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Estimating thermal boundary conditions of boiler membrane water-wall using decentralized fuzzy inference with sensitivity weighting

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HIGHLIGHTS

- Fuzzy inference with sensitivity weighting is used to solve an inverse problem.
- Boundary conditions of membrane water-wall are estimated using this method.
- This method performs better than the conjugate gradient method.

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ABSTRACT

The thermal boundary conditions including the fireside heat flux, temperature of water–steam mixture in water-wall tubes and heat transfer coefficient on the inner surface of membrane water-wall, are estimated at the same time using the decentralized fuzzy inference (DFI) method with the sensitivity weighting based on the local measured temperature on the back of membrane water-wall. The influences of different initial guessed thermal boundary conditions, the measurement points, and the temperature measurement errors on the estimated results are discussed, and comparisons with the conjugate gradient method (CGM) are conducted. The study shows that the thermal boundary conditions of membrane water wall, the temperature distribution on the fireside and the positions of the dangerous points can be determined more accurately by the proposed method. It is concluded that DFI method with the sensitivity weighting is of better anti ill-posed characteristic. It would provide necessary basis for analyzing and monitoring the operation state of power plant boilers.

1. Introduction

In the fields of aerospace, chemical industry, power engineering, materials processing and others, many equipments work in severe thermal environment for long time, and these equipments are suffered extremely high thermal load. Such adverseness reduces the research possibilities using traditional theory and methods, while promotes the broad application of the inverse heat transfer problems (IHTP) in those areas [1–5]. Scholars are active in the research of IHTP and have developed a variety of valuable techniques. As the classical methods, gradient-based optimization algorithms are widely used, such as the Levenberg–Marquardt method (L–M method) and CGM. However, the estimated results of the L–M method and CGM would significantly deteriorate when the number of measurement points reduce and/or the measured temperature data contain errors [6,7]. Besides the gradient-based methods, some other intelligent methods for IHTP also receive much attention. Kim et al. [8] utilized the hybrid genetic algorithm (GA) method to search for emissivities in an irregular geometry. However, the efficiency of the GA is notably degraded when the optimization parameters are highly linear correlated. The premature convergence of the GA will deteriorate its performance and search capability [9], and the convergence speed is slow as well [10]. When the number of optimization parameters is large, especially with significant spatial distribution characteristics, the disadvantages of the GA could be very apparent. Therefore, a main research for the IHTP is to develop some methods with better ant-ill-posed characteristic and higher convergence speed.

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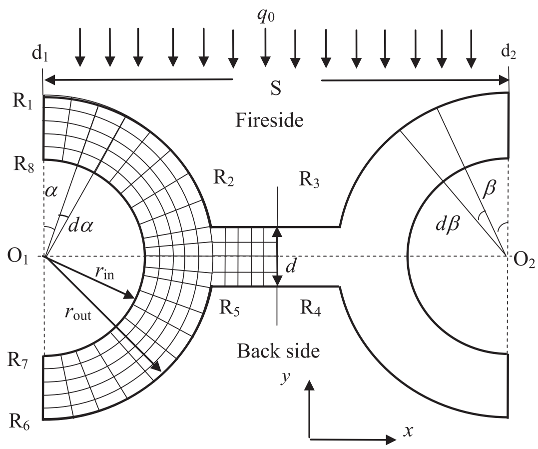

Fig. 1. Diagram of the membrane water-wall.

Wang et al. [6,7,11,12] proposed the decentralized fuzzy inference method (DFI method) based on the fuzzy logic. Their researches show that the DFI method has some advantages, such as the strong capacity of resisting disturbance to input information, good robustness and fault tolerance to inference process. The imprecise and incomplete information can be effectively used for fuzzy inference and decision-making. All these advantages can provide practical help solving the IHTP.

It is difficult to directly measure the thermal boundary conditions of boiler membrane wall, such as the fireside heat flux, temperature of water-steam mixture in water-wall tubes and heat transfer coefficient on the inner surface of membrane water-wall. While the temperature on the back of membrane water-wall can be measured. For this reason, it is a promising way to determine the thermal boundary conditions by applying the IHTP techniques based on the measured information. The DFI method is applied to solve the inverse problem related to the fireside heat flux, temperature of water–steam mixture in water-wall tubes, heat transfer coefficient on the inner surface of membrane water-wall of power plant boiler. At the same time, effect of different initial guessed thermal boundary conditions, the number of measurement points and the temperature measurement errors on the estimated results are discussed, and comparisons with the CGM are also conducted.

2. Mathematical model of membrane water-wall

The physical model of membrane water-wall is shown in Fig. 1. The heat of flame and flue gas transfers through the metal line tubes to the working fluid by convection and radiation.

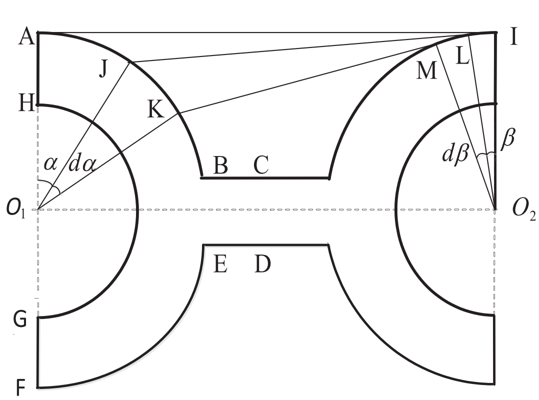

Fig. 2. Angle factor on the circles.

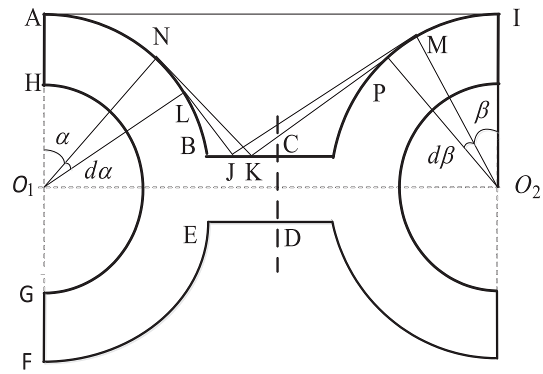

Fig. 3. Angle factor on the fins.

Due to the symmetry, half of the membrane water-wall is selected as the research object, and the heat transfer process is assumed as follows:

(1) The temperature gradient in the horizontal direction of the membrane water-wall and the fins is much larger than the temperature gradient in the height direction which is measured in the z direction and normal to the plane shown in Fig. 1. The heat flux transferred in the height direction is ignored. Thus the heat transfer process is considered as a two-dimensional one.

(2) The membrane wall heat transfer is treated as steady state under given load. The thermal conductivity of tube is constant. The temperature and convective heat transfer coefficient of working fluid are steady, and distribute uniformly along the circle direction.

(3) The heat flux q_0 transfers from the hypothetic plane d_1d_2 to the membrane water-wall.

(4) The back side of the membrane wall is covered with insulation material, and can be considered as the adiabatic surface.

Based on the above assumptions, the governing equation and boundary conditions of the membrane water-wall are:

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} = 0 \tag{1a}$$

$$-\lambda \left(\frac{\partial T}{\partial m}\right)_{\widehat{AB},BC} = q(x) \tag{1b}$$

$$-\lambda \left(\frac{\partial T}{\partial m}\right)_{\widehat{GH}} = h\left(T - T_f\right) \tag{1c}$$

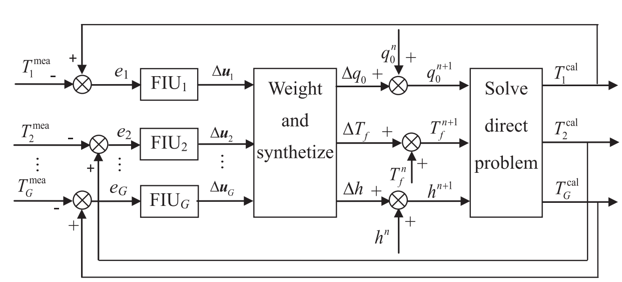

Fig. 4. Fuzzy inference system.