Condition monitoring and reliability assessment, an essential tool for Boiler Plant Maintenance - A review

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Abstract. Condition monitoring is an essential technique which is usually deployed to monitor the health parameters and conditions of a boiler plant in such a way that variations or significant changes can like failure can be identified and proffer adequate solutions to it. It is an important aspect of condition-based maintenance which is used in maintaining an equipment according to its conditions. Thus, this study focused on the fundamental principles of condition monitoring which involve the identification and selection of a physical measurement that will show the deterioration stage and the importance of taking the readings at intervals. More so, the study established that monitoring and measurement should focus more at critical components that have high frequency of failure. Thus, condition-based maintenance of boilers will help in improving the availability of the boiler.

Keyword: Condition-based, maintenance, reliability, boiler, efficiency, availability

1 Introduction

The heart of any industrial process lies in the effective operation of boilers. Thus, optimization and effective maintenance of the boiler components is critical from the economic, environment and efficiency as well. Inadequate boiler feed water treatment will cause serious operating failures which will eventually affect the effective operation of the boilers [1].

Enhancement of the service life of the equipment, prevention of downtime and minimization of the boiler failures such as excessive corrosion and formation of scales, maximization of the steam condensate, control of the internal boiler water chemistry so as to stop the entry of impurities as well as reducing the cost-prohibitive maintenance represents the consequences of a well-designed boiler feed water treatment process [2-4].

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Pulverized coal during the combustion process has been developed. Also, based on cost, blowing has been optimized using Gamma accelerated accumulation model to estimate the optimal blowing efficiency so as to obtain the blowing of the ash at reduced cost.

However, it was further established that the model has some form of deficiencies especially in blowing some soot that cannot be restored to a perfect working condition [15]. According to [16], leakage of water from the superheater tubes of boiler is common in the boiler plants during its operation. Leakage usually occur as a result of cracks in some regions of the tube. This damage is traceable to the attacks from chemicals which is a consequence of the reaction between the flue gas and the super heater tube. It was equally established that one of the main causes of this problem is due to the inadequate treatment of the flue gas causing metal particle retention, gas particulates in substantial quantities. Also, using the same flue gas in the boiler will cause the reaction of Sulphur dioxide with the tube surface at higher temperature. This will cause the thinning and pit formation on the surface of the tube. Consistent thinning of the wall and increase in the pit formation result in crack formation which eventually cause the failure of the tube material.

It was established that 35% of energy used by commercial buildings for cooling comes from both chiller and boiler plants, while about 21% of the energy for heating a commercial building come from the same source in the United states. However, operation faults affect the energy efficiency of the boiler plants [17]. One of such faults is inadequate air inlet settings which can result in increased fuel consumption to about 20%. Since these faults has a significant effect on the energy efficiency, several efforts have been developed to reduce their overall effect on the boiler plant. Some studies classified such faults as fault impact analysis and automatic fault detection and diagnostics. While the former tries to estimate the impact of the various faults during the building process so as to aid the operators identify the critical faults so as to guide proper research directions, the later attempts to develop strategies for detecting the operational faults and isolate the causes of the fault. This has been an active research area [18].

Despite the fault detection and analysis described above, modelling the faulty chiller plant as well as the boiler plants is very important. Modelling the plant systems helps in quantifying the impacts of faults. Fault models of both chiller and boiler plants are classified into three groups. Fault models can be classified using the parameters from fault free models. For instance, the rated capacity of fault free chiller fault free boiler can be modelled using EnergyPlus. Similarly, models of faulty building structures can be achieved via the introduction of new parameters to fault free models. For instance, six different parameters can be added to the chiller model in EnergyPlus to estimate the power caused by faults like overcharging, excessive oil, non-condensable in the refrigerant as well as the fouling of the condenser [19]. Lastly, the third group deals with the development of the faulty building systems via treatment of faults explicitly using the underlying physics. For instance, physics-based approach was developed for a non-condensing boiler to investigate the problems that usually occur within the boilers.

Despite these fault models for chiller and boiler plants, there are still drawbacks associated with the existing fault models which limit their potential applications. One of the drawbacks is the tendency to ignore fast building dynamics and the adoption of the ideal control. Thus, the existing models are easily modified by addition of parameters to fault free models. Secondly, using the existing fault models is quite difficult and labour intensive especially for large scale fault related research. thus, it is possible to observe several faults occurrence at varying operating conditions [20]. Thus, modelling the dynamics of boiler and the chiller operation can help in fault diagnosis as well as reducing maintenance cost, thus, improving the reliability of the equipment [21].

In a study by [22], it was affirmed that steam boilers could be represented by a heat exchanger having a pressure above the atmospheric pressure. Some of the boiler parameters of the steam include consumption of metal, weight, equipment for automation, temperature and pressure. The boiler components formed with the steam boilers to achieve the required steam with adequate properties the element of the steam boilers are 01 (2023) E3S Web of Conferences 430, 01228 (2023) ICMPC 2023 https://doi.org/10.1051/e3sconf/202343001228
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According to Ikonen et al. [28], it was established that the accumulation of materials at the exterior of convective heat exchangers is termed fouling. In the case of boilers that are fired using waste from biomass, the waste could be cleaned more often as an adequate maintenance strategy to maintain the adequate heat transfer between the flue gas and fluid. Furthermore, excessive cleaning of this component involves huge resources, and there is a need to sort for alternative maintenance strategies; however, while adaptive timing may be important, it is difficult to obtain the real-time condition of the heat exchanger. Thus, this study focused on the estimation of fouling in a fluidized bed that circulates. The knowledge of physical modelling and process measurement data were deployed. Also, a condition monitoring plan using modal vibration sensing was integrated for direct estimation of fouling degree on the heating surface. The result provides soot blowing optimization methods and improvement in the fouling management.

Figure 1: Model of Boiler tube with scales on the inner surface.Source: [27]
El-Bindary et al. [29] developed a chemical sensor with prospect for detecting the degree of oxide of iron rusting in several systems like the boiler systems. This can result to a significant damage to the equipment and reduction in the energy efficiency as well as very costly repairs or replacement of the equipment. Hence, monitoring the rust state in the boiler system is relevant for the equipment performance as well as prolonging the lifespan of the equipment. The study reported that 2-acetylpyridine condensate formed the basis for the sensor material. Thus, the sensor material has the capacity to detect the iron oxide concentration. This result from the study provide insight on the quick detection of iron oxide in the boiler system. Furthermore, Leffler et al. [30] established that a major cause of agglomeration could be traced to the thermal conversion of biomass fuel when mixed with fluidized bed. Thus, to resolve this, there is a need to exchange the bed material using virgin bed material thus, resulting in the disposal of used ones. However, the bed material exchange represents another cost especially for new one, land fill and the unplanned downtime of the boiler plant. Thus, this study deployed a method for evaluating the bed material quality which is electronic tongue. This eventually helps in reducing the cost of the unnecessary exchange of the material.

The recent advancement in technology with improved reliability has made the steam power system an important player in the generation of power as well as other fields. The supercharged boiler represents an essential part of the power system which generate a high temperature and pressure at the same time for steam in the entire system. Thus, its safety affects the normal operation of the system, however, the complexity of the structure and the harsh working environment of the boiler has elevated the frequency of failure especially if the fault is not identified and removed in time, this can cause the entire paralysis of the steam power generation, in most cases, it led to irreversible consequences [31-33].
conventional fault diagnoses depend on the use of models, experience and signal processing for fault identification and diagnoses. This method relies heavily on the complexity of the structure and the physico-chemical systems of the equipment; thus, its effect is only adaptable with the simple structures and equipment. More so, the boiler which is supercharged is associated with numerous parameters with complex operation conditions. Thus, the advancement of in the automation has brought numerous increases in the complexity of the supercharged boiler. Hence, the conventional method is becoming inadequate for the fault diagnoses of the boiler. Condition monitoring of equipment by deploying the data monitoring and power of computation as well as intelligent based data-fault diagnoses techniques can be used in the supercharged boiler monitoring. These methods could be convolutional neural network, artificial intelligence and support vector machine. These techniques can be used to learn the characters via large number of collected fault data. Thus, reducing the overreliance on manual computation and increase the fault diagnoses efficiency, condition monitoring, machine maintenance and the overall reliability of the equipment. A major approach for monitoring the condition of the supercharged boiler to avoid failure is to prevent it from entering the fault condition. Especially, where frequent burst of tube that will result to leakage, blockage, exchange of heat surface failure and other failure effects during the boiler operation. Although, other minor failures like transfer of heat surface contamination and reduction in efficiency usually occur under steady conditions. Hence, degeneration of faults in boilers can take several months or years. In fact, all these problems constitute unrealistic data around fault samples and this contribute to the few shot fault diagnosis of the boilers. Based on the aforementioned issues regarding the supercharged boiler, established that the fault samples of the supercharged boiler are usually small, but contains excess noise. Thus, the study proposed deployed the few-shot fault diagnosis method for monitoring the boiler using Siamese Neural Network by introducing the variable analysis as well as the two screening processes to train the model. It was reported that the technique yielded good result and this provides useful insights for the diagnosis of the supercharged boiler. According to [40], physical examination, chemical analysis, microstructural analysis as well as water chemistry analysis of a boiler also revealed rupture on both the flue gas and the water side, while there was decarburization as well as growth of grain on the external diameter of the tube. More so, there was formation of thermal oxidation in the internal diameter of the boiler tube. This was equally attributed to corrosion as a result of scales formed in the external diameter of the boiler tube. Thus, monitoring boilers would help to reveal the localized corrosion as well as heat distribution inside the tube that could result to thermal oxidation, reduction in performance and low equipment availability. A major problem associated with boiler waterfall tubes in power plants is thermal fatigue cracking. This problem usually results unscheduled shutdown of the plant. Thus, development of models for monitoring the rate degradation is very vital for its efficient operation and performance. This will help in the prediction of future characteristics and the condition of the waterfall tubes [41]. One of the challenges for developing the models capable of this prediction is inadequate data. Also, there is limitation to the access as a result of the difficulties. This is due to the fact that boiler represent a critical system and the data for degradation modelling are scarce [42]. In a study by Jin et al. [43], it was established that one of the methods of reducing carbon capture, its utilization as well as storage is the application of oxy-fuel combustion method. However, this technique is associated with high cost of energy as well as operating hazards. To further ensure the reliability of thermal power plant, there is a need to combine both optimization and safety techniques in deploying the oxy-fuel combustion process in boilers. There is a need to have a controlled parameter as well as optimization of desirable variables. Thus, ensuring controllability and maintenance of high operating efficiency. However, failure in the concentration of oxygen can result to fluctuations in the behavior of the operating parameters at water-steam and flue gases.
According to a study by [44], it was established that biomass boilers find greater applications for the generation of heat when compared with other types of boilers especially in the United Kingdom. This is traceable to the policies developed by the government. However, this boiler plant is associated with hardware design problems and the variations in the controls. Although these problems are traceable to the extended response time of the biomass boilers when compared to the gas or coal fired boilers. Thus, some of the causes of the shutdown could be inadequate design of the hardware, installation and the overlay reactive control [45-47]. In the same vein, fouling is another challenge associated with the boiler. Leading to the formation of soots which accumulate during operation [48-49]. This will eventually result to transfer of heat to water and greater heat is lost in the exhaust air. In fact, for the biomass boiler, fouling is more problematic compared to the other types of traditional boilers due to the volatility of the biomass particles when compared to the ones being fired by coal [50].

4 Conclusion

The production processes in several industries has great dependence on the efficient functioning of the several important units among all is the steam boiler which is used in processing and packaging of products. However, there is high susceptibility to its incessant failure owing to its rupture of its internal tubes caused by corrosion, scaling as well as excessive internal pressure. Thus, these failures could result in total shutdown of the production processes, thus, also resulting in significant manpower loss and maintenance cost.

In this study, the focus had been the importance of condition monitoring of boiler plants for efficient operation. Also, the study established that controllability and maintenance of boilers can be achieved adequately via the combination of safety techniques and use of oxy-fuel combustion process in boilers. Thus, improving the availability and reliability of the boiler.

Reference


