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Research on the three-dimensional wall temperature distribution and low-temperature corrosion of quad-sectional air preheater in larger power plant boilers

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ABSTRACT

To overall control the wall temperature of rotary quad-sectional air preheater and ensure the safety of boiler units, it is important to research its three-dimensional temperature field. Computational fluid dynamics method (CFD) is used to simulate the heat transfer performance of a 300 MW circulating fluidized bed (CFB) boiler. The temperature of rotor heating surface is defined as user-defined scalar (UDS) to solve scalar equation. Numerical results which are validated by experimental data present the essential parameters such as three-dimensional temperature, heat flux and heat transfer distribution of both working fluid and heating surface. The temperature difference between working fluid and heating surface, heat transfer quantity per unit volume are also obtained. Numerical results show that the different materials and types of heating surface will cause the differences in heat transfer performance between cold end and hot end. The temperature of working fluid are different between cold end and hot end, resulting in volume flow changing to make the scouring velocity different. That is the structural reason for the distinctions in heat transfer performance. It is concluded that low-temperature corrosion mainly occurs in the heating surface at the inlet of hot end in flue gas channel, where the metal temperature need to be kept above acid dew point so as to retard the low-temperature corrosion.

Contents

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Nomenclature

c_p	heat capacity of metal heating surface (kJ/(kg·K))
C	resistance coefficient
C_B	coefficient of heat-exchanger elements
C_L	correction factor at the inlet
C_T	coefficient considered the temperature difference between working medium and heating surface
d	equivalent diameter of heat-exchanger elements (m)
k	convective heat transfer coefficient between working fluid and heating surface (W/(m^2·K))
L	dimensionless height
n	rotation speed of rotor (r/min)
Nu	Nusselt number
Pr	Prandtl number of working medium
Re	Reynolds number of working medium
S_φ	source item of user-defined scalar φ
$S_\varnothing$	inherent source item generated by the interaction between working fluid and rotor heating surface
$S'_\varnothing$	inherent source item of motion governing equation
T	temperature difference between working fluid and heating surface (K)
u	velocity component of x axe in the Cartesian coordinate system (m/s)
v	velocity component of y axe in the Cartesian coordinate system (m/s)
v_i	velocity component of working medium in rotor heating surface (m/s)
x	coordinate value of x axe (m)
y	coordinate value of y axe (m)

Greek letters

ρ	density of flue gas or air (kg/m^3)
ρ_A	area density of heat-exchanger element (m^2/m^3)
φ	user-defined scalar
ϕ	undetermined scalar
Φ	dimensionless angle of rotation
ω	angular velocity of rotor (rad/s)
σ	porosity of cross section which depends on the heat-exchanger element of rotor heating surface at the hot and cold end
λ	heat conduction coefficient of working medium (W/(m·K))
Γ_ϕ	generalized diffusion coefficient of undetermined scalar ϕ
Δp_i	pressure drop (Pa)

1. Introduction

Air preheater is an important component of circulating fluidized bed (CFB) boiler equipment. According to operation characteristics of CFB, the pressure of primary air can be up to 25–30 kPa [1]. Therefore, primary air channel is placed between left-secondary and right-secondary air channel to effectively reduce the air leakage caused by the differential pressure between adjacent air channels, that is quad-sectional air preheater.

The thermal calculation method for traditional bi-sectional air preheater is not applicable to quad-sectional air preheater any longer [2]. The quad-sectional air preheater operates in the region where the flue gas temperature is low, that will cause the low-temperature corrosion to exist in heat exchange plate [3,4]. Zhang [5] established heat balance equation for bi-sectional air preheater by using the finite-difference method for iterative solution, but the accuracy of temperature field was still to be verified by actual project. For tri-sectional air preheater, Yan [6] and Liu [7] used the finite-volume method to make the heat transfer process more stable, and established energy conversation equation by regional discretization. However, the iterative process needed strict space step and leaded to divergent calculation easily [8]. Chi [9] installed thermocouple in the cold end of air preheater to measure the temperature variation of metal. But the installation measurement points were complex to cause the results influenced by its structure and operation easily. The solution process of three-dimensional temperature field obtained by analytical method was complicated [10], hence the numerical method was usually adopted to complement experiment and theory. In the numerical calculation, Skiepko [11] took account into the heat conduction of heating surface, flue gas and air when deduced analytical solution of heat transfer equation for bi-sectional air preheater [12]. It indicated the analytical solution which was considered heat conduction along axial direction had higher precision [13]. The influence of other parameters on the temperature distribution of heating surface, flue gas and air were researched, and experiment was compared with numerical values to testify the accuracy of numerical calculation [14]. In the meanwhile, the specific expression of heat transfer equation was gave by Ref. [14]. Wang [15–17] proposed analytical-numerical calculation model for tri-sectional air preheater, and carried out the numerical iteration to obtain the temperature field of heating surface and fluid. By assuming that the distribution of heating surface and fluid were linear along rotation and axial direction, Leng [18] solved the heat transfer differential equation by Laplace transformation to get the temperature distribution in air preheater. Gan [19–21] used Pelcet number to evaluate the importance of convection for heat transfer. For quad-sectional air preheater, only Jin [1] proposed the calculation method based on finite-difference method, but its modeling and iterative process were complicated to make the results debatable.

The low-temperature corrosion usually occurs in the area with lowest temperature of air preheater. The influencing factors of low-temperature corrosion are the amount of condensation, the concentration of sulfuric acid and the wall temperature of heating surface. Based on the above factors, the low-temperature corrosion can be prevented. The heating surface of quad-sectional air preheater is designed along the axial direction, including hot, middle and cold end. The cold end is most vulnerable to low-temperature corrosion, hence the corrosion-resistant materials are used in the cold end. Only the heating surface of cold end need to be replaced when materials changed, which can simplify the maintenance of heating surface and reduce cost effectively. In order to overall control the wall temperature of air preheater to prevent low-temperature corrosion in some position, it is impor-