A Review on Boiler Deposition/Foulage Prevention and Removal Techniques for Power Plant

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Abstract:- Burning coal in power plants produces significant amounts of deposits like fouling and slagging on boiler surfaces which contributes to the overall poor performance of the power plants (by reducing electricity generation capacity, decreasing boiler efficiency and increasing overall maintenance cost). Recent research and development on boiler fouling and slagging problems, with the current preventative measures and technologies available to minimise this deposition, is reviewed and discussed in this paper. There are several technologies to minimise the deposition problems in boilers, such as pulse detonation wave technology, intelligent shoot blower, anti-fouling coatings, chemical treatment technology, etc. The effectiveness of these technologies to prevent foulage problems is addressed, and concluding remarks and recommendations are drawn according to their effectiveness.

Keyword: Coal, fouling, slagging, pulse detonation wave, intelligent shoot blower, electricity generation.

1 Introduction

Boilers are the main heat transfer units in a power plant, though there are other heat transfer units associated with power plants, but unwanted deposits like slagging and fouling occurred mainly in boilers. A large percentage of of power plant boilers use coal as a fuel for steam generation. Coal characteristics affect the overall performance of the plant including electricity production capacity, equipment failure rate, and waste disposal requirements, and overall this affects the environment. The most problematic and trouble some effect of coal is the creation of sticky and hardened deposits on furnace or convection surfaces of boilers.The operating system and design properties of boilers also have impacts on the deposition. Coals contain different mineral materials in various forms. During combustion, the mineral matter is transformed into fly ash, which is deposited on heat transfer surfaces of boilers.

Accumulations of these deposits are known as slagging or foulage problem which can have a negative effect on total plant performance, causing lower production capacity and higher maintenance cost. One of the main effects of the formation of slagging and fouling deposits is that they reduce the heat transfer process between the fireside and the water-steam side and resulting in a sensible increase of the flue gas temperature, reducing the efficiency of the system and increasing corrosion problems in boilers. Fig. 1 shows a schematic diagram of the coal ash deposition process in utility boilers where deposition occurs through 6 stages [1]. Depositions like fouling and slagging are the vital problem for power plant in terms of economic and environmental issues. It has been estimated that for reduced power generation and increased equipment maintenance due to slagging and fouling problems the global utility industry expend several billion dollars annually [2]. The European Union has set the target to achieve 22% of electricity generation by 2010 from renewable sources, though this extensive use of “green” energy source is being affected by the technical problems associated with boiler problems like fouling and slagging [3]. In this review paper an initiative has been made to investigate the current fouling problem in boilers and current prevention and removal techniques associated with power plant and discuss the effectiveness of these technique and possible technologies that can be applied to prevent foulage problems in boiler in a safe manner.

2 Slagging and Fouling in Boilers

Different types of depositions accumulated in boiler. When the deposition of ash on furnace walls, mainly in the radiant section, is in a highly viscous state and forms a liquid layer then it is called slagging, when the deposit is built up by condensed materials, forming a dry deposit, generally in the convective section, then it is called fouling, [4,5]. Slagging is mainly a molten deposit of ash particles. When the molten ash contacts the boiler tube surface then it tends to solidify due to the lower temperature of the boiler tube. For particles to fuse to the tube wall and not rebound from the inertia force, it is necessary that the particles be sticky [6].

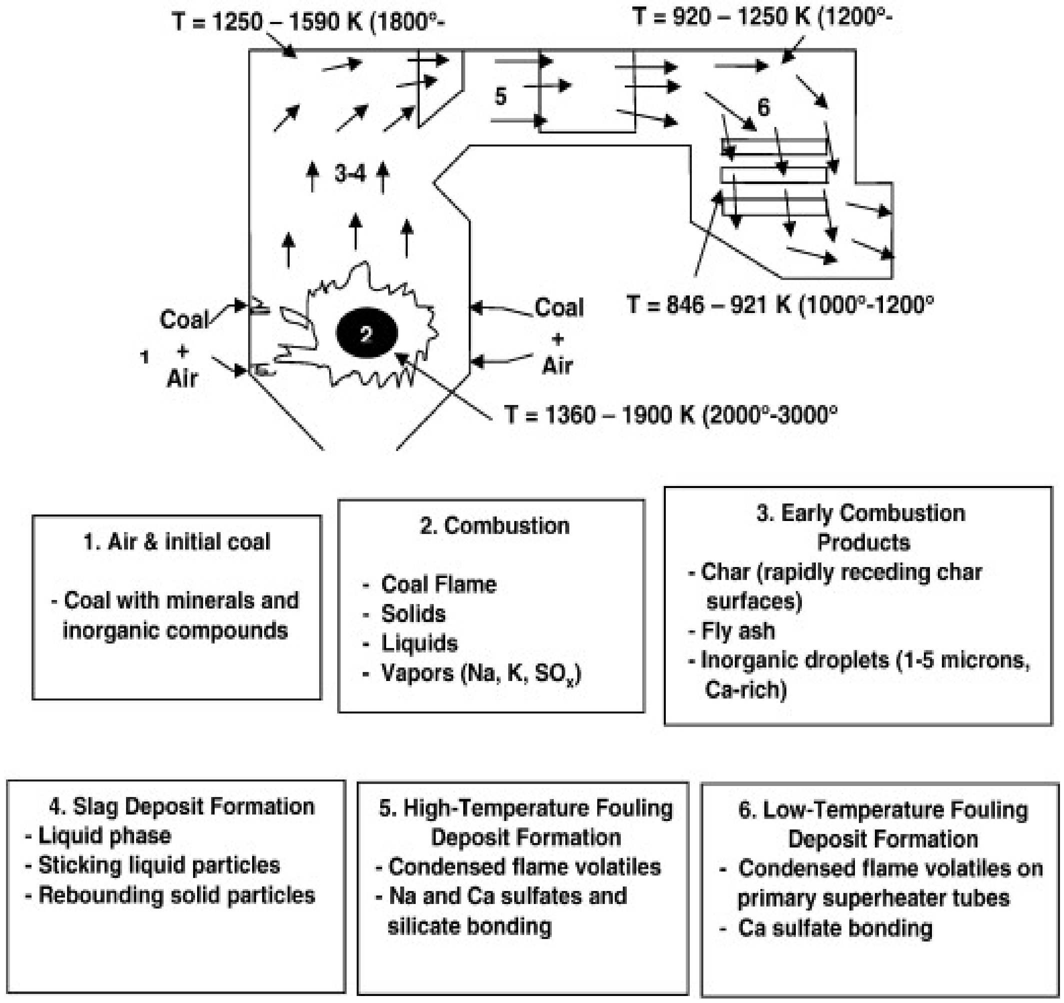

Fig. 1: Schematic of coal ash deposition process in utility boilers [1]

The particles require a certain amount of force to carry them from the centre of the boiler to the where they impact the wall. This can be done in different ways. The most common process is inertial impaction where the particle gains inertia from the flame and is thrown towards the wall [7]. Reference 8 defines the term fouling as sintered or cemented deposits that form on convection surfaces. In general, slagging occurs on the water walls near the high temperature region of a furnace, and fouling is most likely on the preheated and superheater surfaces where the flue gas temperatures are much lower than in the combustion zone [9]. Fouling and slagging phenomena are affected by different coals used in boilers. It has been demonstrated that bituminous Scottish coal has a slightly higher fouling propensity compared to the Colombian bituminous coal. It has been demonstrated that the Na_2O content of coal ash and the chlorine content of the coal, are indicators of likely fouling problems[9]. Deposition in a boiler depends mainly on the amount and type of inorganic materials present in the coal being used. One of the main effects of deposits formed by slagging and fouling is that they reduce the heat transfer process between the fireside and the water-steam side and result in a significant increase of the flue gas temperature, reducing the efficiency of the system and increasing corrosion problems in boilers. The primary factors that impact the removal of the fouling/ash deposits are the strength of the deposit and the adhesive bond between the ash deposit and the heat transfer surface. The removal of the deposit involves breaking the deposit matrix and/or breaking the adhesive bond. Slagging and fouling problems in boilers of coal fired power plant can create significant production problem. There may also be increased frequency and duration of outages for maintenance or for cleaning and deslagging of the furnace. All of these costs are cumulative and can increase expenses for operating the plants.

3 Mechanisms and Technologies Available for Prevention of Deposition Problem in Boiler

3.1 Soot Blowers

Soot Blowers can be used to clean the heated surface of boilers during operation with a blowing medium of

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water or steam (compressed air). The blowing medium is directed at the deposit through a nozzle. That causes the deposit to crack and be eroded away. Mainly steam is used due to its'ready availability as well as it being suitable to remove large accumulation while causing less thermal shock to the tubes. The application of soot blowers varies widely based on the quality of coal, and range of boiler operating conditions. Two distinct types of soot blower are used, the long retractable soot blowers that extend a fair way in and clean the handing pendants such as the superheaters and the another type is short retractable shoot blower that extend a short way into the blower and release steam onto the tubes close by. The main disadvantage of these methods is that percentage removal of slag on the back side of tubes is very low [10].

3.2 Ash Behavior Prediction Tool

There are some ash behavior prediction tool like AshPro^{SM} used to assess the slagging and fouling situation in coal-fired boilers, integrating boiler computational fluid dynamic (CFD) simulations with ash behavior models including ash formation, transport, deposition, deposit growth and strength development. This integration enables the provision of a prediction result of qualitative and quantitative descriptions of the slag formation and deposition phenomena, indicating, deposit thickness, chemical composition, physical properties and heat transfer properties in a specific region of the furnace wall and convective pass processes. These prediction results are very important to assess the overall performance of power plants including fuel quality, ash properties, fouling, slagging, etc [11]. Micro beam Technologies Inc (MTI) also provides advance quantitative information on the impurities in fuels, ash behavior and determining and predicting the effect of ash on power system performance using computer controlled scanning electron microcopy (CCSEM). MTI's processes also identify problematic deposits, slagging and fouling. This predicted information is very useful in reduction of abrasion and erosion, slag flow problems, convective pass fouling, ash resistivity and deposit strength [12].

3.3 Wet Pretreatment of Brown Coal-fired Power Utility Boiler

This technique is suitable for brown coal-fired utility boilers. In this technique brown coal is treated with aluminum solutions at temperature ranging from 1000–1400°C to adjust the levels of Na, Al and Cl. At the temperature of 1250°C, the deposition behavior of treated and raw coals is compared using a deposition probe maintained at temperatures of 500, 600, 700 and 800°C. Experiments showed that this technique is effective in reducing ash-related problems [13].

3.4 Using Mineral Additives in Coal Fired Utility Boiler

Experiments have shown that mixtures of candidate mineral additives and sodium compounds with brown coal at temperatures ranging from 1000 to 1400°C are effective in reducing ash related fouling and slagging problems. Experiments with mineral additives also showed that sodium could be captured by clay minerals, especially kaolin. It is estimated for Victorian brown coal-based power station boilers, that10–20 μm kaolin making up 2–3% by weight of the feed is effective in reducing the ash problems [13].

3.5 Monitoring of Fouling Tendencies

Continuous fouling formation on heat transfer surfaces is a great problem in existing conventional coal fired utility boilers. A cost effective way to minimise this difficulty is the continuous monitoring of fouling tendencies in boilers as a tool of operation. Improvement of soot blowing procedures from monitoring fouling can lead to significant savings in power plant [14]. Heat flux meters can be been used to study thermal absorption diagnostics in boilers as a part of the boiler-monitoring systems. These sensors can be installed at power plants by a supplier of soot blowing systems though it is difficult to quantify the energy saving obtained from the development and application of such a sensor [15].

3.6 Chemical Treatment Technology: Targeted in Furnace Injection (TIFI) Technology

Chemical treatment technology is used in western USA coal fired utility boilers to control slagging, fouling and tube cracking. This Targeted in Furnace Injection (TIFI) technology involves the radiant and convection sections of boilers where fouling and slagging are occurring and this technology involves different forms of fluid dynamics modelling and a virtual reality engine. Chemicals are injected in to the flu gas system after mixing with water and air. Magnesium hydroxide slurry diluted with water and then atomized with air is the most common application of TIFT technology. This mixture is sprayed into the furnace at computer determined ports that allow for complete coverage of the problem areas. These cause a chemical reaction with existing deposits and affect their physical crystal characteristics. This chemical treatment program was successfully applied for inhibition and reduction of slag formation in the superheater, reheat and the furnace walls sections [16].

3.7 Internal Cameras

Internal cameras (3.9 micrometer band) can be used to monitor the fouling problem. Special infrared cameras for this purpose are designed to scan the fouling by filtering the light from the boiler. This allows the camera to see through the flames to the walls by blocking the appropriate wavelengths. These types of cameras are hand held thus must be used through viewpoints[17]. Internal cameras can be installed in areas that are prone to clinker build-up or can be installed in adequate numbers to cover the all relevant areas of the boiler. If rotatable cameras are used they will also be able to see multiple places of the boiler.

3.8 Slagging Indices

Slagging indices are used to determine the mineral composition of the ash present in the coal and if the ash is likely to foul or not foul. Some of these indices are based on minerals, some on the basic and acidic ratio in the ash and others on the viscosity of the minerals at certain temperatures [18]. It may be noted that even though these indices are usually reasonably accurate, they should generally be used only as a guide. In some cases certain indices have shown no correlation to slagging. To use these indices, a more accurate coal analyser should be installed.

3.9 Coal Blending

Coal blending is used for combining different types of coals to produce different effects in boiler. Coal blending does not always work properly, as in a number of cases the blended coals produce more of a slagging effect than do either of the parent coals used separately. The TMA (thermo mechanical analysis technique) developed by the CSIRO has proved successful in predicting ash deposition in blended coals [19]. In theTMA method, the shrinkage of ash particles is measured against temperature. The shrinkage of ash from melting can be correlated against slagging to produce a slagging propensity index [20].

3.10 Pulse Detonation Wave Technology

Pulse detonation wave technology has good potential to remove slag from various parts of boilers. It is in particular more effective in the convective pass or the low temperature sections of boilers, and has potential to remove deposits all around the exchanger tubes.Also it is convenient, and inexpensive. This technology is based mainly on a supersonic combustion process, in which a shock wave is propagated forward due to energy released in a reaction zone behind it, where an ignited fuel/oxidiser mixture burns and releases energy. Experiments using a pulse detonation engine and heat exchanger tubes with different types of slag placed in different places on the tubes, placed at various distances from the detonation tube with different configurations, found that this technology is very effective for online slag removal especially for slag on the back sides of the tubes. Two types of detonation waves are used to remove slagging and fouling, strong detonation wave and weak detonation waves. A strong detonation wave, also known as the Chapman–Jouget (C–J) wave has a velocity of up to 2200 m/s and a maximum pressure jump of approximately 20 times that of the unburned reactants. The removal can also be enhanced by making the engines move on a tracking device along or/and around the tube banks. Fig. 2 shows that certain types of slag behave differently according to their bond strengths and according to the distance from the exit of the detonation tube.

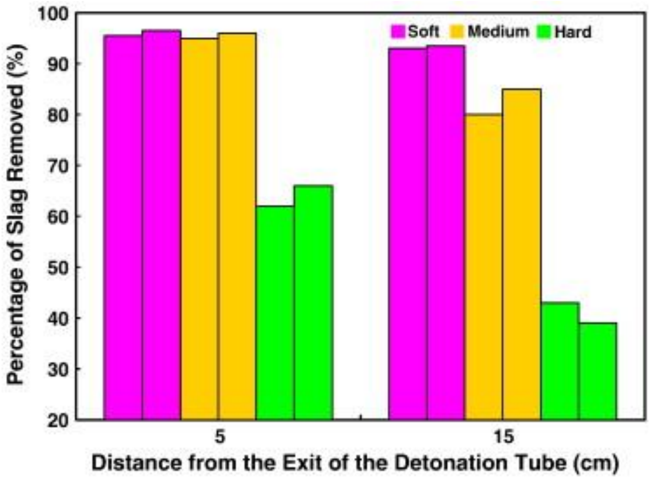

Figure 2: Percentage slag removed for different slags and different distances [1]

The significant characteristics of the pulse detonation technology are, high temperature, high velocity, high pressure waves, producing direct impact, thermal stresses, wave reflection, and wave reverberations and exceptionally high shearing capability which is an important factor to remove slag and fouling deposits. It is found in the literature that both single and multi-shot detonation waves have potential to remove fouling deposits. Researchers have found that softer slags are removed more easily with multiple waves. Slag on the top of the tube generally breaks up into smaller pieces when exposed to the wave, while the slag on the side of the tube and in the webbing shears off while still staying whole. PDE's (pulse detonation engines) are very effective for producing C-J detonation wave (strong wave) for removing clinker formations without damaging the boiler. This PDE method would be useful particularly in areas where clinker builds up and is

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sometimes not adequately removed and in areas where the black side of tubes are difficult to clean due to their reverberation effect. The PDE is powered by an electric motor and injection valves feed the combustible fluid into the ignition section. Instruments mounted on different sections of the device are necessary to check the performance of the engine. These instruments include pressure transducers, thermocouples and thin film gauges [1, 21].

3.10 Anti Fouling Coatings

Ceramic and non-catalytic anti fouling coatings are used on the internal surfaces of boilers. The coating is generally very dense having, being less than 1% porosity, and is able to significantly reduce the occurrence of molten ash particles sticking to the surfaces. It is also able to withstand severe thermal cycling that occurs when boiler loads are changed and when hydro jets are in use [22]. Coatings have limited effectiveness in some areas of the boilers especially upper slopes and the wing-wall tubes. On the lower angle slopes of the upper walls specific gas flow patterns sometimes render the coatings ineffective while the small gaps that are sometimes present in the wing wall designs allow slag to bond itself between the tubes [23]. However the reliability of the coatings is questionable even though there have been a number of reported cases of great success.

3.11 Intelligent Soot Blowing

The working schedule of the normal soot blower can not always have the necessary effect on the actual fouling present in a boiler. But intelligent soot blowing always considers the fouling situation currently existing in the boiler by incorporating the data from foulage measuring devices. Intelligent soot blowing is particularly important where fouling is a problem or where there are large changes in coal quality [24]. Intelligent soot blowing techniques can work in two different ways, direct and indirect. Indirect systems incorporate first principle modelling, genetic algorithms, expert systems, fuzzy logic and artificial neural networks (NN). Direct systems perform actual boiler operating parameter measurements. Besides this, 'intelligent' system can incorporate other cleaning methods such as hydro jets. Artificial neural network systems and expert systems are the two types of indirect system. Neural networks have the capability of 'learning' and consist of a number of non-linearities, called 'neurons'. In this way, the soot blowing or hydro jet system can 'learn' to produce the target output which is to keep the boiler as free from fouling as possible [3, 25]. Another expert system attempts to replicate the actions of a good operator under conditions that trigger initiation of the appropriate sequence. In this way when a certain circumstance is presented in the form of data, a number of set rule-based techniques are run [24]. The Hybrid Systems combines neural networks (NNs) with a Fuzzy-Logic Expert System (FLES) to control boiler fouling and optimise boiler performance, minimizing the effect of fouling. Different objectives like , boiler monitoring, fouling forecasting, prediction of boiler behaviour and the cleaning effect are also used with neural networks in this system. Several sets of NN with different objectives like, boiler monitoring, fouling forecasting, prediction of boiler behaviour and the cleaning effect are used in this Hybrid System [3].

3.12 Stain Gauges

Stain gauge are a devices to measure the deformation of an object. This gauge is designed with insulating backing which supports metallic foil. When an object begins to change shape the foil is deformed which causes the devices' electrical resistance to change. This change in electrical resistance can be detected and converted into a strain value. When fouling forms on the surface the overall weight of the boiler pendants increases. Due to this the rods connecting the pendants to the top of the boiler deform elastically and the result of the deformation can indicate the amount of fouling present in the boiler [26].

4 Conclusion and Recommendation

Available techniques and methods for minimising deposition problems in boiler have been reviewed and discussed. Their implementation in any power plant is considered and the following remarks can be made regarding their effectiveness:

- To use slagging indices, a more accurate coal analyser and a mathematical programme needs to be set up to determine the mineral composition of ash; this would need a large capital investment, but considering the minimal potential benefit, this technique is not always likely to be useful.
- Coal blending using the thermomechanical analysis (TMA) method requires specific lab equipment, but it may be recommended considering the low investment cost and high potential to minimise fouling and slagging problems.
- An adequate number of internal cameras to monitor boiler deposition problems can be installed covering all parts of the boiler, and this method is very useful and cost effective.
- Installing pulse detonation wave technology in boilers requires large amounts of capital investment, but it may be highly recommended due to its high

effectiveness in power plants.

- Potential success of anti fouling coatings is still questionable.
- Intelligent soot blowing and stain gauge methods are very promising technologies. These can be implemented in power plants to improve efficiency.

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