STM JOURNALS

Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 13, Special Issue 1, 2025
DOI (Journal): 10.37591/JoPC

https://journals.stmjournals.com/jopc

Research JoPC

Choking & Corrosion in Biomass Fired Boilers

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Abstract

Biomass or Agricultural Waste is being widely projected and Promoted as an alternate to Fossil Fuels. Not only the reserves of Fossil Fuels - Coal and Oil are getting depleted, they are responsible for adding to the menace of pollution. Hence Biomass aptly qualifies as a non-polluting and renewable source of energy. One of the direct and common use of Biomass Fuel is for producing heat by combustion in a boiler furnace. The chemical properties of bio-mass fuel results in the emission of flue gases and fly ash, which contain traces of minerals, corrosive substances, and moisture and are deposited on the surface of the heat transfer pipes in the pressure part section of the boiler at high temperatures. This results in corrosion of the metal surface of the tubes and a reduction in the section's heat transfer capacity. This is choking of the boiler tubes and effects its efficiency and performance with frequent shut down required to carry out the cleaning process which is cumbersome. This paper attempts to study the reasons for deposits and choking in a biomass fired boilers, the effects of choking on temperatures and boiler efficiency.

Keywords: Biomass; combustion; boiler; minerals; corrosion

INTRODUCTION

With the uncontrolled population explosion, the demand for Energy is increasing, especially in developing countries like India. Conventional energy sources are based on fossil fuels, which are causing Pollution and global warming. Moreover, their reserves are fast depleting. Several Biomass fuels, such as Agricultural wastes and forest wastes, are now being used as alternative fuels in power-generating boilers, replacing coal and oil. This results in a reduction of Carbon dioxide emissions. Agricultural wastes like Mustard husk, Paddy straw, Paralli, Cotton sticks etc are commonly used in boilers for generating both power and heat [1,2].

The chemical makeup and behavior of combustion of biomass fuels vary widely. Alkali metals that are largely found in organic compounds or as simple salts make up the majority of biomass fuels. This indicates that during burning, they are quickly transformed into gaseous form. The high alkali content of herbaceous crops, such cotton, paddy, and mustard straw, among others, significantly raises the deposits on the heat transfer tubes, which ultimately causes the metal surfaces to corrode [3,4]. Renewable energy sources known as biomass fuels are produced from organic resources including timber, algae, vegetation, and additionally animal waste. Because biomass fuels originate from live or recently living organisms, which may be regenerated through natural processes, they are regarded as renewable fuels. Biomass fuels come in a variety of forms, each with unique properties and uses, such as wood and wood pellets, agricultural products and leftovers, biogas, and plankton [5–8].

Biomass fuels have the potential to play a significant role in a sustainable energy mix, particularly in sectors like heat generation and

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Received Date: April 23, 2024
Accepted Date: June 08, 2024
Published Date: December 18, 2024

Citation: Mahesh Sachdeva, Ashish Shukla, Nakul Gupta. Choking & Corrosion in Biomass Fired Boilers. Journal of Polymer & Composites. 2025; 13(Special Issue 1): S389–S397p.

transportation where electrification may not be feasible or cost-effective(9). Several theories exist regarding the development of depositing layers on heat transfer pressure tubes in a boiler. These deposits typically contain various substances such as ash, soot, scale, and corrosion. Several factors, including fuel composition, combustion conditions, water quality, and tube material, can influence the formation of these layers [10–16].

Ash Deposition Theory

When solid fuels, such as coal or biomass, are burned in a boiler, they produce ash as a by-product. Due to factors like high temperature and flue gas flow patterns, the ash particles may adhere to the heat absorption tubes. Ash deposition can occur through mechanisms such as inertial impaction, gravitational settling, and thermophoresis [17].

Soot Deposition Theory

In boilers that burn liquid or gaseous fuels, incomplete combustion can result in the formation of soot, which consists of carbonaceous particles. Soot particles can adhere to the heat absorption tubes due to electrostatic attraction or condensation of volatile organic compounds. The presence of excessive unburned hydrocarbons, inadequate air-fuel mixing, or improper combustion conditions can contribute to soot deposition [18,19]

Scale Formation Theory

Scale deposits typically occur when water with a high mineral content is used in the boiler. The high temperature in the boiler causes dissolved minerals, such as calcium, magnesium, and silica, to precipitate and form solid scale layers on the heat absorption tubes. Scale formation can be influenced by factors like water chemistry, temperature, pressure, and flow rate [20–24].

Corrosion Product Deposition Theory

Corrosion of metal surfaces within the boiler can generate corrosion products that may deposit on the heat absorption tubes. Corrosion can occur due to dissolved oxygen, acidic gases, or high-temperature gradients [25–27]. It is clear that these theories are not mutually exclusive, and multiple mechanisms may contribute to the formation of deposit layers in a boiler. The specific factors and dominant mechanisms vary depending on the boiler system design, fuel type, operating circumstance, and maintenance practices. Proper boiler operation, regular cleaning, and appropriate water treatment can help mitigate deposit formation and maintain efficient heat transfer in the system. Many biomasses include considerable amounts of potassium and chlorine, which are extremely dangerous components because they can cause corrosion and the development of loose, non-adherent scales. The thermodynamic properties of potassium during biomass burning are significantly influenced by sulfur and chlorine. Potassium is mostly present in the flue gas state as potassium hydroxide (KOH) and potassium chloride (KCl). At lower temperatures, potassium forms compacted sulfates, chloride compounds, and silicates. In general, chlorine enhances the volatility of potassium [28–30].

The combustion process in biomass fuelled grate boilers produces a lot of ash. The majority of this ash never makes it to the super heaters because it is taken from the boiler as bottom ash. In actuality, nevertheless, it is seen that some sizable silicon particles are carried to the super heaters by the airflow produced by the FD and ID Fans, together with fly ash and flue gas. As the fly ash travels up stream it looses velocity and on colliding with the tubes and the casing of the superheater chamber the particles drop and accumulate in the gaps between the tubes thereby forming layers of deposits on the tubes and between the gaps. With passage of time this accumulation builds up to form a loosely adhered wall disrupting the passage of the flue gas. This is called choking of the boiler [31–35].

When temperatures reach highs of 600–800 degrees Celsius, the highest rates of corrosion show up on deposit-covered super heaters. Other than potassium, calcium and silicon are the most prevalent elements in agricultural waste. Superheated tube corrosion is influenced by the chemical makeup of deposits that accumulate on the tubes as well as the metallurgy of the tube material. Particularly

ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

detrimental to the corrosion of heat transfer surfaces are deposits produced during the burning of straw and other agricultural wastes, which include high concentrations of potassium and chlorine [36–41]. The presence of Chlorine results in fast corrosion due to increased oxidation Choking phenomenon occurs when fuel particles or fly ash continues to accumulate on the heat transfer tubes of a biomass-fired boiler, till it partially or totally blocks the flow path of the flue gases from furnace combustion zone to the stack and can significantly affect the performance, efficiency, and safety of the boiler.

LITERATURE REVIEW

Berlanga (2012)

The two major problems of using biomass are fouling and Choking, which result from Biomass combustion and affect the performance of Boilers. A variety of fuels with different chemical compositions and combustion properties are included in the category of biomass. Wheat straw and Mustard Straw are particularly problematic due to elevated levels of potassium and chlorine, which possess a high corrosion potential. In contrast to coal-fired power plants, the burning of straw causes corrosion problems. By weight, the wheat straw has 1.0 wt% K, 0.4 wt% Cl, and 0.15 wt% S. The corrosion mechanism is greatly influenced by the sulfur concentration. SO2 and potassium chloride are released into the flue gas during burning. After that, the flue gases undergo condensation, which causes deposits high in potassium sulfate and chloride to accumulate on the superheater. Blowing soot is one of the cleaning methods used to remove the ash buildup in the boiler. Boiler efficiency is further decreased by more ash buildup on the heat transfer tubes, which causes a slowdown in heat exchang [42].

Peter (2013)

Biomass-fired boilers encounter significant corrosion issues, particularly affecting critical components such as superheater tubes. Achieving high temperatures in the superheater tubes is essential for optimal efficiency. However, in practical terms, attaining excessively high temperatures is challenging, as it compromises mechanical strength and corrosion. resistance. In contrast, coal-fired boilers can reach steam temperatures as high as 650 °C, whereas biomass-fired boilers typically operate at around 550 °C, and waste-to-energy boilers maintain steam temperatures between 350-450 °C. The limitation on achieving higher steam temperatures in biomass and waste-fired boilers is primarily attributed to corrosion concerns. The distinct composition of biomass fuel, in comparison to coal, results in significant variations in flue gas composition [43].

Jan Sandberg (2011)

The study provides a comprehensive explanation of the processes involving deposits, fouling, and choking, delving into various factors primarily linked to the fuel composition. The mention of soot blowing as a means to remove deposits on the line is noted. However, the study lacks an exploration of solutions to address this issue. Based on the earlier research, it is evident that the presence of hygroscopic salts like CaCl2, MgCl2, NH4Cl, as well as condensation of H2SO4 and HCl, along with low-temperature corrosion, may contribute to the significant deposition of ash and low-temperature corrosion in biomass boilers [44].

K. S. Shanmukharadhya (2007)

The inherent characteristics of raw bagasse, with varied particle sizes and moisture levels emerging from the mill, play a pivotal role in the boiler's efficiency. Excessively wet bagasse poses challenges, as it struggles to ignite and introduces stability issues in the furnace. Increased fuel moisture can lead to the accumulation of damp bagasse on the grate. The bagasse composition comprises 83.01% volatile matter, 4.2% ash, and 12.7% fixed carbon on a dry basis, with the thermal decomposition of bagasse significantly influencing combustion. The diverse sizes of bagasse particles exhibit distinct densities and drying rates, contributing to their impacts on combustion. Effectively addressing these particles' demoisturization and thermal degradation holds crucial importance for optimal combustion [45].

KOTZE C. (2019)

A bagasse-fired boiler's efficiency is highly dependent on its moisture content; even a one or two percent difference in this content can have a noticeable impact on the boiler's performance. Fuel moisture has an effect on more than just boiler efficiency and combustion stability; it also impacts absorbed power, convective surface erosion rate, and a host of other variables. Fuel moisture concentration has a major impact on unburned carbon loss, which is mainly caused by fuel reactivity, furnace upward velocity, and physical fuel characteristics. Because it depends on velocity, moisture content has a significant impact on erosion rate. Ash carried over from the furnace decreases as a result of lower furnace velocity while burning drier fuels and lower fuel usage. As such, variations in moisture content, no matter how little, can have a significant impact on the pace at which convective heating surfaces and equipment downstream erode [46].

Anand Arjunwadkar (2016)

Boiler tubes are subjected to high temperatures and pressures due to flue gas flow, high outside temperatures, and internal steam. The second most common worry for boiler utilities is tube failure. Conditions within a CFB boiler could indicate substantial wear on some parts, however the rates of wear are not higher than in boilers that burn pulverized coal. Tube failures may result from corrosion, mechanical waste, or both. The three main processes that lead to metal waste in tubes are fretting, abrasion, and erosion. Particle impact causes erosion, which is the loss of metal, whereas mechanically loaded particles cause abrasion. The waste that arises when two solid surfaces are compressed together with a little relative amplitude is known as fretting. Alkali metals like salt and potassium accumulate on heat exchanger surfaces in biomass-fired boilers, lowering heat transfer rates and thus affecting boiler capacity [47].

Ayhan Demirbas (2003)

The authors contend that vegetable oil fuels were rejected because they were more costly than petroleum fuels. Due to the recent increases in petroleum prices and the unpredictability of petroleum supply, there is a resurgence of interest in vegetable oil fuels for diesel engines. Although the viscosity is reduced by dilution of oils with solvents and vegetable oil microemulsions, certain issues with engine performance persist. The transesterification procedure is used to reduce the oil's viscosity. More biogasoline is produced during pyrolysis than biodiesel fuel. Vegetable oil produced from soap pyrolysis can be utilized as a substitute fuel for diesel engines. Among the various novel, clean, and renewable engine fuel options, ethyl and methyl esters of vegetable oils provide a number of noteworthy benefits. The molar ratio is the primary component influencing transesterification [48].

L. Baxter (1996)

The effect of ash on conventional boiler performance varies based on the fuel's inorganic makeup and operating parameters. Ash is a major problem in traditional power systems, resulting in annual financial losses that are enormous because of decreased efficiency, unscheduled shutdowns, equipment failures, and cleaning requirements. There are several facets to using cutting-edge technology to solve boiler ash problems. Ash has detrimental impacts on boiler systems that include fireside ash accumulation, boiler component corrosion and erosion, and the production of small particles that are difficult to recover Top of Form [49].

R. Saidur (2011)

Layers of substance, usually ash, that build up on the surface of heat transfer equipment are referred to as fouling or deposits. Conversely, corrosion is the natural deterioration of a material's qualities brought on by exposure to external factors. Deposits, gas-phase materials, or a mix of the two can directly cause corrosion to begin. These problems are generally recognized as major ones that can affect the functionality, longevity, and design of combustion equipment in the context of boilers. They are linked to greater operating costs, worse boiler efficiency, higher emissions of carbon dioxide, poorer combustion behavior at higher temperatures, higher concentrations of carbon monoxide and nitrogen oxides, decreased heat transfer efficiency, and the beginning of corrosion and erosion. The composition of ash, together with sulfur and chlorine amounts, are the main causes of fouling, deposit formation, slagging, and corrosion. These elements make it easier for different inorganic compounds to move around, especially alkali compounds like sodium and potassium, which combine to produce alkali silicates, which melt at low temperatures (maybe as low as 700 °C). This produces a surface that is sticky and facilitates deposition. Because biomass fuels include a wider variety of inorganic elements than coal, it is imperative to address the problems of fouling and corrosion. This is particularly true for freshly planted trees and some agricultural leftovers, where the ash may contain comparatively large concentrations of alkaline metals, especially potassium and salt [50].

Nielsen (2000)

Many biomass sources include increased potassium and chlorine levels, which might be dangerous for corrosion. Chlorine can cause corrosion to proceed more quickly, which can result in increased oxidation, metal waste, internal degradation, void formation, and the growth of loosely attached scales. In regions where locally reducing conditions arise due to incomplete combustion and flame impingement, the partial pressure of HCl in flue gas derived from biomass can contribute to scale failure and increased sulfidation of water walls, even though it is usually insufficient for severe gas-phase corrosion attacks. It is expected that deposits high in chlorine that accumulate atop superheated tubes would cause the most serious corrosion problems in biomass-fired systems. These deposits include alkali chloride salts, which can hasten corrosion much below the salt's melting point. When air is present, corrosion might be more intense. Additionally, SO2 can cause alkali chloride deposits to become sulfated within the deposit, which releases hydrogen chloride (Cl2) or HCl gas near the metal surface [49].

Kleinhans (2007)

Higher moisture contents, a wider range of ash-forming metals, and a more varied assortment of minor components, such as Cl, S, P, and N, distinguish biomass fuels from coal. Municipal solid waste, wood or straw, forest leftovers, or demolition timber are a few of the fuels that are frequently employed. Without any prior preparation, these fuels are usually burned on a moving grate with combustion air supplied from below. To reduce nitric oxide emissions, modern systems use a staged air supply strategy and low stoichiometries in the grate's combustion zone. A significant amount of the inorganic material aggregates via the grate and leaves the system as solid ash particles. However, inorganic vapors and fine ash particles might be drawn in by combustion gases, let out of the grate, and moved into the boiler's flue gas duct. To stop molten ash particles from sticking to the boiler wall and causing severe corrosion, the first duct is usually covered. Because of the increased chlorine concentration in the raw fuel, steam temperatures are frequently restricted to values below 500°C, which presents a danger of corrosion caused by chlorine at high temperatures. Research on fire straw grate ash has shown that fly ash is generally richer in salt species, namely S, K and Cl, than bottom ash, which has a composition similar to silicate and is rich in Ca, K, and Si. This fly ash, especially on secondary or tertiary superheaters, can result in serious operational problems such downstream fouling or furnace slagging at lower temperatures [51].

Magasiner, N. (1991)

A fuel's ash sintering temperature is more important than its ash fusion temperature. The temperature at which ash particles begin to stick to one another when they come into contact and accumulate on boiler tubes is known as the sintering temperature. Screen tubes and superheaters are particularly vulnerable to this kind of fouling. Much as with fuels with large ratios of alkali-metal oxide to silica, this problem may be avoided by making sure the furnace has enough heating surface to bring the temperature of the gas exiting below the sintering temperature. Bulk density, particle size, and matting qualities are important physical characteristics. The bulk densities of all biomass fuels are modest, ranging from around 100 to 400 kg/m^3. With a density of about 140 kg/m3, burning biomass fuel requires about 20 times the volume of coal to produce the same amount of steam. Because of their strong matting properties, bagasse and bark present significant challenges for boiler designers when it comes to handling, storage, and even distribution into the furnace. Fuel moisture is a major factor in determining combustion parameters [52-53].

RESULTS AND DISCUSSION

Biomass-fired boilers have emerged as a promising source of renewable energy, offering an alternative to fossil fuels and contributing to the green energy movement, aiming to reduce the greenhouse effect and combat global warming. Despite these benefits, biomass-fired boilers encounter several challenges and hardships due to the unique properties and density of the fuel.

The deposit material in biomass-fired boilers mainly consists of unburned matter in vapor, melt, and solid particle states, transported in the flue gas. Biomass fuels typically contain small amounts of chlorine, possibly zinc, and alkali metals, which contribute to high deposit growth rates and rapid increases in corrosion rates. The primary concern is corrosion, particularly on the primary and secondary superheater tubes, as the ash deposits contain alkali chlorides.

Corrosion is influenced by the components and temperature of the flue gas, properties of the deposits on the tubes, tube material, and surface temperature. Deposits and the accumulation of fuel particles and ash reduce heat absorption capacity, leading to higher downstream flue gas temperatures and reduced boiler efficiency. Gradual accumulation of fuel particles and ash can result in choking, tube overheating, and failures, necessitating boiler shutdowns.

Corrosion, fouling, and slagging processes occur outside the tube surface. Biomass differs significantly from coal in terms of organic and inorganic composition, physical properties and energy content. Compared to coal, biomass generally has less carbon, more oxygen, higher levels of silica and potassium, lower heating value, increased moisture content, and lower density and friability. Because biomass fibers frequently contain more chlorine than coal, burning them, especially some types like straw, is difficult. There is a significant chance of corrosion because of this increased chlorine present. Alkali metal concentrations in biomass fuels are also frequently high, especially for sodium and potassium. These metals can mix with chlorine to create compounds that have shallow melting points. Achieving the ideal temperature for superheater tubes is essential to improving efficiency. Reaching these higher temperatures requires striking a careful balance between the tube material's resistance to corrosion, increased temperature, and decreased mechanical strength. Biomass-fired boilers typically attain a maximum temperature of 550°C, while waste-to-energy facilities are limited to even lower temperatures of 350–450°C. In contrast, coal-fired units may run at steam temperatures as high as 650°C. The primary cause of the steam temperature reduction in waste-fired boilers and biomass continues to be corrosion problems.

The Literature review shows that majority of the papers highlight the challenges associated with biomass-fired boilers which are mainly linked to their ash content, including higher proportions of alkali metals, chlorine content, and the associated issues of fouling, deposition, corrosion, and slagging.

CONCLUSION

Although garbage and biomass are promising ecologically friendly energy sources, their diverse composition, higher moisture content, and lower thermal values provide several challenges. These qualities require careful consideration during the burning process. The chemical composition introduces an additional degree of complication, especially when significant amounts of chlorine and alkali are released into the flue gas during combustion. Compounds from the hot flue gas, such as alkali chlorides, tend to build up on heat-exchanging parts of the boiler, including superheater tubes. This accumulation reduces the effectiveness of heat transfer and increases the danger of corrosion. As a result, corrosion-related problems increase maintenance, replacement, and downtime costs and impede boiler performance. Incidents related to fouling and corrosion may cause abrupt shutdowns and interruptions in operations. Developing solid and practical solutions for deposit development and blockages in biomass-fired boilers requires devoted study and hands-on testing.

ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

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