Optimizing Boiler Fuel Combustion through Oxygen Analysis for Improved Efficiency

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3 authors, including:

Bhawana Garg
Ramrao Adik Institute of Technology

Sharad Jadhav
Ramrao Adik Institute of Technology

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[1]Narendra Ashok Tayade, [2] Sharad Jadhav, [3] Bhawana Garg
[1] Narendra Ashok Tayade,[2] Sharad Jadhav, [3] Bhawana Garg
[1] : narendratayade23@gmail.com,[2] sharadpjadhav@rait.ac.in, [3] garg.bhawana@rait.ac.in

Abstract— ***This paper introduces a novel approach to enhance the combustion efficiency and reduce fuel losses in boilers by modifying the traditional design. There are many boiler manufacturers in the industry who can design the standard boilers and customize it based on application. The solution for increasing the combustion efficiency with the standard boiler design is to improve the fuel combustion system. In this system, oxygen detector is used for analysis of the combustion efficiency in the boiler. Earlier fuel combustion process was improper which leads to rise the production losses. An algorithm is developed to control the speed of ID, FD fans that helps to maintain the air inside the boiler and fuel ratio of combustion. The sugar industry is working for 4 to 6 months every year, and it is a cyclic process. This industry has very low running span to make a modification in the boiler successfully during maintenance period of the sugar industry. In this work, we have installed oxygen detector in the boiler to understand the production loss and increase the fuel combustion efficiency. We implemented some mechanical changes in the boiler and run a trial of boiler combustion process. During the process of boiler combustion, oxygen level inside the boiler has been measured and observed the combustion of boiler and it found 10% to 30% fuel loss***.

Index Terms — Oxygen Sensor, Boiler heat losses, Boiler combustion efficiency, Process control, Environment

I. INTRODUCTION

Highlight In the process industries some standard practices for the plant operation like, raw material management, water management, power plant management, administration management, production management and supply management are followed. The boiler, steam and energy management also come under the operation and process control. Boiler is a major part of the primary process. If appropriate amount (ratio) of fuel & air is available, then the fire will catch and that fire control according to air to fuel ratio is the main challenges in industries or combustion control technique where the combustion can increase with proper way [1]. Even after maintaining proper air to fuel ratio fire, sometimes it gets change and at that time the unburn fuel comes out form the ash pit and that unburnt phenomena increases the flue gases like CO, CO2, CH4, SO2, NO etc. That's why efficient combustion control techniques are very important for this application. In maximum process industries combustion control is the major challenge and improper combustion will emit the polluted and hazardous gases which are harmful to environment and that's the reason behind the industrial zone and residential zone are far away to each other. To maintain the proper combustion, increase the productivity and monitor the air to fuel ratio the oxygen analyser is introduced. During the fuel combustion process, the heat necessary for production is generated. Fuel is fed in the boiler for the burning, and the operator is not aware about quality of burn, as they feed randomly, and it causes the production losses [11]. When the fuel burns it produces many gases and the amount of oxygen is very less in this gaseous mixture, so oxygen is sensed by the oxygen sensor and feedback to the operator. Based on this measurement, fuel feeding activity can be controlled and the production losses can be improved [6]. There are different types of boilers and their operation according to fuel combustion control system is designed. Fuel inserted in the boiler furnace to produce the heat and it results in boiling the water and that steam, which will be used for rotating the turbines. Then further processes will be carried out continuously or based on load requirement. The initial fuel types are coal, oil, gas, biogas etc. and while burning it produces many gases hazardous- nonhazardous [10]. Oxygen analysers measure the oxygen after the combustion and send the feedback to process operator which can easily control the fuel and air ratio according to oxygen reading. The organisation of boiler is ESBEE power, and that boiler is used to produce energy up to 1.5 MW. The purpose of boiler is to boil the water and generate the steam. It is a continuous process and responsible for effective production. Recently hybrid technology came into market, in which coal and Biogas or many other fuels are available for boiler operation. Inside the boiler water tubes are mounted which carries the hot water and exchange the heat in terms to steam and exhaust flue gases with the temperature of around 120°C to 170°C. At such high temperature of flue gases, which contains maximum amount of heat can reproduce the thermal energy from 70%-80%. Despite four decades of development, boilers still hold less than 25% of the global market share, underscoring the imperative to innovate and enhance tools.[2]
optimizing their operational processes. There is a clear need for new methods to improve boiler efficiency and functionality. Some of the major reasons for heat loses are, due to vent gases having the sufficient amount of heat which my reused, improper combustion, heat exchange due to improper insulation and many mechanical reasons. The combustion efficiency of a boiler is the indication of burner's ability to burn fuel. The two parameters which determine the burner

efficiency are unburnt fuel quantities in exhaust and excess oxygen levels in the exhaust. As the amount of excess air is increased, the quantity of unburnt fuel in the exhaust decreases. This results in lowering the unburnt fuel losses but elevating the enthalpy losses. Hence, it is quite important to maintain a balance between enthalpy losses and unburnt losses. Due to the industrial growth and production demand in process industries, there is a necessity to upgrade existing boilers. It involves implementing effective operation and control systems at a moderate capital cost, significant outcomes to fulfil the existing demand. Opting for a lower-grade pipe in the boiler to cut costs compromises product quality and leads to a reduced output response. The strength of the boiler is its enclosure to sustain the heat as well as steam pressure. To maintain the proper parameters, a control system is the most important part of this process. There are so many interdependent interlocks to prevent accidents and to increase the quality of output. The guardianship of control constructions over the arrangement of the air-fuel mixture accompanying a likely speed and overdone dependability of custody the Extra Air Percentage (EAR) at the stoichiometric stage stays restricted. The author consistently examines how the EAR influences the discernible and estimated configuration of pipe vapor during the detonation of herbaceous vapor, biomass, and diverse fuels. The development competency of fuel control and heat control with respect to the steam flows through the pipes are more energetic expanding. Improving the effectiveness of Boiler is the basic challenge that is very tough to survive on account of few approaches and designs it may be attainable [4].

II. Boiler combustion process

1.1 Techniques for controlling the fuel combustion

Presently, many techniques to easily measure the air to fuel ratio are available, but earlier it was expensive to control the air to fuel ratio (AFR). At present, some changes have been incorporated in the process with the help of electrical controlling system to control AFR. Most of them produce CO and O2 after combustion in pipe gases. The main issue with this method is production of uncontrolled gases, which may affect the environment and harm human health [5]. The problem of air and sound pollution can be overcome by measuring the oxygen. Oxygen sensor plays the vital role in this case. The fuel is passed through the furnace of the boiler, and it will produce heat, and this heat will be used to generate the steam based on the demand of the production team. During the burning of fuel, some gases are produced depending on the fuel. Oxygen analyser is used to measure the available oxygen in the flue gases to identify the amount of combustion. Here some fans are imposed in this process, but the ratio will change that means combustion will change. Figure 2.1 shows a zirconia-based oxygen sensor including small accessories in it , which controlling the fuel combustion regardless the alteration in the quantity of gas coming into the boiler furnace.[4][5].

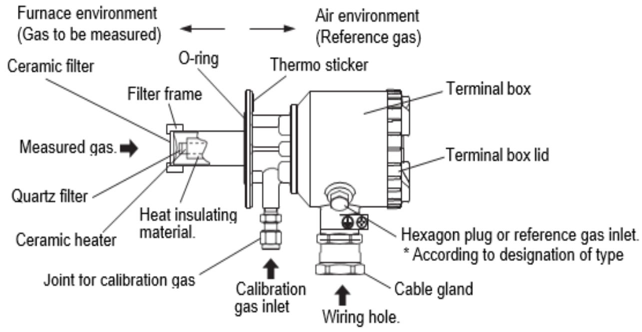

Figure 1 zirconia-based oxygen sensor

Figure 2.2 shows the graphical control system of the boiler. Air to fuel ratio is maintained by the system and controls the boiler operation. The screen shown in figure is the HMI (Human Machine Interface) controlled by the PLC (Programmable Logic Controller). To control the motor of fan based on frequency, VFD (Variable Frequency Drives) is used. Such a motor is used to control, and fulfilment of the AIR required for the combustion. The oxygen sensor is installed on the first phase, where the fuel gets passed to the boiler. It is continuously observed and stored the data of oxygen concentration in the flue gases and generate the feedback signal to the masters in the production. Increasing the air to fuel ratio or combustion efficiency is a major challenge, as a result it will lead to saving the fuel. The required fuel for consumption is less and thus reduction in the heat losses with flue gas. [5]

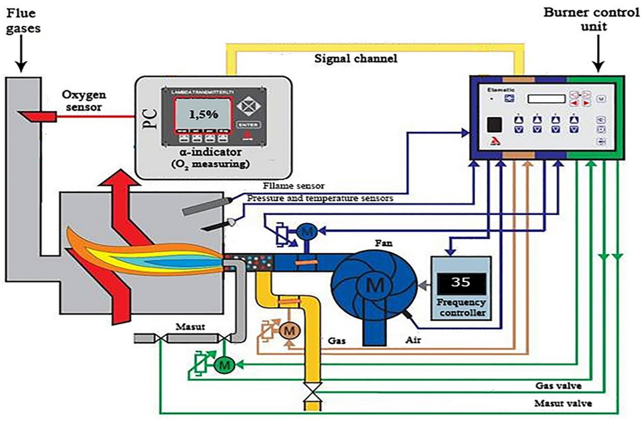

Figure 2 Schematic diagram of combustion process

2.2. Features of Oxygen Sensors

For implementing the control system of the fuel combustion in boilers of low and medium power, a fuji make oxygen sensor is used, which operates based on the zirconia cell. This zirconia oxygen analyzer makes use of the oxygen ion conductivity of strong electrolytes composed mainly of zirconia (ZrO_2) at excessive temperatures.[4]

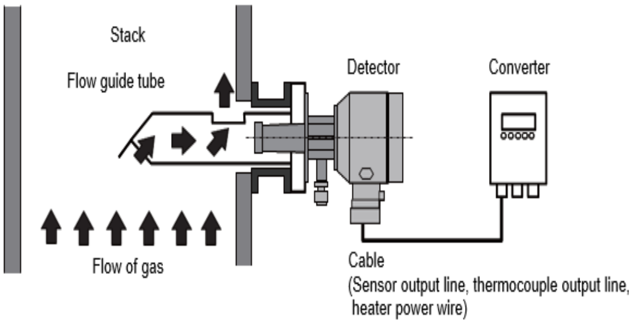

Figure 3 Overview of zirconia Oxygen Analyzer[4]

Figure 3 shows the overview of the zirconia oxygen analyzer consisting of two cells: measuring cell and reference cell. Flue fuel passes via the boiler chamber with 150°C - 200°C temperature. Zirconia cell works at round 800°C. C and the ion begin interacting with the O2 molecule. Through the probe in the duct chamber sensor mounted or cell installed, the flue gases enter the measuring chamber (diffusion gap) in the cell. This configuration is characterized by using ability of a consistent real time analysis of the system AFR in the diffusion gap. The instrument that continuously measures the flue gas composition mixture corresponds to $\alpha = 1$ (Servic service manual for oxygen analyser ZKM , n.d.)[12]

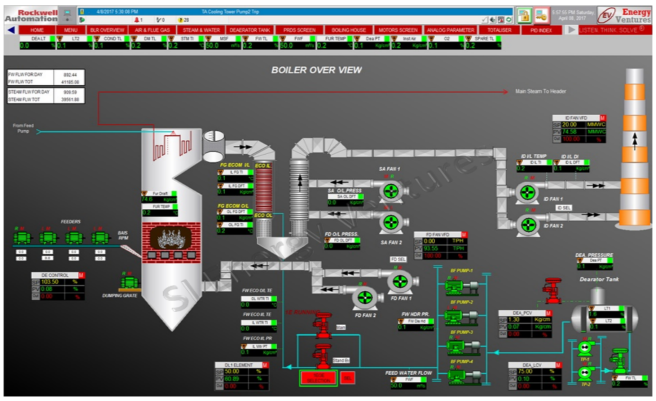

Figure 4 Combustion control system

III. CONTROL SYSTEM ALGORITHM

The algorithm of the automatic control system works to ensure proper functioning of boiler. According to the load of process, AFR is adjusted, and this is fully automated control system. PLC is used to control the process. Figure 5, a one-of-a-kind feature of the algorithm is the use of frequency control, through which the extent of air furnished to the combustion quarter varies smoothly. [1] The sensor measures the interest of oxygen in the flue gases and the system strategies the receiving information. A manipulate sign is generated relying on the obtained EAR price – the fan rotation frequency is decreased or expanded by way of 0.1 Hz (for $\alpha > X$ or $\alpha < X$, respectively, the place X is the measured EAR value). After the steady-state operation of the fan is established, the gadget is wondered again [9]. The detector with sensor unit, the flow guide tube is directly inserted to the stack or the boiler outlet it may duct, economizer or air preheater or something similar to supply the gases though out the detector and controller is handling the controlling action of the detector, signal processing, output /display and external transmission make up the direct insertion type zirconia oxygen analyses. Cables are used to make a transmission between detector and sensor that carries the feedback signal as well as controlling action signal taken form the controller. Flow guide tube is used for the supportive system to handle the 400 °C temperature and the make of that flow guide tube is ss-316.[1]

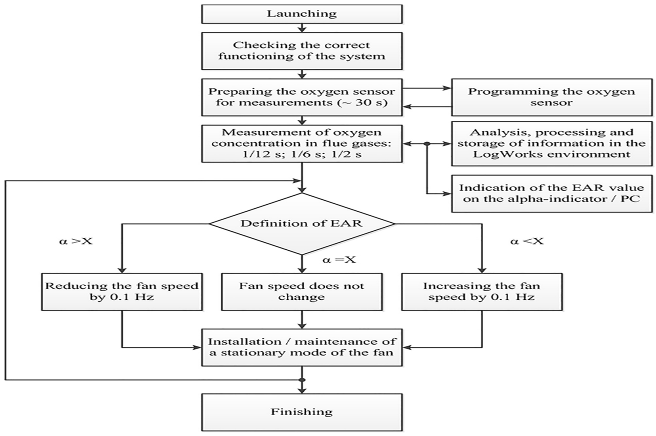

Figure 5 Flow chart of the process

IV. RESULT AND DISCUSSION

Figure 6 Actual image of the oxygen analyzer installed on the Boiler

This project had been carried out at Siddapur Distilleries Limited to develop the process control system. It is done at site of the ESBEE power boiler manufacturer and the boiler capacity is 4 PTH. In figure 6 oxygen analyzer of fuji electric make is installed in the boiler ignition system has shown. The results have been observed after installation of the oxygen analyzer in the boiler and the combustion efficiency of the boiler has improved as compared to the older process system.

After installation the system have been observed for one week and found that the air to fuel ratio is comparatively good and fuel feeder is improved the feeding frequency. The quality of burning is checked from the collected ash and analyzed. The project aimed to enhance boiler combustion efficiency, and it successfully achieved its goal. [4][5][12]

Oxygen Reading Vol%	Output of Detector (mV)
0.01	168.15
0.05	132.68
0.1	117.41
0.5	81.94
1.2	62.65
1.4	59.25
1.5	57.73
1.6	56.31

Table 1 Output of the Oxygen Detector

By incorporating an oxygen analyzer into the boiler and assessing the overall system response, the outcome revealed an improved combustion ratio.[5]

Figure 7 Visual representation of O_2 system

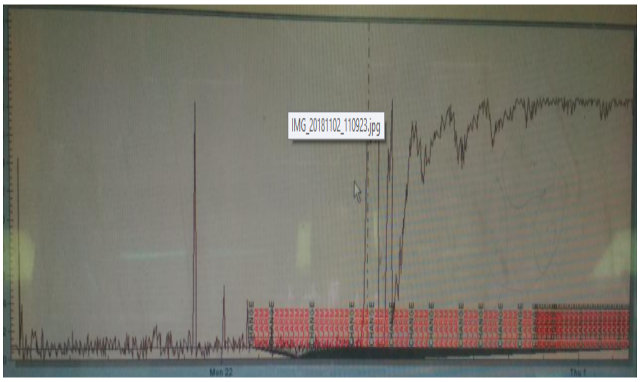

Figure 8 Trend of Combustion (before O_2)

Figure 8 presents the graphical trend of air to fuel ratio without oxygen combustion losses and fuel loss. [12]

V. CONCLUSION

The project aimed to enhance boiler combustion efficiency through the incorporation of an oxygen analyzer. The focus was on optimizing the fuel combustion process to reduce losses and improve overall performance. The research introduced a novel approach by modifying the traditional boiler design and implementing a system that utilizes an oxygen detector for combustion analysis. The results demonstrated a significant improvement in combustion ratio with a reduction in fuel losses ranging from 10% to 30%. The implementation of a zirconia-based oxygen sensor provided accurate and continuous analysis of combustion efficiency. The graphical representations of the combustion trends before and after the oxygen analyzer installation further Validate the positive impact on the performance.

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REFERENCES

[1] A. Zaporozhets, "Analysis of Control System of Fuel Combustion in Boilers with Oxygen Sensor", Period. Polytech. Mech. Eng., vol. 63, no. 4, pp. 241–248, Jan. 2019.

[2] Software & Licenses – Technoshot & V9 (Fuji Electric Pvt Ltd).

[3] Artur Zaporozhets Department of Monitoring and Optimization of Thermophysical Processes, Institute of Engineering Thermophysics of NAS of Ukraine https://doi.org/10.3311/PPme.12572

[4] Zirconia instruction manual- “The Direct Inserssion Type Zirconia Oxygen Analyser Detector type – ZK8

[5] Servic service manual for oxygen analyser ZKM mahttps://www.fujielectric.com/products/instruments/manual/top.htm

[6] Semkov, K., Mooney, E., Connolly, M., Adley, C. "Efficiency improvement through waste heat reduction", Applied Thermal Engineering, 70(1), pp. 716–722, 2014. https://doi.org/10.1016/j.applthermaleng.2014.05.030

[7] Garg, B., & Mishra, D. K. (2020). Precision measurement of ADC parameters with cumulative histogram technique using Gaussian noise. Microelectronics Journal, 104, 104875.

[8] Gawde, R. R., Jadhav, S. P., & Garg, B. A. (2022). Design and Implementation of Soft Computing-Based Robust PID Controller for CSTR. In Proceedings of International Conference on Computational Intelligence and Emerging Power System: ICCIPS 2021 (pp. 301-317). Springer Singapore.

[9] Liu, H., Chaney, J., Li, J., Sun, C. "Control of NOx emissions of a domestic/small-scale biomass pellet boiler by air staging", Fuel, 103, pp. 792–798, 2013.https://doi.org/10.1016/j.fuel.2012.10.028

[10] Babak, V, Mokiychuk, V., Zaporozhets, A., Redko, O. "Improving the efficiency of fuel combustion with regard to the uncertainty of measuring oxygen concentration", Eastern-European Journal of Enterprise Technologies, 6(8), pp. 54–59, 2016. https://doi.org/10.15587/1729-4061.2016.85408

[11] Heil, P., Toporov, D., Förster, M., Kneer, R. "Experimental investi- gation on the effect of O2 and CO2 on burning rates during oxyfuel combustion of methane", Proceedings of the Combustion Institute, 33(2), pp. 3407–3413, 2011. https://doi.org/10.1016/j.proci.2010.05.047

[12] Siddhapur Disilary karnataka actual site location. https://sdlsiddapur.com/ethanol/