the combustion of bituminuous coal firing. Two level air staging yields a greater reduction in NOx [21].

The practice of coal blending is commonly employed throughout power plant industry. It is beneficial both environmentally and economically. Blending can achieve SO2 regulation as well as NOx emission reduction. Coal blending can cause excessive and severe unwanted boiler slagging and fouling if it is not done correctly. Some plants in US invested in a digital fuel tracking system and online coal analyzer to allow the operators to make operational changes proactively to accommodate changes in fuel condition [22].

Coal blending process is done for a number of reasons including cost savings, reduction of SO2 emission, extending the limited supply of high quality coal, enhancing fuel flexibility and controlling the mineral content of coal. The paper describes the numerical investigation of the influence of blending method on the combustion characteristic and NOx emission in a 500MW coal fired boiler [23]. The analysis was done using computational fluid dynamic (CFD) code. Simulations were carry out for three cases for the in-furnace and out-furnace blending methods. The simulation shows the blending method has a great effect on the carbon in ash content. At the same time, the distribution of O2, CO and gas temperature in the furnace are closely related to carbon in ash; the higher O2 concentration and gas temperature, the lower the CO concentration which produce the reduction on carbon in ash at model exit. Further validation test at actual coal fired plant demonstrated that the in-furnace blending method produce substantial NOx and carbon in ash compared with out-furnace blending method [23].

The paper discuss the difference between air-based combustion with the oxygen regime implemented at two variants, recirculation of dry and wet exhaust gases and the influence of combustion condition onto emissions of Nox and SO2 gaseous pollutants. It was found that the emission of NOx and SO2 gasesous are lower for combustion in oxy-atmosphere, compared with air-based combustion [24].

The coal blending between low rank coal with bituminuous coal in a 15th kW small scale pulveriser furnace is discussed [25]. The combustion and emission characteristics of bituminuous, lignite and their blends were also evaluated. Influences of staged air injection, primary zone air ratio, coal types and blending ratios of these coal on NOx emission and particle burnout were also investigated. The result shows that for bituminuous coal, NOx emission decreases with the decrease of primary zone air ratio and increase in staged air injector level. Blended coal with 10% addition of lignite shows a minimum value of NOx concentration and a similar temperature distribution to bituminuous coal case. This cause by higher devolatilization rate of lignite and the formation of a strong reducing environment at high temperature from the reaction between oxygen and combustible gas species [25].

The CO2 emission is affected by both moisture content and coal pore structure. Minerals like sodium and potassium contributed to SO2 generation while calcium and magnesium inhibited SO2 generation. Blended coal technology is an effective way to reduce pollutant emission during low temperature oxidation. Coal blended process is widely adopted for many advantages, such as improving combustion performance, meeting pollutant emission limits, controlling ash deposition, extending the range of acceptable coals and reducing the fuel cost. Low temperature oxidation occurs whenever carbon containing material is exposed to oxygen in the air. This process span from room temperature to nearly 300 Deg C when ignition of coal combustion start. The article objective is to study pollutant emission characteristics of blended coals and the interaction between different coals during low temperature oxidation under air atmosphere by thermogravimetric analyzer and the pollutant emission is then detected by using Fourier transform infrared measurement [26].

The dual strategy based bi-level multi objective coal blending model to reduce both carbon and PM10 emissions is discussed [27]. The method give comprehensive consideration to all stakeholders whose decision may impact on the sustainable development of the coal fired power plant. The proposed bi-level modeling considered both the relationship between the authority and the plant as well as equilibrium between economic development and environmental protection [27].

The numerical simulation studies of the coal combustion field in a 750 kW test furnace is discussed [28]. The studies were performed by using three models for fuel NO formation to investigate the effect of fuel NO formation models on the prediction of NO reduction characteristic. The result shows that the model proposed by Mitchell could reproduce the tendency of the measurement result better than the models proposed by De Soete and Chen. The cause of difference between the NO conversion ratio of bituminuous and sub bituminuous coal that contain high level moisture was found that the formation of region with low oxygen mole fraction immediately downstream of a region with high net NO production rate is essential condition for realizing low NO conversion ratio [28].

## DISCUSSION AND CONCLUSION

There are many approaches for coal blending. Blending between different rank of coal, different type but with the same rank, blend on belt, blend inside furnace are few examples of blending practices. Coal blending optimization can diversify the prepared coal, ensure coal quality stability and ensure flexibility of production. It also assists in solving transportation capacity. Blended coal behavior are not additive of the parent coal. As such, thorough understanding of the blended coal must be obtained before applying in the actual operation.

Serious slagging, fouling or process repercussion are on the horizon if the blending process is wrongly done. On the other hand, emission characteristic of coal firing need to be comprehend as well. Influence on stage combustion, low NOx burner application and flue gas recirculation are important to get optimum firing and thus achieve emissions below limit. The largest source of CO2 is from the combustion of fossil coal for power generation. Precaution measure need to be taken to extract the CO2 release to mitigate the climate change effect. Other pollutants from coal firing, SO2 and NOx plays important roles for photochemical smog and acid rain. Many techniques have been proposed by the researchers to reduce the emission of these pollutants.

## ABBREVIATIONS

| | |
|---|---|
| Al | Aluminium |
| $CO_2$ | Carbon dioxide |
| Ca | Calcium |
| CFD | Computational fluid dynamic |
| CO | Carbon monoxide |
| FC | Fixed carbon |
| Fe | Ferrum |
| FF | Fabric filter |
| FGD | Flue gas desulphurization |
| GCV | Gross calorific value |
| HHV | High heating value |
| LHV | Low heating value |
| MW | Mega watt |
| NOx | Nitrogen oxide |
| NO | Nitrogen oxide |
| O2 | Oxygen |
| PFBC | Pressurized fluidized bed combustion |
| PM | Particulate matter |
| S | Sulphur |
| SOx | Sulphur oxide |
| VM | Volatile matter |



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