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Placement of Oxygen analyzer Probe in Blast Furnace Fuel-Fired Boiler for Effective Combustion

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Abstract - Effective combustion is crucial in the boiler section of any type of power plant. This can be achieved through accurate measurement and prediction of oxygen, NOx, and CO. A review of numerous studies has revealed that placing probes in power plants is a difficult task; at the maximum, we found that O_2 Analyzers are placed between the preheater and economizer sections. Once the oxygen level is controlled, it takes some time to read the updated values of oxygen; during this time, losses occur from the distance of the probe placement and the high temperature that makes direct placement of probes in boilers impossible. In order to discover an alternative choice, we are employing two ways in this study. In method 1, we introduce a circular pipe for flue gases directly into a sensor panel that is located close to the boiler section fuel quantity measurement. We do this by taking a tapping point through a boiler knob. This method allows for the possibility of rebuilding the boiler by replacing the well of the oxygen analyzer near the economizer and preheater section by directly taking a tapping point in the boiler for flue gas fed back to an externally installed oxygen analysis panel. High fuel pressure is reached through this tapping point to an oxygen sensor panel placed outside near the boiler. The installed system was used for the commissioning work. The ideal boiler operating conditions were established (with the amount of CO formation in the flue gases at a minimum) and relative outputs get more accurate and quick response against previous process efficient for further process. In method 2, indirect oxygen measurement using a charge-coupled device was carried out by directly installing a camera in the furnace section to obtain high-definition images and facilitate additional variable prediction.

Keywords - O_2 measurement, combustion, boiler tapping, boiler efficiency, image acquisition, Classification model

Introduction

Optimizing the combustion efficiency of boiler fuel is a crucial tactic, with the goal of conserving fuel and minimizing heat loss through the flue gas mixture. Controlling fuel combustion in an autonomous process boosts boiler efficiency and lowers atmospheric emissions of hazardous gases like carbon monoxide, nitrous oxide, and hydrogen[1].

Among the most significant obstacles that a BFG today is minimizing hazardous gases while simultaneously enhancing boiler efficiency and reducing fuel use. The minimum flue gas temperature for a gas-fired boiler is between 120 and 130 °C. Because the exhaust gases temperature removes condensation from the smoke stacks and flues, natural draught increases. Nevertheless, the actual temperature of flue gas in many boilers is between 180 and 200 °C, which results in a significant energy loss and low thermal efficiency of about 86%. Condensation will still occur in a boiler even with the development of condensing boilers over the past 40 years to recover the heat from the flue gases[2][3]. A few causes of the boiler's low efficiency variables such as mechanical combustion, slag, and external exhaust cooling, and chemical composition. The process of heat recovery will boost efficiency in all of the aforementioned cases, and burning carbon fuel has environmental benefits. The fundamental two dual-sensors for measuring combustor performance (CO/O_2) and NOx (NO/NH_3) are described for coal-fired electrical utilities and efficient combustion [4]. Research has shown how crucial it is to regulate NOx, CO, and O_2 when burning biomass. Pital and Mižák also mentioned the relationship between CO and O_2 emissions at the same time [5][6].

This is a practical and affordable way to reduce the concentration of hazardous substances in flue gases. It is still important to update control systems to maintain the excess air ratio at the stoichiometric level and the air-fuel mixture's composition at a certain speed and with high dependability. [7].

The authors showed how the additional air ration value affected the flue gases' quantitative and qualitative composition during the burning of natural gas, biomass, and other fuels. Furthermore, methods and resources for managing the quality of heat and power equipment are always being developed. [8].

In this project, we're attempting to relocate the Zirconia-based oxygen analyzer from the preheater and economy sections. We're also using flue gas tapping to obtain gas directly fed to the O2 analyzer near the boiler. In a different approach, a charge-coupled device is directly placed to the boiler to acquire images using a soft sensor technique, analyze those images using a deep learning model, and assess those images using an endurance model and convolution neural network for O2, CO,Nox Content by which it reduces the amount of ash content generated and controls the boiler's content variable process quickly to achieve effective combustion[9][10][11].

2. Methodology

Two approaches are derived for the unique execution of this research work for efficient combustion in the boiler section measurement of oxygen by replacement of oxygen analyzer & CNN's classification model, which shows best result and their effectiveness.

2.1 Method 1 Boiler exhaust flue tapping to regulate fuel combustion

There are a lot of different systems available right now to adjust the (FAR) fuel-air ratio automatically. The majority of them try to fix CO and O_2 in flue gases at the same time. The disadvantage of this approach is the uneven rates of gas, air, and rarefaction caused by the inertia of smoke exhausters and fans. This raises the likelihood of an emergency situation resulting from a brief release of air pressure and vacuum above allowable limits. However, reducing the concentration of dangerous compounds in the flue gases and preventing the generation of incomplete combustion products (H2, CH4, CO, and C) are not possible using CO content measurement. By monitoring the. This control will be maintained even if the quantity of gas that enters the boiler fluctuates. The boiler room system benefits greatly from these large energy savings[12].

Fig1: **(a) O_2 Analyzer Probe Placement**

Fig 1(b) -Tapping point taken for Flue gas Acquisition

Fig 1 (c) O_2 analyzer Probe monitoring Control Panel

Boiler efficiency $OH/OI * 100$ ------------- (1)

Where O_H represent generation of Output Heat and O_I represent Input heat

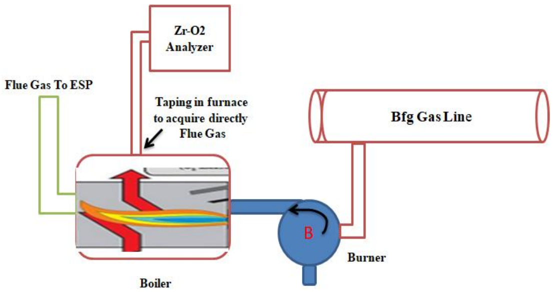

Fig.2:- Proposed Method for direct Probe Tapping in boiler for O_2 Measurement

In above fig we directly acquire flue gas from boiler and nearby boiler place panel of Oxygen analyzer to measure content of oxygen. BFG Gas received from blast furnace and directly fed to burner ignited with LPG gas and fuel injected inside the boiler high pressure boiler burnt the fuel and returning flue gas is fed back to electrostatic precipitation in between that we acquired flue gas from tapping pipe in high pressure side and fed to O2 analyzer panel it measures the Content of oxygen immediately without any loss of fuel by which air and fuel ratio maintain.

2.2. Proposed Method Soft Sensor Image Acquisition method:- utilized in the design of Our second artificial neural network (ANN) model predicts the oxygen level by using the temperature, gas, and air volumes as inputs. The aforementioned characteristics are obtained as continuous data for all oxygen percentages between 2.7 and 3.4. Next, we forecast the oxygen level using ensemble technique—more precisely, weighted ensemble technique—which significantly increases accuracy[13]. We experimented with two ensemble settings: in one, we used the weighted sum of the two models directly; in the other, we concatenated the feature vectors of the two models and employed a further set of fully connected layers to predict the oxygen level. Rarely has one such CNN technique in artificial neural networks been used in combustion processes[14].

Mean square [MSE] measurement is the definition of error metrics. absolute error (AE) and relative error (RE) input variables are sorted into control and state variables. [17].

Fig 3:- Real time data acquisition of Flame Images

Images are taken from a gas-fired boiler at various temperatures over an extended period of time, and the oxygen content is also assessed. together with the gas feeding rate over that time [15].

Proposed method is depicted in block diagram as shown in figure

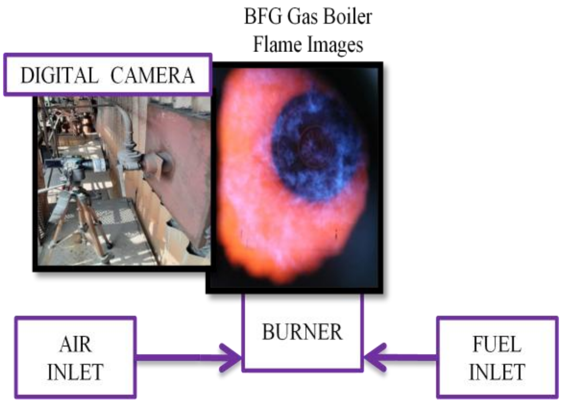

Fig. 4: Online flame Image Monitoring

In order to fire the furnace heavy oil and LPG, Figure 4 depicts a working combustion method where cotton fibre is used to prepare and wrap the boiler wall. First, gas is employed as fuel; later, blast furnace fuel is used as boiler fuel[16]. In a gas-fired boiler, a direct-drive variable frequency fan capable of producing up to 21,600 m^3 of air per hour is used to supply the combustion air. The concentrations of O_2, CO, and NOx in exhaust gases are measured by a gas analyzer. A SCADA system automatically measures every process variable, such as temperature, pressure, fuel gas flow rate, and air flow[23]. The photographs of the flames in the furnace were captured with a digital color camera.

$A_j = f\left(\sum N_i = lI_i * K_{i,j} + B_j\right)$--------------(2)

A_j is f is a nonlinear activation function, I i is the input matrix in the K (i,j) kernel, and B j is the bias value that will be applied to each matrix element. The result is the output matrix on the convolution layer.

Reduced dimensionality is one of the pooling layer's goals. The convolution layer's output matrix will be reduced in order to speed up calculation[17]. Other strategies, like minimum, average, and max pooling, can be used to achieve this. On the flatten layer, the 2D matrix of the pooling layer will be converted to a 1D matrix. Every matrix element in this layer will be positioned inside a one-dimensional array before it reaches the fully connected layer. The completely linked layer is where the classification process will take place. CNN's architecture is depicted in Fig 4.

Datasets of two types of images, 'training' and 'testing', are gathered in this work to provide a sample image that serves as a local perspective of the image. Cut down on computation time; convolutional neural networks are mostly used for multiple weight calculations [14]. In the filters step, CNN generates several filters that extract different kinds of data. CNN extracts translation-invariant features using sub sampling, sometimes referred to as down sampling, which lowers computation complexity. In contrast, handcrafted features are needed for training in traditional machine learning techniques, which can be time-consuming and errorprone. When all features are linked together, the CNN employs multiple convolutions and pooling to connect all of the recovered features.

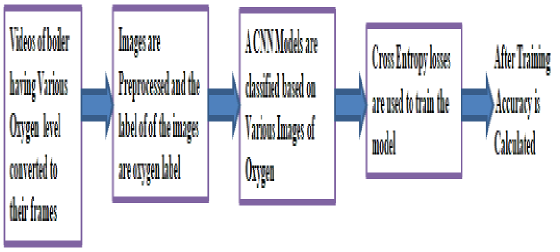

Fig:- 5 Steps for Training the CNN Classifier

In above figure 5 boiler internal video acquire and various temperature their oxygen level converted to oxygen frames and images are further processed and labeled that images of oxygen label classification of images are further performed afterward cross entropy losses are used to train the model and finally accuracy calculated and predicted the level of oxygen in the boiler.

3. Results

Following results shows boiler oxygen condition when tapping point taken in boiler section(method-1) with different temperature air gas quantity their oxygen linear relation are acquired in table 1 temperature ranges between $573^{0}C$ to $807^{0}C$ where level of Air and Gas quantity differs following tables are shows different level of temperature, duration of time taken images are 1:30 to 2:15 PM(45 Minutes) variation of graph is acquired represent ass per temperature changes.

Table 1:- Relative Air, Gas and O_2 at different temperature ranges

Sr.No	Temp.	Air quantity	Gas quantity	O_2 %	Sr.no	Temp.	air quantity	Gas quantity	O_2 %
1	573.374	27532.58	12003.7	3.1	22	697.54	26098.34	17567.22	3.3604
2	567.954	27641.18	12002.7	3.09	23	697.13	26114.73	17495.09	3.3588
3	557.114	27858.38	12000.7	3.08	24	681.14	26753.94	14682.02	3.2964
4	551.965	27961.55	11999.75	3.07	25	723.14	19346.78	18739.28	3.39
5	597.582	27048.36	12004	3.15	26	713.84	22080.68	18435.68	3.38
6	593.552	27128.96	12004	3.14	27	701.44	25725.88	18030.88	3.37
7	589.522	27209.56	12004	3.13	28	747.42	21310.38	21668.98	2.7792
8	585.492	27290.16	12004	3.12	29	746.99	21262.11	21613.81	2.7924
9	577.432	27451.36	12004	3.1	30	743.12	20827.68	21117.28	2.9112
10	622.42	27000	13347.9	3.17	31	742.69	20779.41	21062.11	2.9244
11	613.82	27000	12840.9	3.16	32	738.82	20344.98	20565.58	3.0432
12	605.22	27000	12333.9	3.15	33	738.39	20296.71	20510.41	3.0564
13	648.41	26251.06	13500	3.2358	34	734.52	19862.28	20013.88	3.1752
14	645.76	26336.16	13500	3.2288	35	734.09	19814.01	19958.71	3.1884
15	632.51	26761.66	13500	3.1938	36	725.92	18896.88	18910.48	3.3888
16	629.595	26855.27	13500	3.1861	37	772.6	22232.26	24258.08	2.7
17	625.885	26974.41	13500	3.1763	38	797.06	23270.64	25823.54	2.8
18	672.36	26914.32	13589.5	3.27	39	777.46	22408.24	24647.14	2.7
19	667.96	26771.52	13572	3.26	40	816.2	31140.02	30400.04	2.9
20	659.16	26485.92	13537	3.25	41	807.2	26840.12	22400.24	2.8
21	650.8	26214.6	13503.75	3.24					

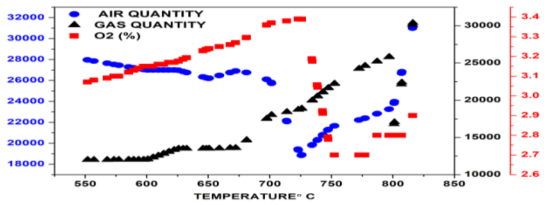

Fig 8:- Experimental Analysis of Oxygen at different Temperature Ranges

Experimental results showing how boiler power depends on the amount of residual oxygen in the combustion process.

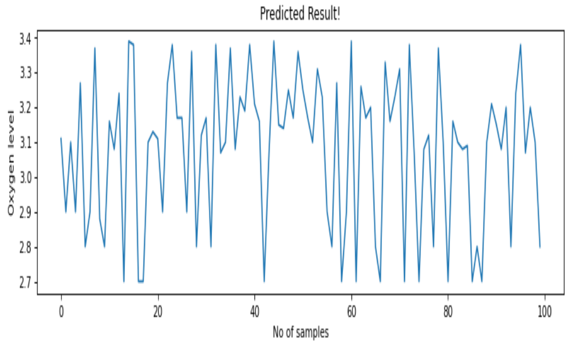

Fig. :- 9 Prediction of oxygen level by CNN classification model[18]

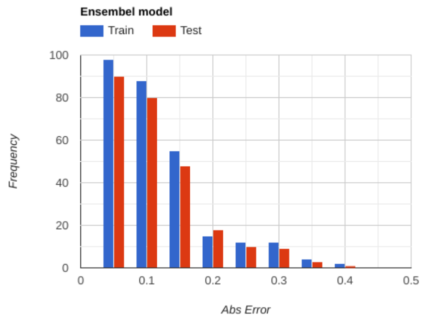

Fig.:- 10 Prediction Value[18]

4. Conclusion

Reducing loss is a common issue and combustion is a crucial component of a gas powered boiler. A precise estimation of the oxygen content is crucial. In this study, a Boiler Fule Taping process are used to retrieve oxygen data and found accuracy of 15% more than previous used method of probe placement at Ecnomizer and preheater section as well as we get immediate data of Oxygen variables from boiler as quick action mode in another method used to The CNN model is suggested as a workaround to these problems in order to anticipate the amount of oxygen in flue gases. The algorithm's three facets— Data pre-processing, feature selection, and data analysis modeling —are investigated. The use of fully connected filters, max pooling and convolutional ReLU are significant aspects. CNN Technique is used to produce correct data, as opposed to the DBN Method. By gathering 41 distinct classes and using the CNN model for prediction, oxygen levels in a power plant's BFG gas-fueled boiler are anticipated. Following model training, the accuracy was as low as 0.04 and as high as 97%. The outcomes demonstrate how effectively the suggested combination modeling technique and feature selection techniques work as well as their potential. In the future, a predictive control application can be developed using the recommended approach. Additionally, we have access to ensemble models, which employ additional characteristics to produce very accurate prediction models.

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