Transparent and Explicable Boiler Fouling Monitoring with Fuzzy Neural Network

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Fouling on boiler heating surfaces is one of the important factors that damage boiler's economical performance and safety. With on-line monitoring of fouling states on boiler heating surfaces, it is possible to optimize sootblower system, to visualize fouling states, to improve performance, as well as to remedy the insufficiency of experiment research in boiler heating surface fouling process. New method based on Fuzzy Neural Network (FNN) is presented to monitor fouling states on boiler heating surfaces on-line. Compared with regular methods, since FNN's reasoning process is transparent and comprehensible, it is possible to explain and comprehend reasoning process, which makes the FNN based system perform as an additional operation consulting system.

Keywords: Fuzzy Neural Network (FNN), fouling, monitor, boiler..

BOILER HEATING SURFACES FOULING MONITORING

Fouling is unavoidable for all heating surfaces in boiler. Fouling on heating surfaces is one of the main factors that affects key performance parameters such as main steam temperature, boiler evaporation capacity, exhaust flue gas temperature, boiler efficiency, etc. Under certain situations, fouling states define boiler's fail-down frequency and maintenance cycle, which will reduce boiler's availability. Thus, it is necessary to monitor fouling states on boiler heating surfaces in order to avoid serious fouling and slagging problem via adoption of reasonable measures, based on prediction and alarm of potential failures. In order to avoid serious fouling and slagging, modern large capacity boilers are equipped with various sootblowers that can ensure the cleanness of heating surfaces. Regularly, sootblower system adopts periodic performance pattern. Since this kind of performance pattern is executed blindly under conditions that the real fouling states on heating surfaces are unknown, the problems of insufficient sootblowing and ultra sootblowing can not be solved simultaneously. Both problems will damage boiler's economical performance and safety. Sootblower system's optimum performance pattern should put sootblowers into operation while and only while necessary, according to real fouling states on heating surfaces. Obviously, this kind of performance pattern can only be based on monitoring fouling states on boiler heating surfaces. Monitoring fouling states on heating surfaces can visualize unseen internal states in boiler in the forms of visible chart, diagram and data on computer screens, which can make the boiler performance transparent.

On the other side, for boiler convection heating surface thermal calculation, the main cause that leads to calculation error is that fouling state can not be discerned precisely. This influence is represented in the calculation of heat transfer coefficient $k$. According to basic theory of heat transfer:

$$k = \frac{1}{\frac{1}{\alpha_1} + \varepsilon + \frac{1}{\alpha_2}}$$

(1)

$\alpha_1$-convection coefficient of gas side, $\alpha_2$-convection coefficient of working medium side, $\varepsilon$-heat resistance.
of fouling layer, namely fouling factor. In formula (1), heat resistance of metal tube wall and scale of working medium side is omitted, which is usually considered as acceptable. The overall influence of \( \alpha_1 \) and \( \alpha_2 \) can be considered in the form of ideal heat transfer coefficient \( k_0 \) without fouling consideration. That is

\[
k_0 = \frac{1}{\frac{1}{\alpha_1} + \frac{1}{\alpha_2}}
\]

(2)

In formula (1), \( \alpha_1 \) and \( \alpha_2 \) have already been investigated with sufficient experiment research and theoretic analysis, and have had quite precise calculation methods. It is \( \varepsilon \) that leads to calculation error of \( k \). Because of complex influencing factors (such as gas velocity, tube diameter, ash particle characteristics, gas temperature, with or without sootblowing etc., these factors all can affect the fouling process) and insufficient experimental research, there is still no reasonable and reliable calculation method accepted as standard calculation method of \( \varepsilon \). In practice, the calculation results of \( k \) always have rather large difference from real working conditions. Since it is difficult to discern \( \varepsilon \) in USSR thermal calculation standards of 1973, availability factor \( \Psi \) and utilization factor \( \xi \) (for airpreheater) were introduced

\[
k = \Psi k_0 = \Psi \frac{1}{\frac{1}{\alpha_1} + \frac{1}{\alpha_2}} \quad (3)
\]

\[
k = \xi k_0 = \xi \frac{1}{\frac{1}{\alpha_1} + \frac{1}{\alpha_2}} \quad (4)
\]

to consider generally the influence of fouling. From formula (1), (3) and (4), the following formula can be obtained.

\[
\Psi (\text{or} \xi) = \frac{1}{1 + \varepsilon k_0} \quad (5)
\]

From the above formula, it is obvious that \( \Psi (\text{or} \xi) \) is a less direct parameter than \( \varepsilon \). \( \Psi (\text{or} \xi) \) is subject not only to heating surface fouling state but also to \( k_0 \), which means that \( \Psi (\xi \text{or}) \) has direct relation with performance conditions. In 1973 standards, several recommendatory values of \( \Psi \) and \( \xi \) were given out for certain typical working conditions. It is obvious that this kind of amendatory method with semi-experiential factors is not precise enough, especially for check calculation under off-design conditions. Some experiment researches show that the calculation results of formula (4) are different from experimental results more than 20%. Monitoring fouling states on boiler heating surfaces can help to collect real operating data of fouling states and relevant influencing factors. Dependent on further analysis, the data can be a foundation for design calculation and check calculation, which will remedy insufficient experimental research of fouling.

The research of fouling monitoring in boiler has won more and more attention. In Germany and Canada, practical monitoring systems have been put into operation. Since it is difficult to measure fouling states on boiler heating surfaces directly, it is an excellent idea to calculate them from other easier measurable parameters in case the function relations between fouling states and those parameters have been established. The inputs are directly measurable operating parameters, such as temperature, pressure, coal supply, etc. The outputs are diagnostic parameters that can represent the fouling states on boiler heating surfaces, such as \( \varepsilon \), \( \Psi \), \( \xi \), etc.. Those function relations can be achieved not only through regular thermal calculation programs, but also through Artificial Neural Networks (ANN) which simulate those function relations, even through Expert System\(^6\). In this paper Fuzzy Neural Network (FNN) is used. Compared with regular computer program and common ANN (for example Back Propagation (BP) network), FNN’s calculation course is transparent, and its reasoning process is comprehensible and interpretable. In this paper, the second part gives out a kind of FNN’s structure and algorithm. The third part establishes a heating surface fouling diagnostic network for certain tube type airpreheater, which is an example of how to establish similar networks. At the end of this paper, some conclusion are presented.

**FUZZY NEURAL NETWORK (FNN)**

Fuzzy Neural Network is the combination of ANN and Fuzzy System (FS). FNN inherits both learning ability and reasoning interpretation from ANN and FS respectively. Several typical kinds of FNN have been established by S. Horikawa, T. Furuhashi and Y. Uchikawa\(^3\). Up to date, FNN has been applied in fault diagnosis of engineering problems, such as induction motor\(^4,5\), Diesel engine\(^6\) and chemical system\(^7\). In this part, one FNN will be used in the third part.

**Network Structure**

The network structure is demonstrated as Figure 1. The network has four layers. The first layer is in-

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