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# The Artificial Neural Network On-line Monitoring Model Of Boiler Efficiency

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**Keywords:** Borler combustion, Boiler efficiency, The artificial neural network, Efficiency prediction.

**Abstract.** When adjusting the borler combustion, the borler efficiency need to be constantly monitored.The traditional method of calculating boiler efficiency is complex.Based on the heat balance method,the main factors of influencing boiler efficiency was analysed deeply and the artificial neural network on-line monitoring model of boiler efficiency was established to predict boiler efficiency accurately and constantly in this paper. After precise analysis and tracking, the input variable for the artificial neural network on-line monitoring model of boiler efficiency was selected, so as to avoid larger error caused by the rough selection of input variable in the previous artificial neural network. At last,based on a 600MW boiler,the borler efficiency was predicted in this paper.we can easily know from the prediction result that the artificial neural network on-line monitoring model of boiler efficiency can predict the boiler efficiency accurately and constantly at a wide range condition.

## Introduction

The large boiler has an irreplaceable role in the industrial development,because of the advance of the "12th Five-Year Plan.At the same time, the power plant boiler needs to constantly adjust and optimize in order to reach the requirements of energy conservation and sustainable development.The boiler combustion adjustment of boiler operation need to be adjusted. The traditional calculation methods are ASME standards and our GB calculation method mostly used to counter-balance method.[1]Because the heat balance method needs lots of data and the calculation is more complicated,it is not convenient for use in our work.Based on the heat balance method,the main factors of influencing boiler efficiency was analysed deeply and the artificial neural network on-line monitoring model of boiler efficiency to predict boiler efficiency accurately and constantly established in this paper.That avoided the larger error caused by roughly selecting the input variables in the past.

## Boiler Efficiency Analysis

The boiler efficiency η can be obtained by the heat balance equation[2]:

$$\eta = 100 - (q_2 + q_3 + q_4 + q_5 + q_6),\ \% \quad (1)$$

In the formula:$q_2$—exhaust gas heat loss;$q_3$—gas incomplete combustion heat loss;$q_4$—solid incomplete combustion heat loss;$q_5$—heat loss;$q_6$—ash physical heat loss.

**Exhaust Gas Heat Loss.**The exhaust gas heat loss $q_2$ is the largest heat loss in the boiler. The heat loss caused by exhaust gas is influenced by fuel properties and the export excess air coefficient, formation of heating surface ,and so on.

$$q_2 = \left(h_{py} - \alpha_{py} V^0 (ct)_{lk}\right)\left(1 - \frac{q_4}{100}\right)/Q_r,\ \text{kj/kg} \quad (2)$$

In the formula:$h_{py}$—exhaust enthalpy，kj/kg;$\alpha_{py}$—the export excess air coefficient at the gas Department，kj/kg;$(ct)_{lk}$—1m3 cold air enthalpy，kj/m$^3$，Usually $t_{lk} = 30℃$.

**Gas Incomplete Combustion Heat Loss.**The gas incomplete combustion heat loss $q_3$ is the heat loss caused by incomplete combustion of residual combustible gas in the gas,as for coal-powder boiler $q_3 = 0$.

$$q_3 = \frac{V_{gy}}{100}(12636CO + 10798H_2 + 35818CH_4 + 59079C_mH_n)/Q_r,\ kj/kg \quad (3)$$

In the formula:$V_{gy}$—the dry flue gas volume generated by the incomplete combustion of per kilogram of as received fule, $m^3/kg$;

**Solid Incomplete Combustion Heat Loss.**The solid incomplete combustion heat loss $q_4$ is the heat loss caused by the unburnt carbon or the unburnt carbon ash.It depends on the nature of the fuel, combustion, furnace structure, boiler load,and so on.

$$q_4 = \left(32700\frac{C_{fh}}{100}\frac{G_{fh}}{B} + 32700\frac{C_{lz}}{100}\frac{G_{lz}}{B} + 32700\frac{C_{cjh}}{100}\frac{G_{cjh}}{B} + \frac{B_{sz}Q_{ar,net}^{sz}}{B}\right)/Q_r,\ kj/kg \quad (4)$$

In the formula:$G_{fh}$, $G_{lz}$, $G_{cjh}$ —The quality of the fly ash, slag, and deposition of ash including the Carbon residue,kg/h;$C_{fh}$, $C_{lz}$, $C_{cjh}$—The carbon content of the fly ash, slag, and deposition of ash,%; $B$—the amount of coal-fired boiler, kg/h ; $B_{sz}$ —the stone coal discharged by the Medium-speed mill,kg/h;$Q_r$—1kg fuel's heat;$Q_{ar,net}^{sz}$—stone coal calorific,kj/kg..

**Heat Loss.**The heat loss $q_5$ is the heat loss caused by natural convection and radiation heat transfer of the boiler.It is mainly influenced by the size of the boiler's outer surface area, furnace wall structure, thermal insulation properties, ambient temperature and boiler rated evaporation.

$$q_5 = 5.82(D_{ed})^{-0.38}\frac{D_{ed}}{D} \quad (5)$$

In the formula:$D_{ed}$—rated evaporation,t/h;$D$—actual evaporation,t/h.

**Ash Physical Heat Loss.**The ash physical heat loss $q_6$ is the heat loss caused by the slag, fly ash and settlement ash carrying heat but Failed to take advantage.It is mainly influenced by slag, fly ash settling ash content and ash temperature.

$$q_6 = \frac{A_{ar}}{100}\left[\alpha_{lz}(c\vartheta)_{lz} + \alpha_{fh}(c\vartheta)_{fh} + \alpha_{cjh}(c\vartheta)_{cjh}\right],\ kj/kg \quad (6)$$

In the formula: $(c\vartheta)_{lz}$ $(c\vartheta)_{fh}$ $(c\vartheta)_{cjh}$— the Enthalpy 1kg slag, fly ash and sedimentation gray at the temperature of $\vartheta_{lz}$ $\vartheta_{fh}$ $\vartheta_{cjh}$.

## The Neural Network Model

The artificial neural network is widely interconnected artificial neurons by a large number of simulated biological neuro.Because it has the function of any nonlinear function fitting, good generalization ability, complex problems with self-learning and adaptive ability, It has been extensively studied and applied to the nonlinear system modeling.[3]

The power plant boiler combustion system is a complex system of more than one variable, non-linear, strong coupling.Using conventional methods modeling has considerable difficulty. The neural network has a strong nonlinear mapping ability, so the BP neural network is used to model the combustion process.[4]

Boiler combustion is a complex energy conversion and energy transfer process,so there are many factors affecting the combustion efficiency.

The exhaust gas temperature in the DCS data directly reflects the exhaust gas heat loss $q_2$. The oxygen content of the furnace exit indirectly reflects the excess air coefficient in the chimney,also reflects the exhaust gas heat loss $q_2$.So the exhaust temperature and furnace outlet oxygen on behalf of the exhaust smoke heat loss were selected as the input of neural network in this paper.

The total amount of coal, the carbon content of fly ash and slag carbon content in the DCS data reflect a solid incomplete combustion heat loss $q_4$.They were selected to represent solid incomplete combustion heat loss as the input of neural network in this paper.

Drum pressure in the DCS data reflects the actual evaporation of the boiler,so as to indirectly reflect the heat loss $q_5$.The drum pressure on behalf of the heat loss were selected as the input of neural network in this paper.

In addition, the total amount of wind, and the furnace negative pressure and the hot secondary air temperature on the boiler efficiency also have a significant impact as the input of the neural network.

By the previous analysis,10 major factors were selected,such as boiler load, the total amount of coal, the total amount of wind, the dome pressure,negative pressure in furnace, secondary hot air temperature, the furnace exit oxygen, the exhaust gas temperature, the carbon content of fly ash and slag carbonaceousamount as the input of the neural network, the efficiency of the boiler as the output of the neural network to establish BP neural network model in this paper[5], as shown in Figure 1.

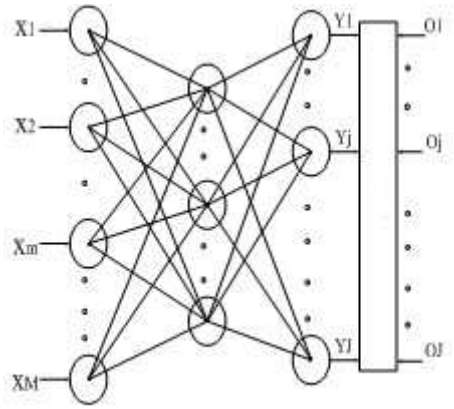


Fig.1 Brief structure of artificial neural network

The prior and post processing functions of artificial neural network model's training samples in this paper are premnmx() and postmnmx();The network weights initialization function is init();The network creation function is newff();The network training function is train();The network simulation function is sim().The hidden layer neurons uses Sigmoid transfer function,and sets 20 neurons in the hidden laye.The output layer neurons uses purelin type transfer function. The training function uses trainbr function. Based on the Levenberg-Marquardt optimization theory,the model will adjust the weights and biases of the network. The training step is 10, and the training accuracy is $10^{-5}$.

In order to achieve better predict the effect, the improved BP neural network was used in this paper.

Bayesian normalization method and LM algorithm neural network integration, accelerate the convergence speed, improve generalization capability.In addition,before training the sample,the sample data normalization process has been done. In this paper, the collected data is divided into the training sample data and the validation sample data.The training sample data trains the neural network model to be best,then reuses the validation sample data to be verified.

## Calculation Example

Using a 600MW power plant boiler as an example, the boiler efficiency will be calculated.This boiler is subcritical pressure intermediate a reheat control cycle furnace, single furnace ∏ type half open layout, burner top the following a tight seal, full steel suspension structure and solid state slaging off.The width of the furnace is 19558mm,the depth is 16940.5mm,the roof elevation is 73000mm,the drum centerline level is 74000mm,the roof plate girder bottom elevation is 81500mm.The boiler's top is metal seal structure.The design diagram is shown in figure.2.

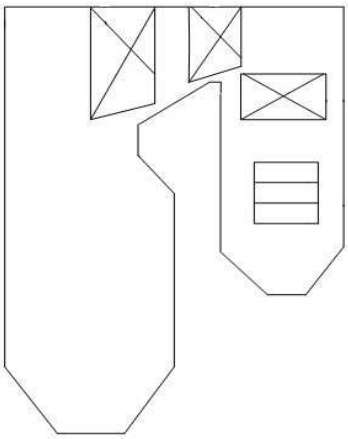

Fig.2 The profile of the boiler

Four kinds of conditions,600MW, 450MW, 330MW, 270MW, were calculated in this paper. Using artificial neural network based on-line monitoring model of boiler efficiency, the boiler efficiency was calculated offline. The calculated data are shown in Table 1.

Table 1, Boiler efficiency training sample and validation sample data sheet

| Item | BL [MW] | TC [t/h] | TW [t/h] | DP [Mpa] | FV [Pa] | SH [℃] | FE [%] | ST [℃] | FA [%] | SC [%] | AE [%] | PE [%] | E [%] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 600 | 221 | 1490 | 18.4 | 100 | 319 | 2.76 | 121.8 | 1.07 | 6.04 | 94.11 | 94.28 | 0.18 |
| | 450 | 158 | 1146 | 17.8 | 110 | 302 | 3.41 | 116.8 | 1.37 | 3.92 | 94.35 | 93.83 | 0.55 |
| TS | 330 | 123 | 956 | 14.3 | 109 | 287 | 5.51 | 113.2 | 1.07 | 3.93 | 93.86 | 93.83 | 0.03 |
| | 270 | 106 | 868 | 12.6 | 79 | 277 | 8.21 | 103.5 | 1.47 | 4.59 | 92.25 | 93.79 | 1.67 |
| | 600 | 223 | 1510 | 18.5 | 99 | 319 | 2.58 | 120.6 | 1.21 | 11.6 | 94.06 | 94.37 | 0.32 |
| VS | 450 | 171 | 1110 | 17.7 | 120 | 297 | 3.56 | 114.8 | 1.12 | 2.58 | 94.19 | 93.83 | 0.38 |

BL stands for boiler load;TC stands for Total coal amount;TW stands for Total Wind Amount ;DP stands for Drum Pressure;FV stands for Furnace vacuum;SH stands for Secondary Hot air Temperature;FE stands for Furnace Export Oxygen;ST stands for Smoke Temperature;FA stands for Fly ash Carbon content;SC stands for Slag carbon content;AE stands for Actual Efficiency;PE stands for prediction Efficiency;E stands for Error;TS stands for training sample;VS stands for validation sample.

Seen from Table 1, the artificial neural network on-line monitoring model of boiler efficiency has high prediction for the boiler efficiency.In the validation sample, the error is only 0.38%, which is completely within the permissible error range of the engineering.In order to avoid the predictable limitations for a single condition,the other conditions in the training sample were predicted in this paper,and the errors are all in the permissible error range of the engineering.This shows that the artificial neural network on-line monitoring model of boiler efficiency has extensive adaptability for boiler conditions.This model can accurately predict the boiler efficiency at different boiler load.

**Summary**

Based on the heat balance method,the artificial neural network on-line monitoring model of boiler efficiency was established in this paper,and the main variables what determine the efficiency of the boiler were analysed.Then this model uses these variables or other variables directly related to these variables testability as the input variables of the artificial neural network,and trains artificial neural network prediction model of the boiler efficiency.

This model has advantages:

(1)This model achieves boiler efficiency calculation intelligent,and avoids the complex calculations.

(2)The input variables of the artificial neural network contain comprehensive information that improve boiler efficiency prediction accuracy.

(3)Seen by the prediction results, even if the boiler load changes, the boiler efficiency changes a litter.

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