Review on Combustion Optimization Methods in Pulverised Coal Fired Boiler

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Abstract - **The demand of electricity is increasing nowadays and has raised the necessity of improved power generation technologies, especially in developing countries like India. Reduction of emissions of greenhouse gases is the need of hour and it could be achieved considerably by improving the efficiency of existing coal fired plants. Operation of non-optimized boiler can lead to reduced boiler efficiency, increased excess air requirements, delayed combustion, increased heat rate, high CO and NO_x emissions and many other. Optimization of combustion in pulverised coal fired boiler is very important today for every thermal power plant. The combustion in pulverised coal fired boiler is affected by quality of coal, pulverised coal fineness, burner tilting angle, air fuel ratio, and slagging and NO_x formation. The review on different optimization techniques has been carried out.**

Keywords: Optimization, combustion, greenhouse gases, burner tilting angle.

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1. INTRODUCTION

India is a seventh largest country and has a very large population. To maintain growth rate, rapid growth in energy sector is needed. About 69.6% of power generation comes from thermal power plants, in which 60.2% generation comes from using coal as fuel [1]. The demand of electricity is increasing day by day and has raised the necessity of improved power generation technologies or to improve the performance of existing power plants. Coal is the major fossil fuel in India and continues to play a prime role in the energy sector. The coal combustion process produces many pollutants, such as oxides of carbon, oxides of sulphur, oxides of nitrogen and particulates. The acid rain and climate change are mainly due to pollutants like SO2, NOx and CO2. Most of the particulates entering the flue gas can be removed by fitting electrostatic precipitators and over 90 per cent of SO2 with the installation of a flue gas desulphurization plant. The best way to reduce CO2 emissions is to improve power generation efficiency. However no practical methods exist for reducing NOx to such a degree, leading to increased research into this area. During the combustion process, nitrogen from coal and air is converted into nitric oxide and nitrogen dioxide; together these oxides of nitrogen are commonly referred to as NOx. The methods for reducing NOx emissions in coal fired power plants can be classified as either primary or combustion modification based technologies, which achieve reduction of NOx formation by limiting the flame temperature or the availability of oxygen in the flame; or secondary or flue gas treatment technologies [2]. The secondary technique of NOx reduction is classified by adding a reagent such as ammonia or urea into flue gas.

Now, operating a boiler that is not optimized can also lead to increased levels of unburnt carbon, increased excess air requirements, incorrect primary and secondary air to fuel ratios, reduced boiler efficiency and increased heat rate, increased slagging etc. Hence it is necessary for all thermal power plants to optimize the combustion. In this paper, review is done on different optimization techniques with the help of research papers.

The paper is organized in the following way. In Section 2, the pulverised coal fired boiler is briefed. In Section 3, the research methods are discussed. In Section 5 conclusion related to study on review is discussed.

2. PULVERISED COAL FIRED BOILER

The first commercial application of pulverized coal firing for steam generation was made in the early 1920s. Since then it has become almost universal in central utility stations using coal as fuel. A pulverised coal-fired boiler is an industrial boiler used in most of the thermal power plants in operation nowadays. It generates thermal energy by burning pulverised coal that is blown into the firebox. The basic idea of firing system using pulverised fuel is to use the whole volume of the furnace for the combustion of solid fuels. Coal is ground to the size of a fine grain, mixed with air and burned in the flue gas flow. Coal contains mineral matter which is converted to ash during combustion. The ash is removed as bottom ash and fly ash. The bottom ash is removed at the furnace bottom. This type of boiler dominates the electric power industry, providing steam to drive large turbines [3]. The general arrangement of pulverised coal fired boiler is shown in Figure 1.

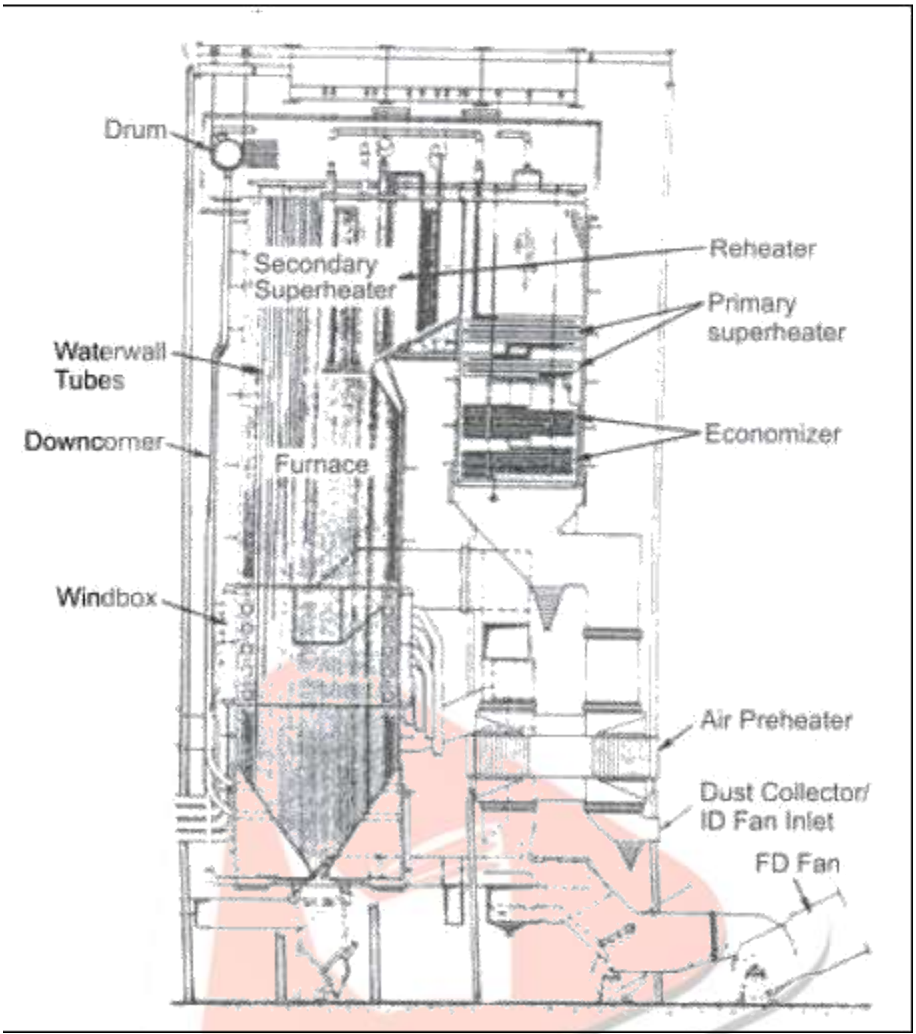

Figure 1. Pulverised Coal fired boiler arrangement[3].

The concept of burning coal that has been pulverized into a fine powder comes from the belief that if the coal is made fine enough, it will burn almost as easily and efficiently as a gas. The feeding rate of coal according to the boiler demand and the amount of air available for drying and transporting the pulverized coal fuel is controlled by computers. Pieces of coal are crushed between balls or cylindrical rollers that move between two tracks or "races." The raw coal is then fed into the pulveriser along with air heated to about 330 °C from the boiler. As the coal gets crushed by the rolling action, the hot air dries it and blows the usable fine coal powder out to be used as fuel. The powdered coal from the pulveriser is directly blown to a burner in the boiler.

To burn pulverized coal successfully, the following two conditions must be satisfied:

1) Large quantities of very fine particles of coal, usually those that would pass a 200 mesh sieve must exist to ensure ready ignition because of their large surface-to volume ratio.

2) Minimum quantity of coarser particles should be present since these coarser particles cause slagging and reduce combustion efficiency.

Advantages of pulverized coal firing

1. Low excess air requirement
2. Less fan power
3. Ability to use highly preheated air reducing exhaust losses
4. Higher boiler efficiency
5. Ability to burn a wide variety of coals
6. Fast response to load changes
7. Ability to use fly ash for making bricks etc.
8. Less pressure losses and draught need

3. Literature Review

A method is presented by Benyuan Huang et. al.[4] to optimize coal combustion based on flame image processing technique and concept of introducing RES into combustion control circuit of coal fired power plant. It showed that by optimal control strategy, we can ensure stability of load and main steam pressure by adjusting secondary air for optimized A/F flow rate and thereby strengthened ad stabilized combustion conditions can be achieved in furnace. Also boiler efficiency increased and NOx emissions reduced at optimized operating conditions.

Ren Jianxing et.al. [5] studied a 300 MW Coal fired unit using three kinds of mixed coal A, B and C. Under the rated load conditions characteristics of coal and burning characteristics were studied. The objective was to optimize combustion and enhance boiler efficiency by undergoing experimental analysis based on parameters such as burning status, flame transparency, unburned combustible in flue gas and exhaust gas temperature. Based on results of experiments, the results showed that mixed coal A was found better than mixed coal B and C on above mentioned parameter and hence it helps to optimize combustion and boiler efficiency.

Ji Zheng Chu et. al. [6] proposed their study on new constrained procedure using artificial neural network as models for target processes. Information analysis based on random search, fuzzy c-mean clustering and minimization of information energy is performed iteratively in proposed procedure. ANN offer an alternative approach to model process behaviour. It is based on extracting imbedded pattern from data that describes the relationship between input and output in any process phenomena. It is capable of handling complex and non-linear problems processing information rapidly and reduces engineering efforts required in model developments. It has been known that delaying mixing of combustion air with fuel is an effective means to reduce production of NOx in combustion process. Also, we came to know that there exists a best air ratio at which thermal efficiency achieves maximum for given fuel.

Combustion optimization has been proved to be an effective way to reduce NOx emissions and unburned carbon in fly ash by carefully setting operational parameters of boiler. Feng Wu et. al .[7] employed Support Vector Regression (SVR) to build NOx emissions and carbon unburnt models. Thereafter improved Strength Pareto Evolutionary Algorithm (SPEA2) , the new multi objective particle Swarm Optimizer (OMOPSO), the Archive-Based Hybrid Scatter Search method (AbYSS) and cellular genetic algorithm for multi objective optimization (MOCell) were used for this purpose. Here the authors compared various algorithms in terms of quality, convergence, accuracy and diversity. The results shows that the method combining SVR and multi objective algorithm could effectively reduce NOx emissions and unburned carbon in fly ash. The results also show that OMOPSO algorithm is best in terms of accuracy and convergence rate. AbYSS has better diversity but poor accuracy. SPEA2 is slowest algorithm and its execution time is one order higher than others. Therefore OMOPSO and MOCell are proposed algorithm for online multi objective optimization of coal fired boiler.

Barry E Pulskamp et.al [8] studied on 440 MW pulverized coal fueled unit. The steam generator had not been performing to design expectations. So number of modifications was made to the boiler. It was noted that the furnace exit gas temperature was varying from other variables, and those variables were suspected to be combustion air and fuel balance. The identification and quantification of the combustion variables was undertaken by a Comprehensive Test Program followed by an approach entitled in ASME paper. It was found that on this boiler, furnace exit had number of individual points that were in a reducing atmosphere, or zero excess oxygen. Since many of the opportunities for improvement that were experienced by them on this boiler were slagging related, this was a significant problem. The comprehensive testing confirmed that significant improvements could be achieved in boiler and steam cycle performance. Using Secondary air balancing to each corner and removing the lower perforated plate sections from each four corners, slag formation reduced in that areas and confirmed boiler sensitivity to furnace slagging in areas of depleted oxygen.

Li Gang Zheng et.al. [9] studied on optimisation algorithms to achieve low NOx emissions from a coal utility boiler using combustion modifications. Support vector regression was proposed in the first stage to model the relation between NOx emissions and operational parameters of utility boiler. A mass of NOx emissions data from the utility boiler was employed to build the SVR model. The predicted NOx emissions from SVR model was in good agreement with measured. In second stage, the authors used two variants of ant colony optimization as well as genetic algorithm and particle warm optimization were employed to find the optimum operating parameters to reduce NOx emissions. The results show that ant colony optimization outperforms those of classical genetic algorithm and particle swarm optimization in terms of quality of solution and convergence rate. It is also noted that PSO have the worst quality of solution among all algorithms for all studied cases.

Hao Zhou et. al. [10] introduced an approach to predict the nitrogen oxides emission characteristics of large capacity pulverized coal fired boiler with artificial neural networks. The NOx emission and carbon burnout characteristics were investigated through parametric field experiments. The effects of over fire air flow rates, coal properties, boiler load, air distribution scheme and nozzle tilt were studied. On the basis of experimental results, an ANN was used to model the NOx emission characteristics and the carbon burnout characteristics. It is noted that when compared with other modeling techniques, such as CFD approach, the ANN approach is more convenient and direct, and can achieve good prediction effects under various operating conditions. It is concluded that it is convenient to employ the ANN model and optimization method developed in this paper to model the combustion characteristics using large amount of training data downloaded from DCS.

Risto V Filkoski et. al [11] applied a method for handling two phase reacting flow for prediction of pulverised coal combustion in large scale boiler furnace and to assess ability of model to predict existing power plant data. This paper presents principal steps and results of numerical modeling of furnace. The CFD/CTA approach was utilised for creation of three dimensional model, including platen super heater in upper part of furnace. Standard k epsilon model was employed for description of turbulent flow. Radiation heat transfer is computed by means of simplified P-N model. Simulation results concerning furnace walls, thermal efficiency and combustion efficiency shows good results corresponding with plant data.

Five step approach to optimize combustion

Step 1 - Inspect Boiler and Calibrate Instrumentation.

To avoid optimizing a boiler with instrumentation and components which are not working properly, it is important to first calibrate instrumentation, balance burners, check coal grind size, and, in general, ensure the boiler and its components are in good mechanical condition.

Step 2 - Gather Parametric Test Data.

With many boilers, variables such as unburned carbon, steam temperatures, and NOx emissions are very sensitive to the boiler control parameters. It is therefore important to run a series of boiler tests in which the variables of interest are measured as the boiler control parameters are varied systematically over their anticipated range of operation. For example, in the case of a tangentially-fired boiler with conventional burners, these would include economizer O2 level, burner tilt angle, mill loading patterns and secondary air register settings.

Step 3 - Develop Data Correlations.

Once the tests have been run, data correlations need to be developed to provide mathematical relationships between the boiler control settings and dependent parameters such as rate of NOx emissions and LOI. This can be done using statistical regression techniques or neural networks. Neural networks are particularly useful in this application because of their ability to develop a mapping between input and output parameters when there are a large number of variables involved. Since this is the case with most boiler optimization problems, the use of the neural network approach is recommended for developing the data correlations.

Step 4 - Determine Optimal Boiler Control Settings.

Once the data correlations have been developed, they are then used to identify the optimal solutions. For very simple problems, engineering experience can be used to “eyeball” the data and obtain the optimal settings. However, for problems involving a large number of variables this is more difficult to accomplish using engineering judgement. For this reason we recommend the use of optimization algorithms— mathematical techniques which determine the minimum or maximum values of a function.

Step 5 - Convert Optimal Boiler Settings

Into new Control Curves. Boiler testing, data correlation and the analysis to determine the optimal control settings should be carried out at different operating loads. Once this is complete, the recommended control settings are used to develop new boiler control curves for parameters such as economizer oxygen level and overfire air register settings as functions of load.

Methods for combustion optimization:

Diagnostic testing

It includes various tests like clean airflow tests, dirty airflow tests, iso kinetic coal sampling, air in leakage survey, insulation survey, flue gas flow measurement, boiler efficiency tests, air preheater efficiency tests and boiler tuning and optimization.

Sensor based approach

Here with the help of sensing tools, combustion control is done. The rate of change of CO_2 should be rather small at the point of optimum excess air. Mainly CO_2 is not a sensitive measurement. So zirconium oxide probes are mostly used to measure excess O_2. The probe should be installed close to the combustion zone. CO is a direct measure of completeness of combustion and is unaffected by air infiltration. Co should be zero whenever there is oxygen in the flue gas. Maximum boiler efficiency can be observed when the CO is between 100 and 400 ppm.

Online Optimization

Here combustion control can be done through online optimization like PADO tools. DCS does not given the system wise efficiencies so the area of losses will remain unaware. Also data from I/O points e.g. temperature, pressure, mass flow could be wrong because of sensor errors, bad connectors etc. DCS does not give advice on certain loopholes. Hence PADO tool comes into effect. PADO stands for Performance, Analysis, Diagnostics and Optimization.

Modeling based approach

Combustion optimization can also be done through CFD modelling. Here after geometry creation of the plant, process parameters has to be entered and we can monitor oxygen and CO profiles in the furnace, we can study effects of coal quality on combustion also effects of burner tilting on combustion and according to the results obtained, combustion can be optimised.

4.CONCLUSION

After studying the literatures on optimization of combustion in coal fired boilers, the following conclusions can be drawn.

1. The new concept of combustion control scheme namely Radiant Energy Signal (RES) based on flame image processing is very helpful in improving the performance of installed power plants because it investigates the use of flame images collected in a boiler to provide information on the internal state and it forecast optimal air fuel rate which ensures stability of load and main steam pressure. The boiler unit performances such as operating conditions, nitrogen oxide emissions and thermal efficiency can be analyzed.

2. With diversification of coal, there are big differences between burning coal and design coal, this affect on the safety of running. Under the rated load, characteristics of coal can be studied. In paper, three mixed coal were chosen and studied experimentally by elementary analysis and industrial analysis, and results indicated that under conditions of experiments and slag severity, serial arrangement of three mixed coals were given. Boiler efficiency of mixed coal A was higher than that of mixed coal B and C.

3. Artificial Neural Network (ANN) offer an alternative approach to model process behaviour. It is based on extracting imbedded pattern from data that describes the relationship between input and output in any process phenomena. It is capable of handling complex and non-linear problems processing information rapidly and reduces engineering efforts required in model developments.

4. Comparison in terms of quality, divergence, accuracy can be conducted with the help of various algorithms like Strength pareto evolutionary algorithm, Multi objective particle swarm optimizer, Archive-Based hybrid scatter search and cellular genetic algorithm for multi objective optimization which will also be helpful in knowing the best algorithm to reduce nitrogen oxides emissions and unburnt carbon in fly ash under different opearating conditions.

5. It is noted that when compared with other modeling techniques, such as CFD approach, the ANN approach is more convenient and direct, and can achieve good prediction effects under various operating conditions. But ANN has its limitations too. Construction of network for complex projects is complicated and time consuming due to trial and error approach. Also to develop a clear logical network is troublesome. The planning and implementation of networks require personnel trained in the network methodology.

REFERENCES

1) O.P. Rao, Coal gasification for sustainable development of energy sector in India. Council of Scientific & Industrial Research, New Delhi. Technical Report, 2003.

2) G.S. Springer and D.J. Patterson, Engine emissions: pollutant formation and measurement. Plenum Press, New York, 1973.

3) Nag P. K., Power Plant Engineering, Tata McGraw-Hill, 3rd Edition, Chapter 4, 2008.

4) Benyuan Huang, Zixue Luo and Huaichun Zhou., Optimization of combustion based on introducing Radiant Energy Signal (RES) in pulverized coal fired boiler, Fuel Processing Technology 91 (2010), 660-668.

5) REN Jianxing, Li Fangqin, Zhu Qunzhi, WU Jiang, Research of Multi Fuel burning stability in 300 MW Coal fired utility boiler, Energy Procedia 17 (2102), 1242-1248.

6) Ji-Zheng Chu, Shyan Shu, Shieh, Shi- Shang Jang, Constrained optimization of combustion in simulated coal fired boiler using artificial neural network model and information analysis, Fuel 92 (2003), 693-703.

7) Feng Wu, Hao Zhuo, Jia-Pei Zhao, Ke-Fa Chan, A comparative study of multi objective optimization algorithms for coal fired boiler, Expert Systems with Applications 38 (2011), 7179-7185.

8) Barry E Pulskamp, Patrick McGowanet, Richard F Storm, Pulverised coal boiler optimization through fuel air control, Coal Utilization Conference 87 (1991), 1-16.

9) Li Gang, Hao Zhuo, Lin Wang, Kefa Cen, A comparative study of optimization algorithms for low NOx combustion at coal fired utility, Expert Systems with applications 36 (2009), 2780-2793.

10) Hao Zhuo, Kefa Cen, Jianren Fan, Modelling and optimization of the NOx emissions characteristics by ANN, Energy 29 (2004), 167-183.

11) Risto V Filkoski, Ilija J Petrovski & Piotrkaras, Optimization of PC combustion by means of CFD/CTA modelling, Volume 10 (2006), 161-179.