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Ignition and Emissions Characteristics of Pulverized Coal Combustion: An Overview

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Abstract
In developing countries like India, coal remains the primary source of electricity despite a significant increase in non-conventional power generation. An essential goal of coal-fired power plants is to achieve nearly efficient combustion while emitting as few harmful gases as possible. This work presents an in-depth review of coal combustion characteristics and emissions. An in-depth analysis of the impact of ash content, moisture content, particle size, and oxygen concentration on coal's ignition and emission characteristics and its blend with different types of coal and biomass is presented. In this review, experimental as well as numerical aspects are discussed. Co-combustion of coal and biomass under oxyfuel conditions holds the potential for negative carbon-dioxide emissions into the environment. This is an effective technology for reducing CO_2 levels in the atmosphere as well as NOx and SO_2 emissions.

Keywords: Coal Combustion, NOx, CO, SOx, Ash, Moisture

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I. Introduction

Electricity demand is increasing due to a growing population and rapid industrialization. As a result, there is an increase in global electricity demand. Currently, coal and natural gas are the primary fuel sources for power generation. Countries such as India, China, Indonesia, and Australia are rich in coal resources. The coal reserves of 10 countries account for about 80% of the world's reserves. About 25% of coal reserves are in the United States, making it the top country on the list (as shown in Fig. 1). Fossil fuels will remain the dominant energy source for many years to come in developing countries like India, where the energy transition from fossil fuels to renewable fuels is still in the primary stage.

India generates power from conventional sources (Hydro, Thermal, and Nuclear) as well as renewable resources (Solar, Wind, and Biomass). In India, the majority of electricity is generated via coal-fired thermal power plants, which account for 75% of total production. It is crucial, however, to remember that emissions from coal combustion, including NOx, CO, SOx, particulate matter (PM), and heavy metals, accumulate in the atmosphere and pose serious health risks [1–3]. Indian coal contains a lot of moisture and ash compared to coal from the USA, Russia, and Australia. Coal combustion is a highly complex process because minerals and carbonaceous materials interact with the gaseous phase [1,4–7]. This Fig. 2 shows Barnes description of the combustion mechanism of pulverized coals [7]. Carbon burnout and pollutants such as NOx emissions are highly influenced by flame stability and ignition during solid fuel combustion. Heterogeneous and homogeneous ignition behavior describe solid fuel particles' ignition behavior. Homogeneous ignition occurs when volatiles are released from fuel particles. When oxygen directly attacks fuel or char particles, heterogeneous ignition occurs.

During coal combustion, a large number of chemical reactions occur when mineral matter sand carbonaceous components undergo an aggressive time-temperature profile. Hence, a complete investigation into the chemistry of coal combustion ignition is required. Understanding the ignition characteristics of a fuel is facilitated by the phenomenon of ignition delay. It is a significant challenge to reduce the high CO and NOx emissions from coal-powered burners. To reduce CO and NOx emissions, various emissions reduction techniques can be applied, such as swirling, porous combustion, and mild combustion. However, a comparative assessment of these emissions reduction needs to be discussed in detail.

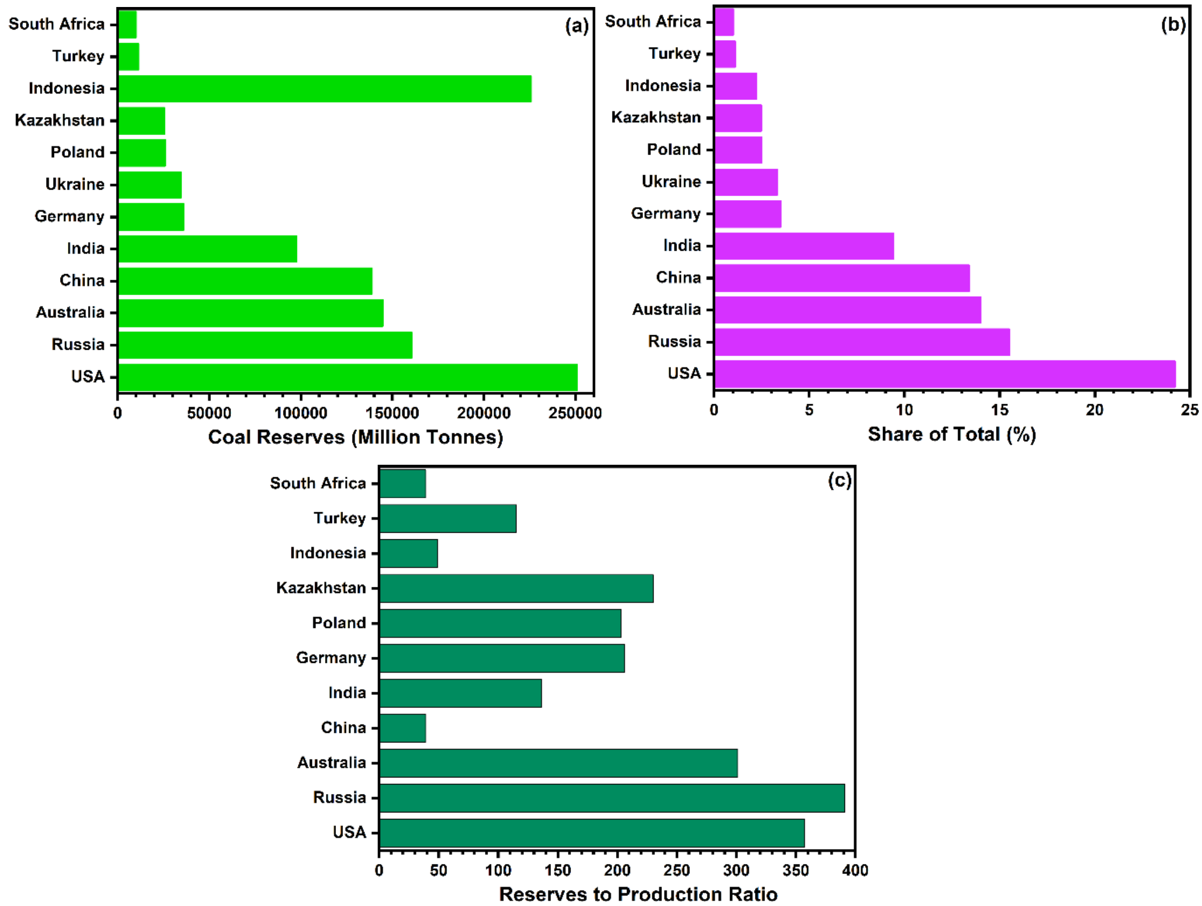

Figure 1 : The total amount of coal reserved worldwide at the end of 2017 [1].

In order to develop technologies that contribute to low levels of CO and NOx, a detailed understanding of pulverized coal combustion characteristics is necessary. It is essential for burners or furnaces that are designed to burn low-grade coal such as Indian coals. In contrast to foreign-grade coal, Indian-grade coal emits more NOx and CO due to its high ash content and moisture content. Solid fuel ignition behavior depends on several factors, such as particle size, fuel properties, furnace temperature, gas composition, heating rate, fluid flow, particle number density, etc [8–11]. The percentage of ash present in the fuel and the characteristic of ash dictates the sizing of the furnace. Fuel with ash characteristics leading to slagging and fouling requires a conservatively sized furnace since ash quantity influences the furnace heat transfer by shielding the radiation. Flame temperature is lowered by increased ash quantity. Indian coal contains a high quantum of ash; consequently, the heat released by fuel will be held up by the ash and will be released slowly, and this necessitates a more oversized furnace. Higher the ash quantity, the greater the shielding of furnace walls. The moisture content in coal greatly influences the heat released during coal oxidation at low temperatures (approximately lower than 400ºC), and this influence differs greatly for different ranks of coal. Firstly, moisture will be totally evaporated out at about 100ºC, which will absorb a lot of heat. For lignite, the influence of moisture is very slight, and during the whole oxidation stage, the coal samples with different moisture content are exothermic. However, the oxidation process of all the coal samples is in an endothermic environment, except for the gas and fat coal, with a moisture content of 3.6%, and anthracite, with a moisture content of 20%. Especially for anthracite, below 400ºC, except for the coal with a moisture content of 20%, the rest of the coal samples (coal samples of anthracite with moisture contents of 1.5, 10, 12, 18, and 25%) are endothermic. Secondly, the vaporized moisture will be absorbed by coal, and this process can be proven by the slight weight increase at about 200 to 400ºC. The weight will decrease again when the absorbed moisture is vaporized out once again. After 400ºC, the effect of moisture will be finished[12]. For the same rank of coal, the different moisture content will affect the coal's exothermicity in very different ways. It was found that certain ranks of coal with higher moisture content will release more heat than the same coal with lower moisture content. Consequently, for each rank of coal, there is a critical moisture content at which the coal has a high tendency for spontaneous combustion. For lignite and anthracite, the critical moisture content is 25% and 20%, respectively. For gas coal and fat coal, the lower the moisture content is, the higher the tendency of the coal to spontaneous combustion.

The aim of the present work is to provide a comprehensive review of the ignition and emissions characteristics of coals and their blend with different additives. The effect of various crucial parameters such as moisture & ash content, particle size, and oxygen temperature will be discussed in detail. This effort will assist beginners and researchers in this area in recognizing future research gaps.

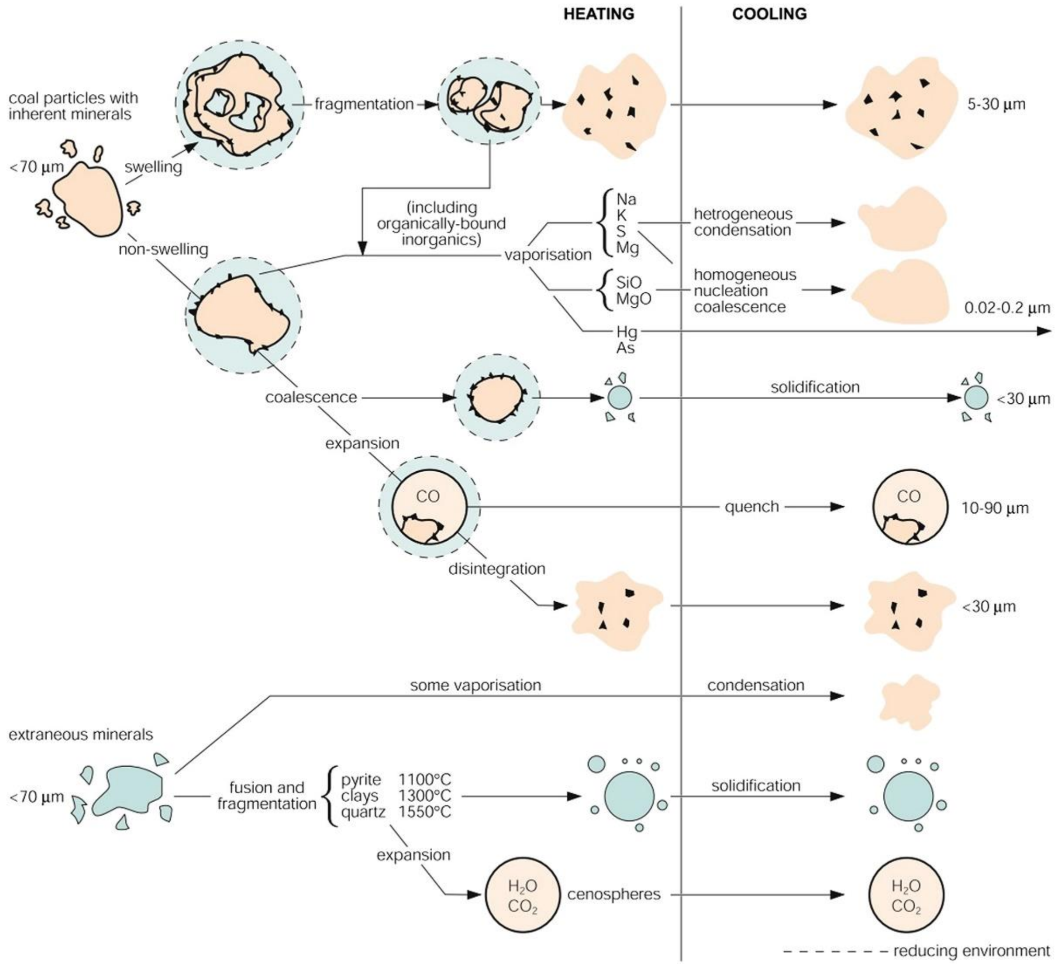

Figure 2 : The main mechanisms involved in the formation of ash during the combustion of pulverized coal [7].

II. Combustion Aspects

2.1 Ignition Characteristics

2.1.1 Ignition Characteristics of Coal and Biomass Blends

In solid fuel combustion, flame stability and ignition behavior play crucial roles in the formation of pollutants as well as burnout. Solid fuel combustion involves both heterogeneous and homogeneous ignition. When coal particles are ignited homogeneously, volatile matters are released, whereas when coal particles are ignited heterogeneously, oxidants attack directly on the surface of fuel/char. Fuel properties and particle size affect flame characteristics and ignition performance during co-combustion. Coal characteristics affect coal combustion characteristics, such as the rate at which energy is released, the burning rate, and the ignition temperature. It is important to note that coal's hydrocarbon composition significantly affects these combustion characteristics. There is a close relationship between ignition properties and flame stability of fuels. As a result, analyzing fuel ignition characteristics is crucial.

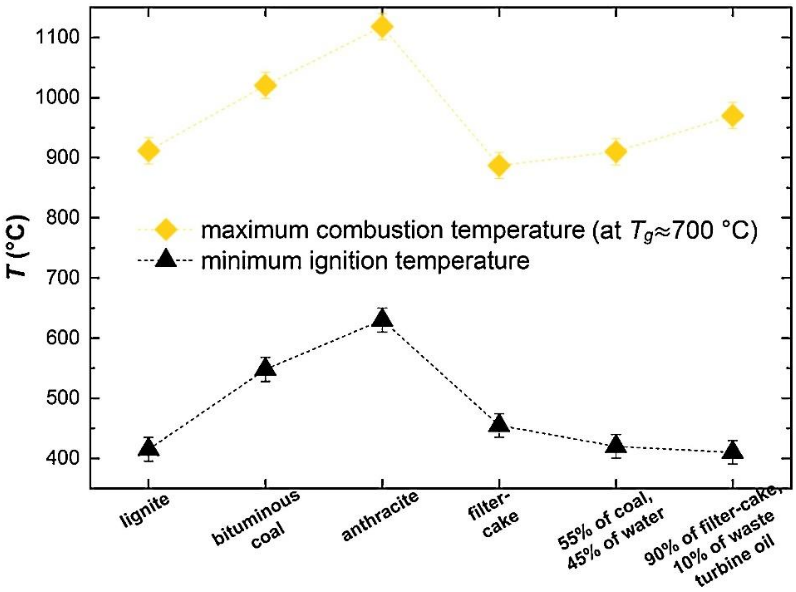

Figure 3: Maximum combustion and minimum ignition temperature of different coals and fuel samples [13].

Vershinina et al. [13] conducted experiments on the igniting characteristics of several types of coal and fuel samples, as depicted in Fig. 3. Figure 3 shows that anthracite has a higher combustion temperature. The difference between the combustion temperature of anthracite and bituminous coals is around 100°C. Indian coal is mostly bituminous. This is a medium-grade coal that has a high heating capacity. The most common type of coal used in India for electricity production is bituminous coal. Kumar and Nandi [14] studied the combustion characteristics of high ash Indian coal (Bhatgaon coal mine), wheat husk (WH), wheat straw (WS), and their blends for the temperature range of 30-700°C at atmospheric oxygen content and pulverized coal particle size of 75 micro meters.

Kumar and Nandi's [14] results show that the combustion efficiency of pure coal and its blend with WH & WS increases with an increase in temperature. The burning efficiency of coal increased from 3.44% to 96.77% as the combustion chamber temperature increased from 300°C to 500°C. Similarly, for wheat husk and wheat straw, the combustion efficiency increases from 43.84 to 100% and 56.02% to 100%, respectively, for the same temperature range. The combustion efficiency increased when the individual WS/WH content increased from 10% to 20% for blend WH2, 33.77% to 42.79%, and for blend WS2, 31.16% to 48.38%, respectively (as shown in Fig. 4).

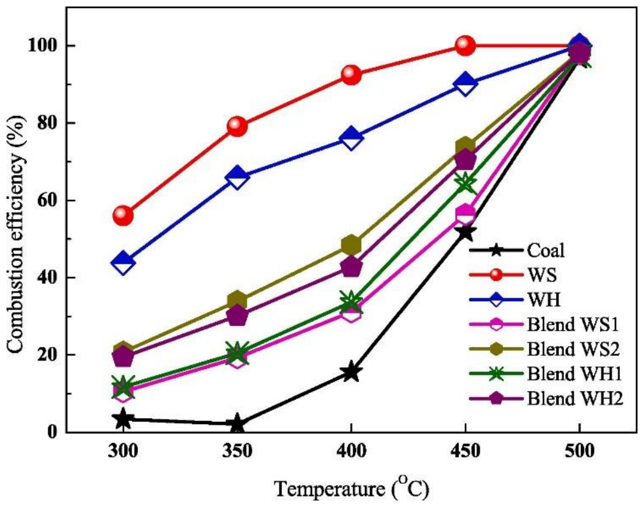

Figure 4: Combustion efficiency variation of high ash Indian coal, wheat straw, wheat husk, and their blends with temperature (WS1= 90% coal; 10% WS, WS2= 80% coal; 20% WS , WH1= 90% coal; 10% WH , WH2= 80% coal; 20% WH) [14].

Wheat straw and wheat husk are the major agricultural residue that is available in India. Various states of India, including Rajasthan, Haryana, Uttar Pradesh, Punjab, and Madhya Pradesh, burn a large amount of wheat straw and wheat husk without proper utilization strategies. The combustion of these agricultural residue's releases submicron particles as well as volatile gases, which are highly harmful to humans and contribute to smog [15]. It may be possible to blend coal with biomass to the extent of 10-20%, taking into consideration the inefficiencies of high-ash coal combustion and the availability of biomass [16]. In addition to India, studies have been discussed around the globe regarding biomass blended coal combustion. Vhathvarothai et al. [17] and Cong et al. [18] results suggest that the activation energy and ignition temperature improve with the addition of biomass with coal. Similar observations are also made in the study of Kumar and Nandi [14] for the blend of high-ash Indian coals with wheat straw and wheat husk (can be seen in Fig. 5). The higher activation energy of coal is due to higher fixed carbon (FC), lower volatile matter (VM), and higher ash content compared to wheat husk and straw.

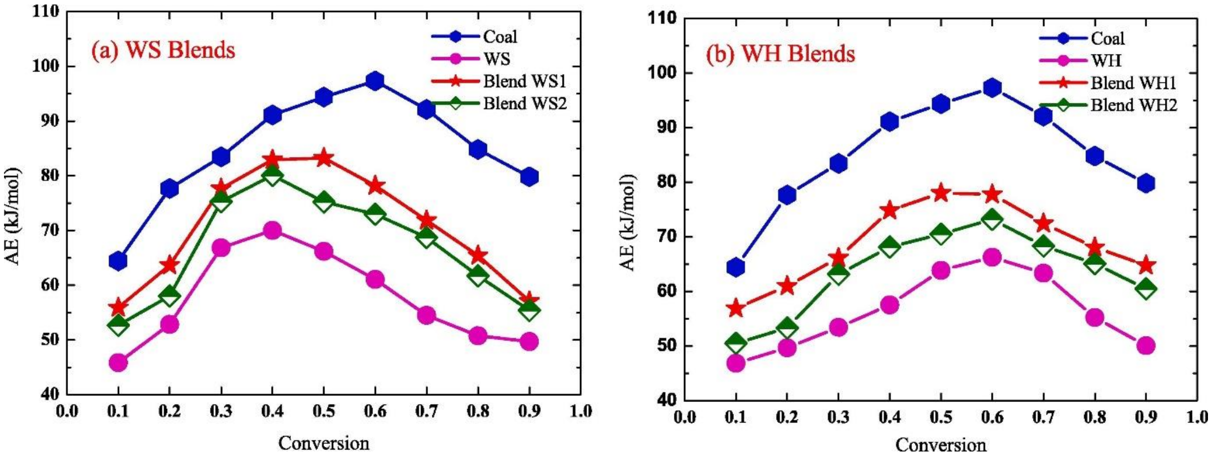

Figure 5: Activation energy variation with conversion for coal and its blend with (a) wheat straw and (b) wheat husk [14].

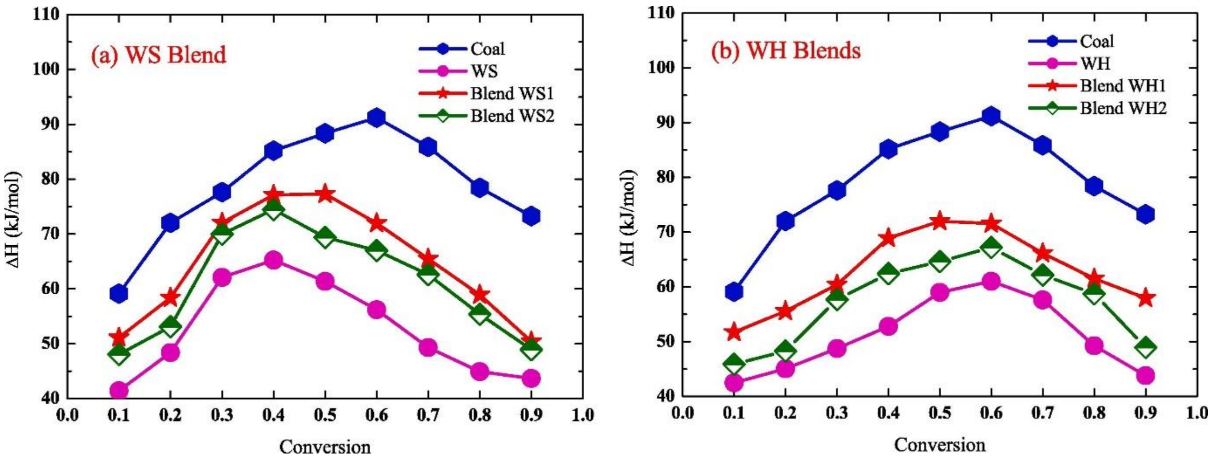

Figure 6: Enthalpy variation with conversion for coal and its blend with (a) wheat straw and (b) wheat husk [14].

Figure 6 shows the enthalpy variation of coal and its blend with wheat straw and husk. In terms of enthalpy values, coal has the highest enthalpy values, while wheat straw and husk have the lowest enthalpy values. Enthalpy values of coal+ wheat straw and coal + wheat husk blend decrease as biomass concentration in the blends increases. This phenomenon indicates that coal/biomass and blend combustion reactions are endothermic. For coal combustion to take place, a high enthalpy value signifies the need for more decomposition energy. Increased wheat straw and husk concentrations reduce the decomposition energy requirement during coal combustion. The reason for this is that biomass provides a necessary enthalpy value by igniting early. Lower combustion enthalpy values required for biomass are due to the presence of lignocellulose and cellulose materials; these materials are easily combustible. A study by Wang et al.[19] found that adding wheat straw to a blend of low-ash coal improved combustion efficiency. Baxter [20] reported that the utilization efficiency of biomass and coal is increased by cofiring biomass and coal. Ballester et al.[10] studied the flame and emissions characteristics of lignite coal, bituminous coal, and biomass oak sawdust in a semi-industrial furnace.

Ballester et al.[10] visual observations show that the combustion intensity in the near burner region increases as the fuel's volatile content increases. Also, the UHC concentrations in lignite coal combustion are very similar, or even lower, than those in bituminous coal combustion despite the higher volatile content. The flame near the burner zone of the sawdust combustion was more intense and wider than the coal flame. The fine fraction of sawdust particles released volatile substances, which may account for this phenomenon. A study on the influences of co-firing of coal and different biomass and its effect on flame stability and temperature is carried out in the industrial scale burner by Lu et al. [21]. In Lu et al. [21] work, the pulverized coal ignites slightly upstream of the combustor compared to the coal and biomass blend (can be seen in Fig.7). This trend is different from the above-discussed coal and biomass blend characteristics. However, the flame temperature is almost similar in pure coal and coal and biomass blends (can be seen in Fig.8). In Lu et al. [21] work, devolatilization or ignition may be delayed as a result of the large size of biomass particles and higher moisture content available in the biomass. Moreover, biomass usually contains a large amount of volatile matter that starts to decompose at lower temperatures, resulting in a more intense flame than pure pulverized coal.

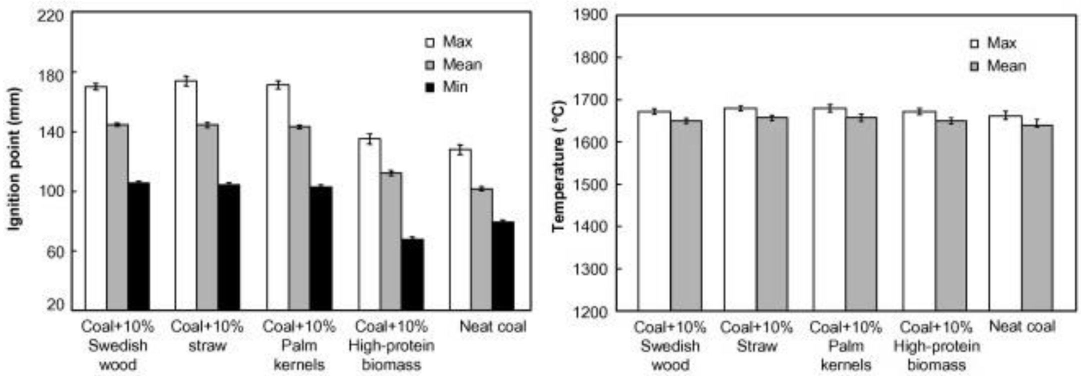

Figure 7: Variation of the ignition location and flame temperature for different types of coal and biomass blends [21].

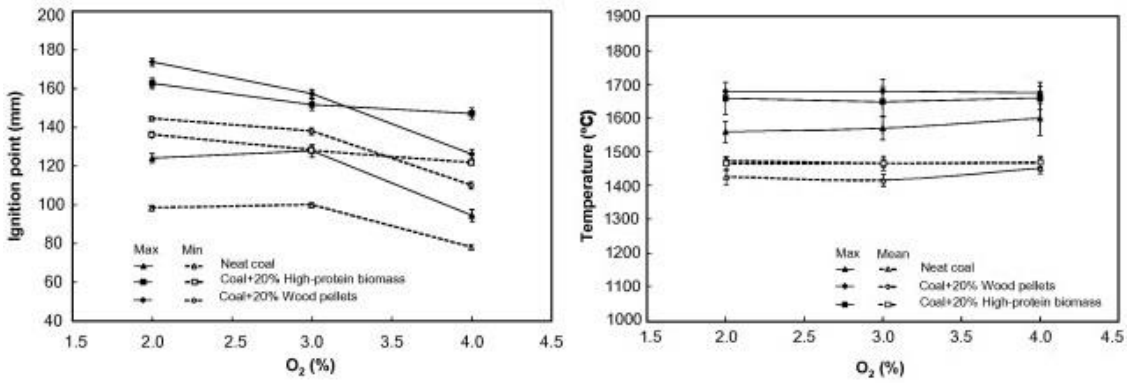

Figure 8: Variation of the ignition location and flame temperature for different types of coal and biomass blends at different excess air ratio [21].

The co-combustion of coal and biomass has received significant attention in the literature [18,19,22–26]. Typically, biomass particles size is larger than coal particles when coal and biomass are co-combusted. The process of grinding biomass is more difficult and expensive than that of grinding coal. There may be some differences between biomass and coal in terms of ignition performance due to particle size differences and fuel properties, which may affect flame characteristics. The blending of different types of coal has also been studied in addition to the coal and biomass blends. The ignition behavior of pulverized coal and coal blends in a drop tube furnace was examined by Chi et al.[27]. According to Chi et al.[27], the ignition behavior resembles that of coal and biomass co-combustion. Figure 9 shows the relative temperature and ignition point variation of different types of coals considered in the study of Chi et al. [27]. In Fig 9., coal A has the highest concentration of volatile matter of 26.76%, while D has the lowest of 8.79%. Due to this reason, coal A has the lowest ignition temperature of 492K. In the case of coal, A and F blends in different proportions, as shown in Fig 10., the blend composition of 70% (A) and 30% (F) has the highest concentration of volatile matter concentration. Due to this, it shows the lowest ignition temperature of 502K.

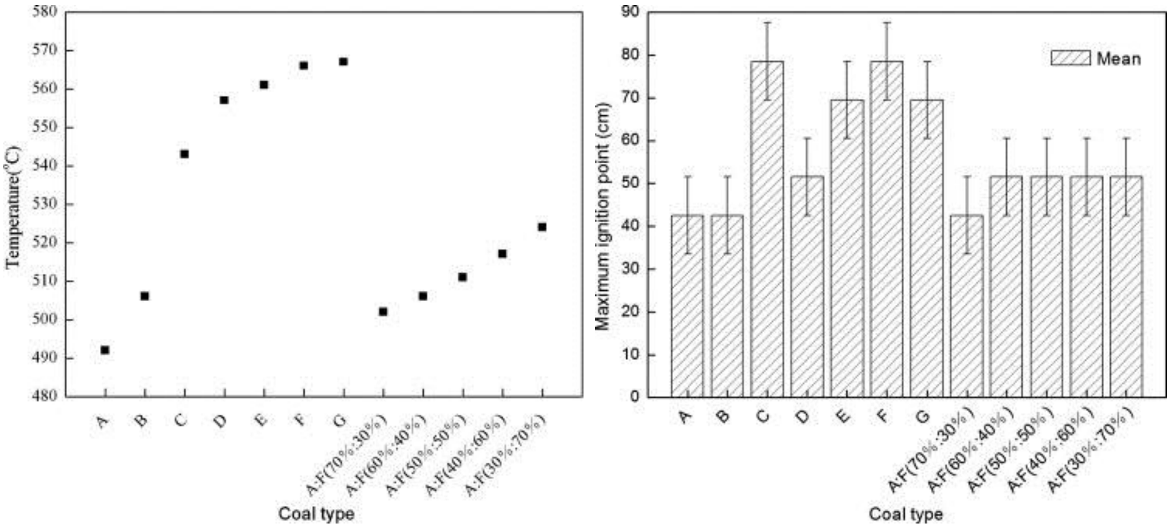

Figure 9: Variation of relative ignition temperature and ignition point of different coals [27].

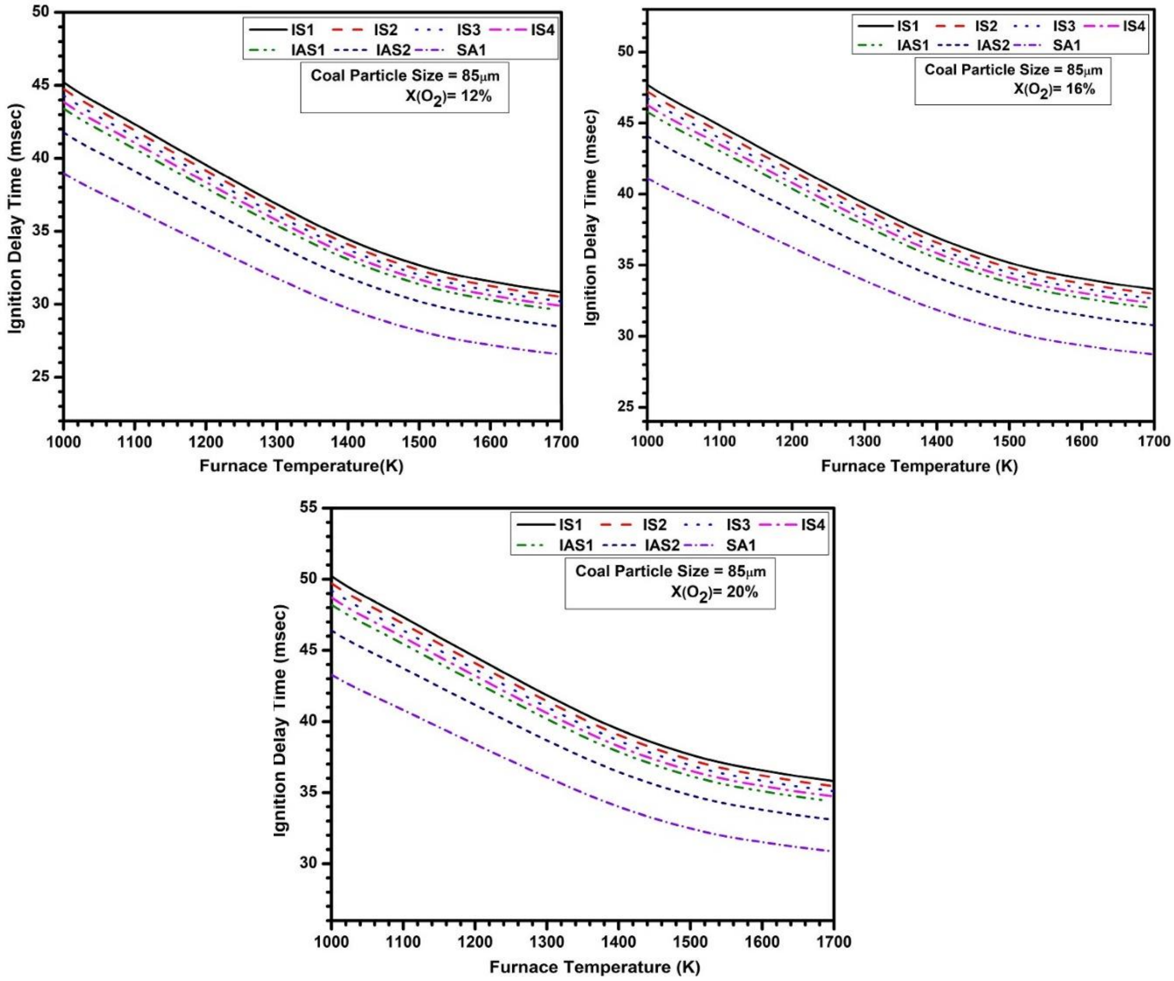

Figure 10: Variation in the ignition delay time of different coals at a particle size of 85 µm and oxygen concentration of 12, 16, and 20%[28].

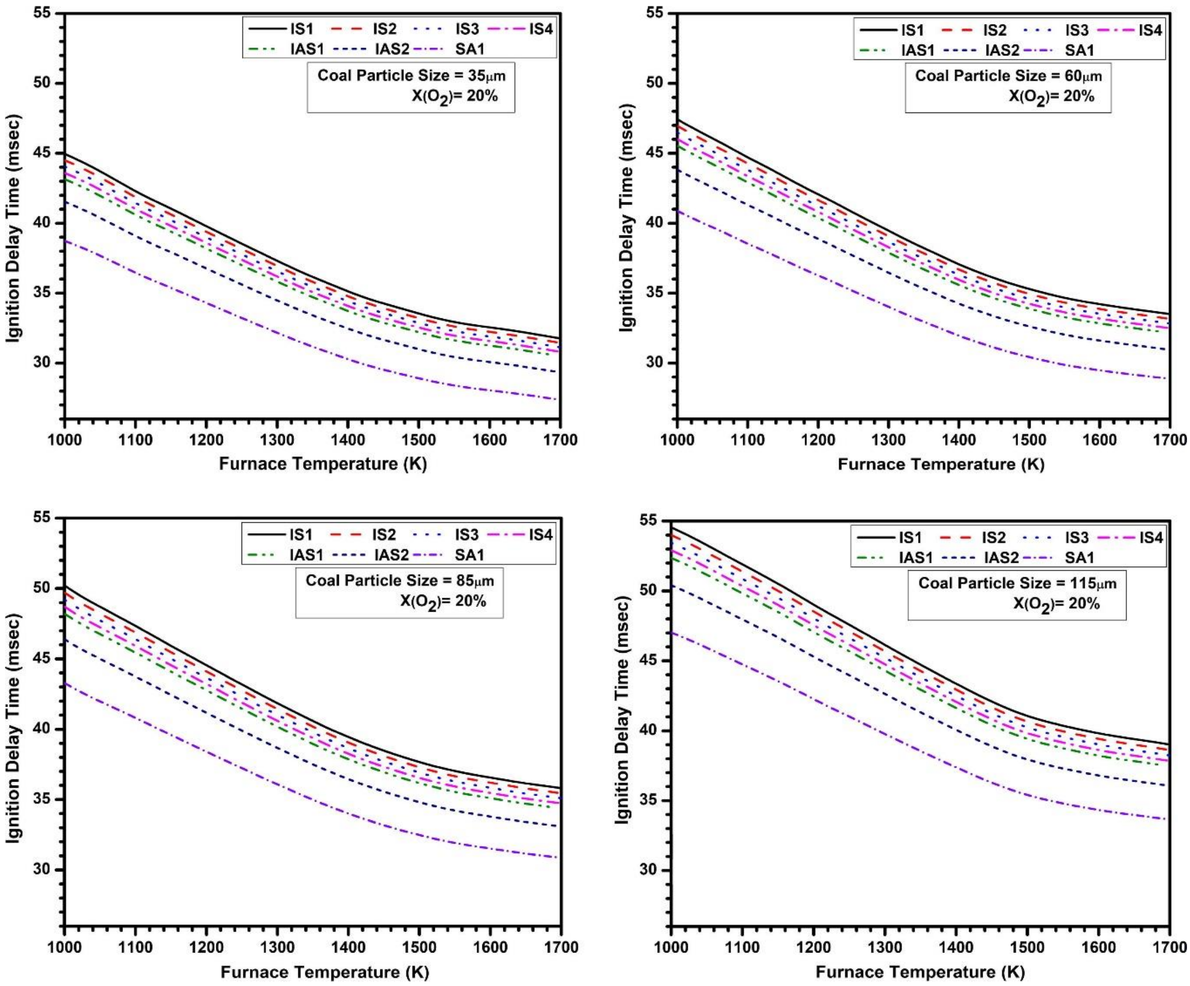

Figure 11: Variation in the ignition delay time of different coals at oxygen concentration of 20% and a particle size of 35, 60, 85, and 115 µm[28].

A coal blend's ignition property is influenced by the coal type having the highest volatile matter proportion in the coal blend. The characteristics of flame are significantly affected by the ignition delay time in pulverized coal combustion. When determining its ignition characteristics, it is essential to consider the particle size and the moisture & ash content of pulverized coal. In our group's recent work, a computational study is carried out to understand the ignition delay time of different Indian-grade coals and their blend with foreign-grade coals [28]. In this study, ignition delay analysis was performed for four Indian coals (IS1, IS2, IS3, and IS4), one South African coal (SA1), and two Indonesian coals (IAS1 and IAS2). Coal particle sizes ranged from 35, 60, 85, and 115 µm, and oxygen concentrations in gas were 12, 16, and 20%. The details of IS1, IS2, IS3, IS4, SA1, IAS1, and IAS2 are given in the previous work [28].

In Fig. 10, curves show that ignition delay time decreases with furnace temperature as pulverized coal mixtures ignite more quickly. Mixture ignition delay times are also reduced with a decrease in coal particle size (can be seen in Fig. 11). Compared to South African and Indonesian coals, Indian coal exhibits slower ignition because of its high ash and moisture content. Coal with higher moisture content requires higher heating time, consumes more energy, and produces volatile compounds. The presence of volatile matter influences a coal's ignition. Coal with high ash content will produce more coal slag, which will decrease the combustion rate. As a result, Indian coal exhibits poor ignition characteristics in comparison to coals found in South Africa and Indonesia. Increases in pulverized coal particle size increase ignition delay time at a specific furnace temperature. As a result of their larger surface-to-volume ratio, large particles take a longer time to ignite.

Higher furnace temperatures accelerate devolatilization and chemical reactions occurring in the gas phase. The burning of low-quality coals with high ash content presents a number of challenges, including problems with pulverizing, low flame temperature, and radiative heat transfer, as well as the production of a large amount of fly ash and unburned carbon. Low-grade Indian coals exhibit improved ignition characteristics when high-grade Indonesian and South African coals are added [28]. The combustion and ignition characteristics of coal in oxy and air atmospheres were numerically studied by Farazi et al.[29]. A decrease in particle size and an increase in initial gas temperature lead to a decrease in mixture ignition delay time, according to Farazi et al.[29]. It takes longer for coal particles to ignite in an oxy atmosphere than in an air environment. A lower initial gas phase temperature results in an increased difference in ignition delay time between the oxy and air atmospheres for a given particle size. As a result of carbon dioxide's chemical and thermal effects, the oxy atmosphere exhibits slower ignition than air.

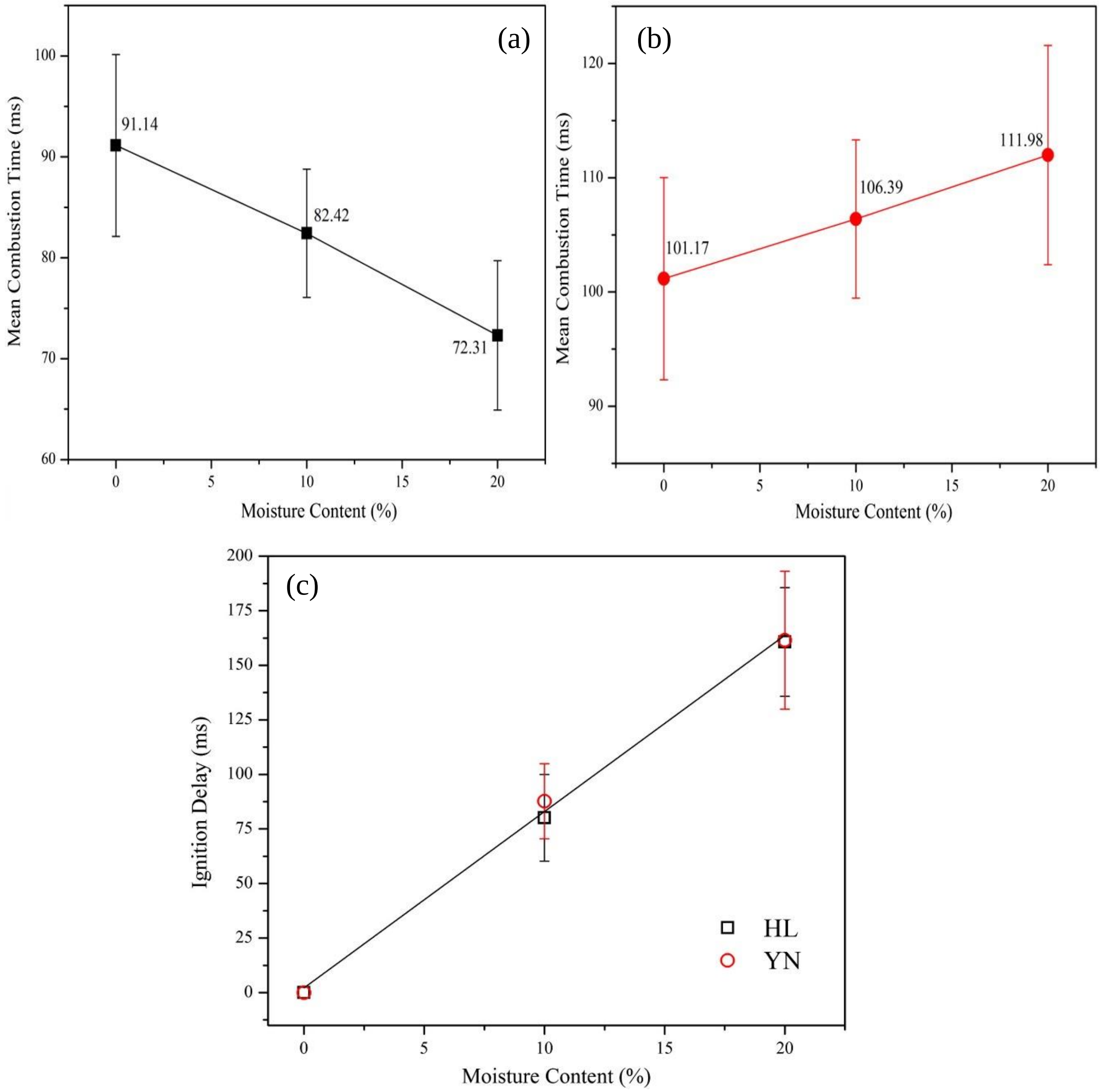

Figure 12: Mean combustion time and ignition delay time variation of Chinese (HL) and Indonesian (YN) lignite coals with moisture content [30].

Liu et al.[31] studied the ignition delay time of Pittsburgh high volatile bituminous and Black Thunder sub-bituminous in air and oxy atmosphere. Liu et al. [31] made similar observations as Farazi et al.[29] and found that the CO_2 dilution level, coal particle size, and oxygen content govern the ignition delay time at lower gas temperatures. However, particle size significantly governs the ignition delay time of the mixture at a higher temperature. An experimental investigation was conducted by

Tahmasebi et al.[30] to study the effect of moisture content on Indonesian and Chinese lignite coal's ignition and combustion behavior. The ignition delay was found to be linearly related to the moisture content of lignite (can be seen in Fig. 12(c)). Lignite particles ignite more slowly when they have a higher moisture content. It is interesting to note that both HL and YN lignite samples showed a similar ignition delay. There was an ignition delay of approximately 83 and 160 ms for lignite samples containing 10% and 20% moisture, respectively. According to these results, moisture content produced similar effects on ignition delay in both samples with similar particle sizes regardless of coal rank. In both YN and HL samples with similar moisture contents, the amount of water to be vaporized before oxygen attacks the particle surface and the increase in the particle temperature is the same. This results in a similar ignition delay time.

A comparison of the total combustion time of HL and YN lignite particles can be seen in Fig. 12 (a) and (b). Burning time is defined as the time it takes particles to burn out completely after ignition. Figure 12 (a) and (b) illustrate the interesting fact that increasing the moisture content of HL lignite decreased the total combustion time because HL particles fragmented more intensely at higher moisture content. The total combustion time of YN lignite was negatively affected by increasing its moisture content. Moisture-rich YN samples burned out more slowly. As a result of the presence of water, the particle surface temperature and oxygen partial pressure were lower, and this leads to the opposite trend of combustion time variation of YN coals.

The moisture content of coal has a major retarding effect on spontaneous heating. The time needed for the temperature to reach 350 K for moist coal is about twice that for dry coal. This temperature is maintained until the coal becomes dry. An increase in gas velocity results in a decrease in the maximum temperature rise because the evaporation rate increases; on the other hand, the temperature rise is proportional to the gas velocity for a dry coal bed. An increase in coal particle size also decreases the maximum temperature rise and moves the maximum temperature point downstream[32].

2.2 Emissions Characteristics

There are several environmental hazards associated with coal combustion, including oxides of sulfur (SOx), oxides of nitrogen (NOx), mercury, and sulfur monoxide. An overview of the emissions from pulverized fired furnaces is provided in this section.

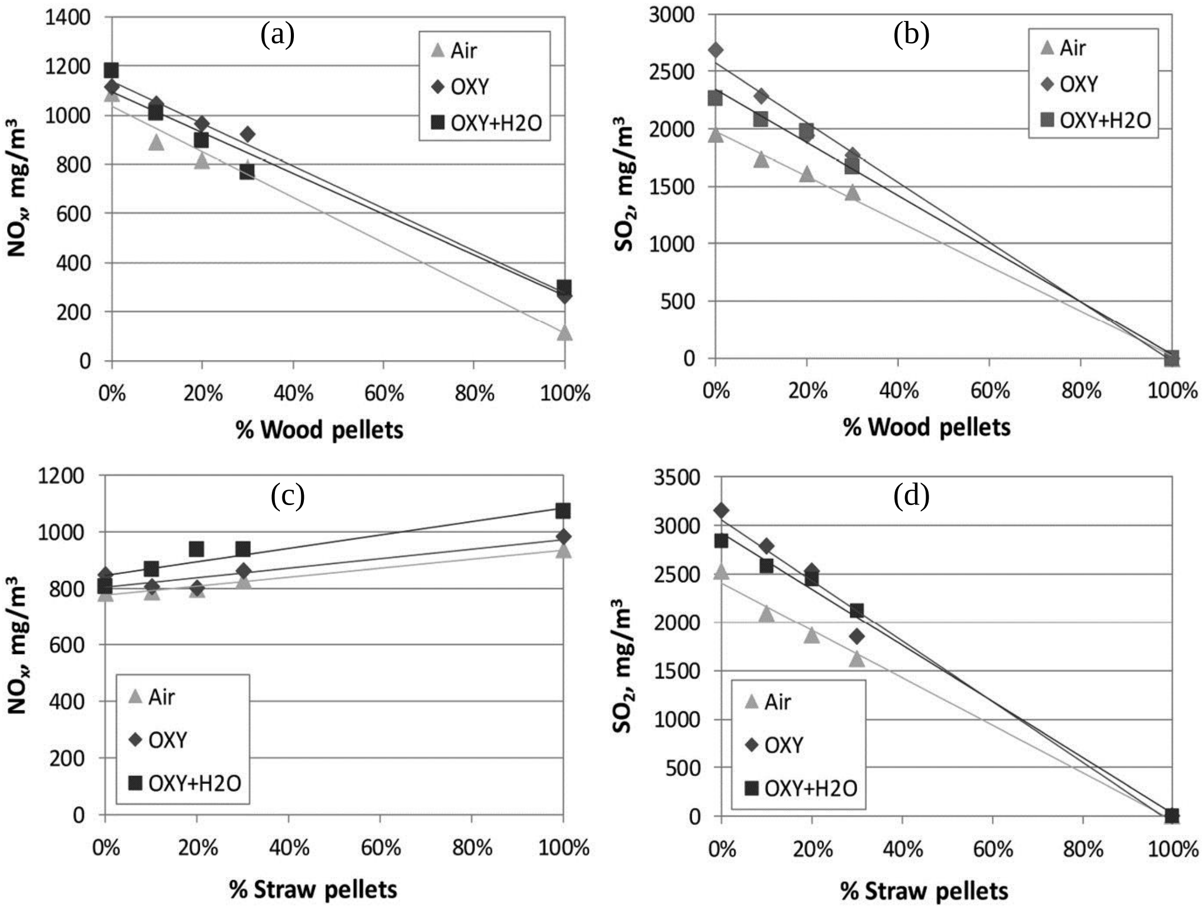

Figure 13: NOx and SO_2 variation of hard coal (a & b) and brown coal (c & d) with straw pellets blend under different atmosphere [33].

According to Moron and Rybak [33], the impact of coal blending with straw pellets on emission characteristics in air and oxyfuel combustion conditions can be seen in Fig. 13. Blending biomass with coal resulted in reduced NOx and SO_2 emissions. However, NOx emissions increase for the brown coal blend with biomass. Riaza et al.[34] reported similar effects of fuel blending on NOx and SO_2 emissions. Emission in the oxy-fuel atmosphere is higher than in the air atmosphere because the volume of wet exhaust gases generated in oxy is lower than in air. Hofbauer et al.[35], Li et al.[36], and Liu et al.[37] also observed the similar emissions behavior in oxy atmosphere. It depends on the nitrogen content of the fuel, whether biomass addition reduces or increases NO emissions. A nearly linear relationship existed between these decreases or increases and the amount of biomass in the blend. Hence, it can be seen that increasing straw pellet content in a brown coal blend will result in higher NOx emissions (as shown in Fig. 13(c)). In their study, Backreedy et al. [38] showed that coal blends has a lower NO concentration compared to single coals.

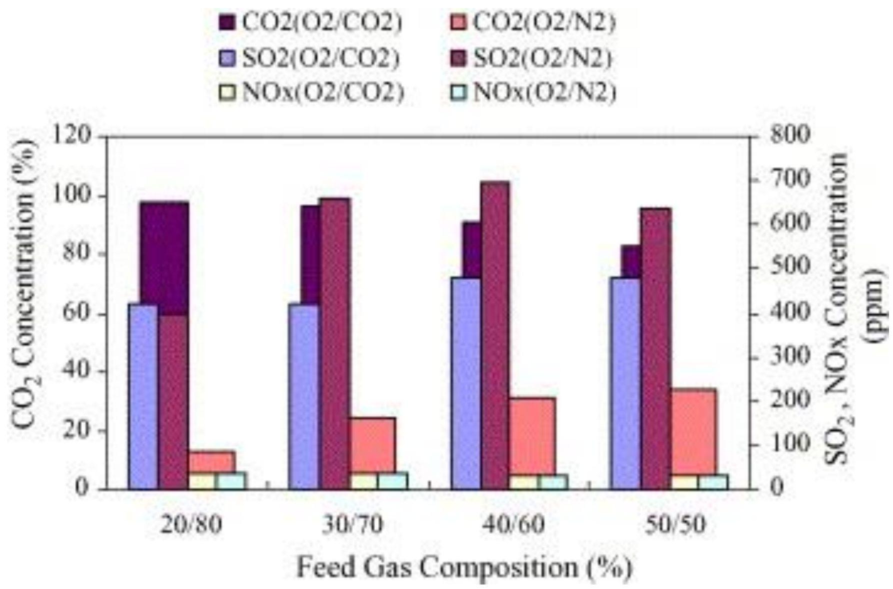

Figure 14: A comparison of SO_2. CO_2, and NOx concentrations at different compositions of feed gases (without recycled flue gas)[39].

A study by Chen et al.[39] examines the emission characteristics of SO_2, CO_2, and NOx in the flue gases of coal combustion by altering the concentrations and compositions of the feed gas ($O_2/CO_2/N_2$) and the ratio of recycled flue gases. Figure 14 shows that carbon dioxide emissions from O_2/CO_2 combustion are clearly higher than those from O_2/N_2 combustion at the same oxygen concentration. For the same feed gas composition as general air, 21% O_2/79% N_2, coal combustion produces only 13% carbon dioxide, whereas O_2/CO_2 coal combustion produces almost 98% carbon dioxide. Additionally, with increasing oxygen concentrations in the feed gas, carbon-dioxide concentrations from O_2/N_2 coal combustion increases. Similarly, Hjärtstam et al.[40] also reported that flue gas recycling reduced the NOx emissions. They observed that increasing the equivalence ratio decreased NOx emissions. Also, increasing recycling ratios increased NOx emissions. Hjärtstam et al. [40]concluded that NOx emissions were strongly dependent on nitrogen release into volatile matter and volatile to char nitrogen ratios.

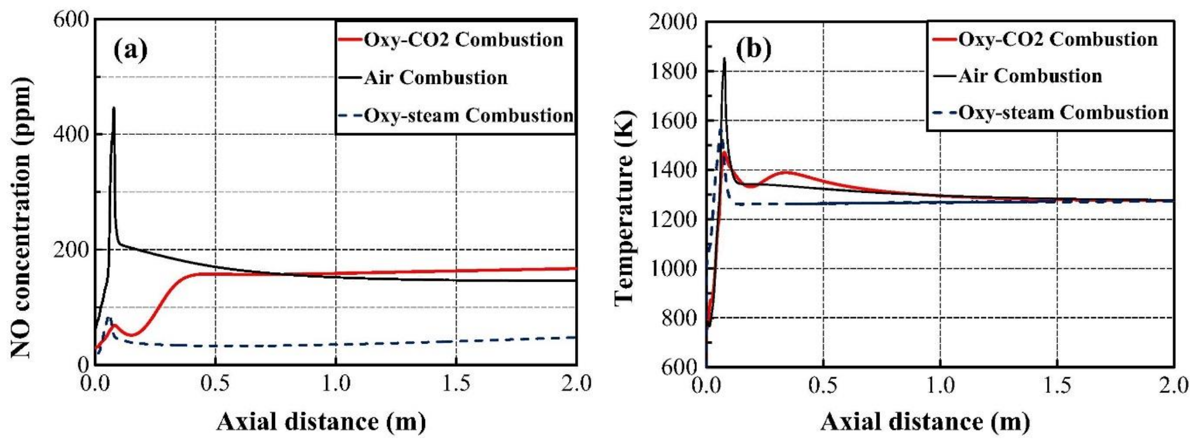

Figure 15: Variation NO concentration and temperature along the axis of furnace[41].

Gaikwad et al. [41] conducted the CFD analysis of swirl assisted two dimensional combustor to understand the combustion characteristics of pulverized coal under air, oxy-CO_2, and oxy-steam environment. Gaikwad et al [41]. found that the oxy-steam environment leads to lower temperatures of flames as well as low NO emissions at burner exit. In study by Ti et al. [42] it was found that increasing the outer cone length increases the size of the internal recirculation zone, which decreases the amount of nitrogen oxide emitted. Adding a De-NOx agent such as ammonia to coal combustion can also reduce NOx emissions. Zhang et al. [43] investigated numerically the influence of the co-firing ammonia ratio on the combustion and NOx emission characteristics of pulverized coal in a swirl-assisted burner. Zhang et al. [43] discovered that the co-firing ammonia ratio significantly affects NOx and unburned carbon emissions. For a 10% ammonia co-firing ratio, more intense combustion results in an increase in NOx emissions and a decrease in unburned carbon and ammonia emissions. Due to the De-NOx properties of ammonia, more unburned NH_3 and fewer NOx emissions are observed when the ammonia co-firing ratio is greater than 10%. In addition, the co-firing ammonia ratio exceeds 40%, resulting in a long, thin flame as opposed to the normal swirl flame. This is because a high-velocity ammonia jet has completely penetrated the internal recirculation zone. The above-mentioned studies demonstrate that swirl type or intensity modification is crucial for NOx reduction, flow mixing, and flame stability. A study by Adamczyk et al. [44] investigated NOx emissions from re-burning gasification gases obtained from sewage sludge. NOx emissions in boilers are affected by the injection location as well as the amount of syngas injected. By increasing the secondary fuel proportion from 10% to 20%, a reduction in NOx emissions is observed.

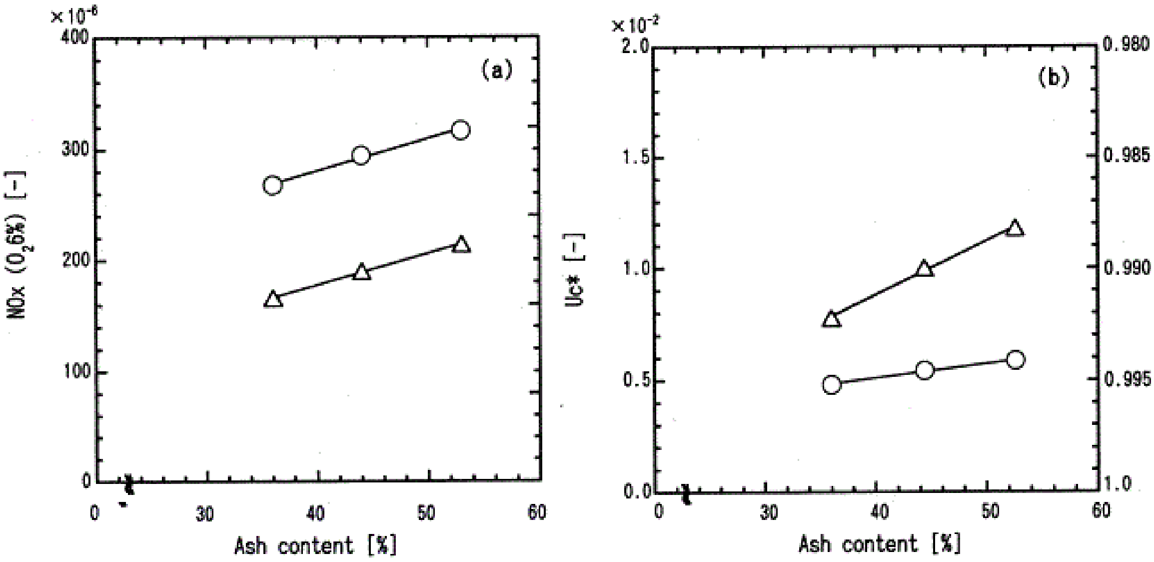

Figure 16: Variation of NOx and unburned carbon emission with ash content[45].

Kurose et al.[45] studied the NOx and unburned carbon variation with ash content in the mixture for standard and staged combustion (as shown in Fig. 16). Observations have shown that staged combustion decreases NOx concentration at the furnace exit and increases unburned carbon fractions. A reduction in NOx concentration is achieved by promoting the reduction of NOx. Meanwhile, the significant deficit in oxygen before the staged combustion air-port causes a significant increase in unburned carbon fractions. A staged combustion also increases NOx concentration and unburned carbon fraction with ash content, similar to the results of standard combustion. Reduced primary zone stoichiometry led to reduced NOx emissions, according to Ribeirete and Costa[46]. Ribeirete and Costa[46] highlight that the staged air injector configuration does not significantly impact NOx emissions. The NOx emission characteristics of superfine anthracite coal were investigated in single and multi-staged atmospheres by Shen et al.[47]. There is an increase of 12 to 22% in NOx reduction efficiency for superfine coal particles compared with regular-sized coal particles, and there is an increase in NOx reduction with multistage combustion over single-stage combustion (can be seen in Fig.17). Chen et al.[48] found that the decrease in the stoichiometric ratio from 1.0 to 0.6 reduced the NO concentration from 661.89 to 169.99 mg/N- m^3.

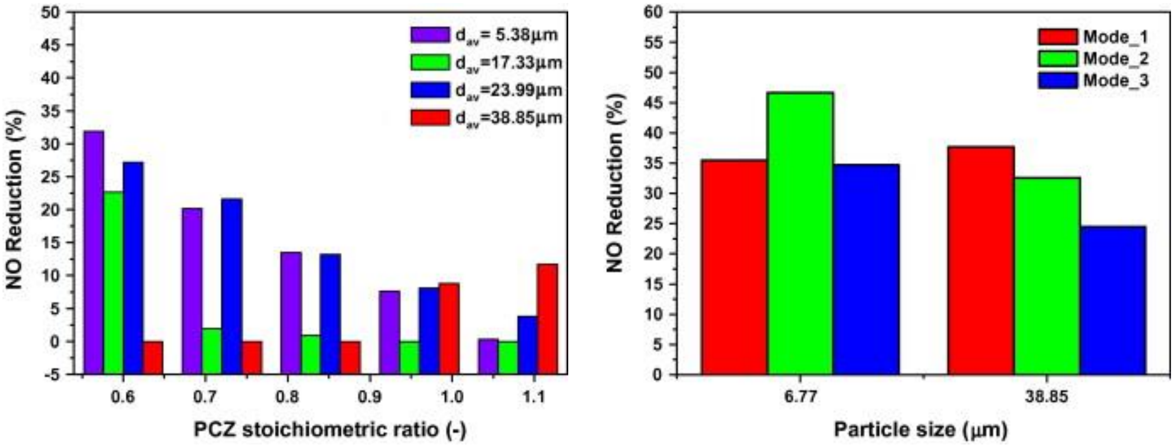

Figure 17: NOx variation in single stage and multistage combustion (PCZ-primary combustion zone, Mode_1, Mode_2, and Mode_3 are different air distribution in multi stage combustion)[47].

A significant source of NOx, SOx, and particulate matter are emitted by pulverized coal combustion. In order to control these emissions, continuous efforts were made. NOx emissions are affected by several factors, such as the fuel type, the ash and volatile content of the fuel, coal particle size, and the furnace configuration [49]. Modifying the combustion process can control NOx emissions. In addition to utilizing low NOx burners, recirculating flue gases, staging furnace air, and reburning fuels. New boilers can easily be modified to improve combustion, but existing boilers are more difficult to modify.

III. Conclusion

The works summarize a detailed review of combustion and emissions characteristics of coal combustion. Ignition and emission controlling parameters such as ash content, moisture content, particle size, and oxygen concentration effect on ignition and emissions characteristics of coal and its blend with different coals and biomass are discussed in detail.

➢ Identifying the problems associated with the combustion of low-grade coal and the utilization of agricultural wastes to minimize various air pollution issues is essential for the development of research on the co-combustion of high-ash coal and biomasses such as wheat straw and husk.

➢ The activation energy of coal + biomass blends improves, while the enthalpy value decreases with an increase in the biomass content in the blend. Therefore, the blend of coal with suitable biomass may be an attractive option to be used in thermal power plants. In addition to reducing NOx, SOx, and CO_2 emissions, co-combustion of biomass with coal is an effective way to generate renewable energy.

➢ Moisture affects coal combustion differently depending on the type of coal. Beyond coal rank, particle fragmentation due to moisture content also plays a significant role in determining the total combustion time of low-rank coals like lignite.

➢ CO_2 can easily be separated by several carbon capture technologies under oxyfuel combustion conditions, resulting in a reduction in greenhouse gas emissions. Plant efficiency is reduced as a result of carbon capture and sequestration (CCS) technologies. A loss of plant efficiency is estimated to range from 8 to 12% when pre- and post-combustion capture is applied, and a loss of efficiency is estimated to range from 7 to 11% when oxyfuel combustion capture is applied.

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