Study on the Heat Transfer Computational Model of Rotary Air Preheater for SCR Denitrification Postprint

Authors: Huang Fengliang, Sun Zhijian, Li Pengcheng, process, Gu Jinfang, Hu Yacai

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Abstract

After SCR denitrification of power plant flue gas, highly viscous and corrosive ammonium bisulfate is produced, causing blockage and corrosion of the air preheater and affecting unit operation. In response to the changed operating environment of rotary air preheaters after SCR denitrification, and based on existing heat transfer model research combined with the structural characteristics of rotary air preheaters, a heat transfer calculation model applicable to air preheaters after SCR denitrification is proposed. Considering the changes in flue gas composition after SCR denitrification and the influence of temperature on physical properties, the internal temperature field of rotary air preheaters after SCR denitrification can be accurately calculated, providing a theoretical basis for the design and retrofit of rotary air preheaters in power plants equipped with SCR denitrification devices. Through case calculations for two-compartment and three-compartment rotary air preheaters before and after SCR denitrification, as well as comparison with field experimental results, it is demonstrated that the heat transfer calculation model proposed in this paper has wide applicability and high calculation accuracy.

Full Text

Title and Authors

The Investigation of Heat Transfer Model of Rotary Air Preheaters Adapted to SCR Denitrification

Fengliang Huang[1], Zhijian Sun[1], Ran Chen[1], Pengcheng Li[1], Gong Cheng[1], Jinfang Gu[2], Yacai Hu[1]
[1]Institute of Thermal Science and Power Systems, Zhejiang University, Hangzhou 310027, Zhejiang Province, China

[2]Zhejiang Kaier New Materials Corporation, Jinhua 321031, Zhejiang Province, China

Abstract

After SCR denitrification in thermal power plants, highly viscous and corrosive ammonium bisulfate (NH HSO) is generated, causing blockage and corrosion in rotary air preheaters and affecting unit operation. Addressing the changed operating environment of rotary air preheaters after SCR denitrification, this paper proposes a heat transfer calculation model for air preheaters applicable to post-SCR conditions, building upon existing heat transfer model research and incorporating the structural characteristics of rotary air preheaters. By considering changes in flue gas composition after SCR denitrification and the influence of temperature on physical properties, the model can accurately calculate the internal temperature field of rotary air preheaters after SCR denitrification, providing a theoretical basis for the design and retrofit of rotary air preheaters in power plants equipped with SCR denitrification systems. Example calculations for bi-sector and tri-sector rotary air preheaters before and after SCR denitrification, along with comparisons with field experimental results, demonstrate that the proposed heat transfer calculation model offers broad applicability and high computational accuracy.

Keywords: rotary air preheater; heat transfer model; SCR denitrification; temperature field; deposition

Introduction

In September 2011, China' s Ministry of Environmental Protection issued the "Emission Standard of Air Pollutants for Thermal Power Plants" [1], establishing denitrification requirements stricter than the current EU emission limits. Denitrification retrofitting has consequently become a critical component of power plant upgrades. The mainstream technology employed is Selective Catalytic Reduction (SCR), which generates byproduct SO that chemically reacts with ammonia to form highly viscous ammonium bisulfate. This compound solidifies on heat transfer elements within the air preheater at temperatures between 180-230°C, simultaneously causing dust deposition in flue gas and resulting in severe ash blockage and corrosion. Without effective countermeasures, excessive resistance increase and sudden heat transfer deterioration in the air preheater can lead to boiler shutdown within a short period [2]. Retrofitting existing rotary air preheaters therefore becomes necessary, focusing primarily on replacing corrosion-resistant heat transfer elements and adopting appropriate soot blowing methods [3].

After SCR denitrification, ammonium bisulfate deposition occurs mainly in the original middle and low-temperature sections of the air preheater. To mitigate ash blockage and corrosion of heat transfer elements, conventional retrofitting approaches replace the middle and low-temperature section elements with corrosion-resistant and easily cleanable enamel-coated elements. The selection of enamel element height and corrugation pattern depends heavily on accurate calculation of the internal temperature field after SCR denitrification. Additionally, power plant SCR denitrification involves injecting ammonia-producing substances such as ammonia water, liquid ammonia, or urea into the flue gas, relying on the reaction between NH and NOx to reduce them to nitrogen [4]. The addition of nitrogen-containing substances alters flue gas composition, which must be considered when calculating the air preheater temperature field.

Currently, no literature in China addresses temperature calculation models for rotary air preheaters after SCR denitrification; existing studies [5]-[12] focus on conventional rotary air preheaters. This paper proposes a heat transfer calculation model for rotary air preheaters applicable to post-SCR operating conditions. Considering changes in flue gas composition and temperature effects on physical properties, the model can accurately determine the internal temperature field of rotary air preheaters after SCR denitrification, providing a basis for selecting cold and hot section heights in retrofit projects.

1.1 Heat Transfer Mathematical Model

For a rotary air preheater in steady-state operation, the energy balance relationships between fluids (flue gas, secondary air, and primary air) and heat transfer elements are expressed as follows [8]:

Heat transfer elements:

$$ahtcmnaht$$

In equations (1) and (2), c_f and c_m represent the specific heat of fluid and heat transfer elements, respectively; w_f and ρ_f denote fluid velocity and density; α is the fluid flow area per unit angle β, and α_f is the heat transfer coefficient between fluid and heat transfer elements; h and m_m are the heat transfer area and heating surface mass per unit angle β and unit height l, respectively; n is the rotor’ s angular rotation speed; t_f and t_m are the temperatures of fluid and heat transfer elements, respectively.

In equations (1) and (2), t_f and t_m can be considered as the average temperatures of heat transfer elements and fluid. Discretizing the energy balance equations (1) and (2) yields:

$$cmn$$

From equations (3)-(6), we obtain:

$$(B + 2A)A + B + 2(B + 2A)A + B + 2$$

In equations (5) and (6), the mass flow rate of fluid participating in heat exchange per unit angle β is represented by $j_{fw}\rho_f\alpha$, denoted as j_{fq} (kg/s). The heat transfer elements participating in heat exchange through continuous rotor rotation are treated as a fluid flow, where $i_{mm}n$ represents the mass flow rate of heat transfer elements per unit angle β and unit height l, denoted as i_{mq} (kg/s).

1.2 Model Solution

The heat transfer coefficient between fluid and heat transfer elements (j_{fc}), the specific heat of heat transfer elements (i_{fw}), fluid density ($j_{f\alpha}$), and fluid properties (mc) are all temperature-dependent functions (fluid ρ_f is temperature-dependent, but the product of density and velocity is temperature-independent). However, for micro-elements within the rotary air preheater, fluid and heat transfer element temperatures vary only slightly, making the discretized model applicable. By dividing the air preheater into grids along both axial and circumferential directions, each grid cell can be solved as a micro-element to obtain the steady-state internal temperature field.

As shown in [Figure 1: see original paper], the computational grid integrates flue gas and air connections. Based on literature [13][15], this paper sequentially determines property correlations for flue gas and air (specific heat, viscosity, etc.), heat transfer element properties, and heat transfer coefficients between fluid and elements as functions of temperature and flow velocity. Properties within each grid are determined using the arithmetic mean temperature of inlet and outlet values.

According to the steady-state heat transfer model for rotary air preheater micro-elements, once inlet fluid temperatures, heat transfer element temperatures, flow rates, and grid dimensions are specified, the outlet temperatures are determined.

The solution process involves first assuming the temperature of the heat transfer element at the leftmost end of the flue gas side. The model then calculates outlet temperatures for each fluid and the temperature of the heat transfer element at the rightmost end of the primary air side. Based on the structural working principle of the air preheater, the heat transfer element should transfer from the primary air side to the flue gas side, meaning the leftmost flue gas side element temperature should equal the rightmost primary air side element temperature.

The iterative relationship thus assigns the calculated rightmost primary air side element temperature to the leftmost flue gas side element repeatedly until the absolute difference between these temperatures falls below the convergence criterion.

Compared with the analytical model proposed in literature [8], this model eliminates the Laplace and inverse Laplace transforms required for direct analytical solution, cleverly simplifying the calculation process by incorporating the structural working principle of the air preheater. Compared with literature [11], this model employs grid division, eliminating the need for complex difference methods while maintaining computational accuracy and simplifying the model.

For multi-layer structural retrofitting calculations of air preheaters after SCR denitrification, one only needs to incorporate the correlation expressions for heat transfer coefficients of each corrugated plate layer as functions of temperature and flow velocity into the calculation model. Using the changed flue gas composition after passing through the denitrification system as input data for the calculation program yields the internal temperature field of the rotary heat exchanger.

2. Flue Gas Composition Changes After SCR Denitrification

Under catalyst action, NH selectively catalytically reduces NOx in flue gas through the following reactions:

$$4NH_4NOO_4N6HO3N6HO$$

$$4NH_2NOO_4NH_6NO_5N6HO$$

$$8NH_6NO_7N12HO$$

These represent overall reaction equations; the actual chemical reactions proceed through intermediate products [16]. Under typical SCR reaction conditions (NH /NO molar ratio 1, O volume fraction $> 2\%$, reaction temperature $<$ 400°C), reaction (9) is dominant because 90%-95% of NOx exists as NO. Therefore, after passing through the SCR denitrification unit, NOx in flue gas converts to N , and this composition change must be considered in air preheater heat transfer calculations.

Additionally, due to SO oxidation, SO concentration in flue gas increases significantly, particularly for plants burning high-sulfur coal. Typically, SO concentration nearly doubles after SCR treatment [17].

When calculating heat transfer for rotary air preheaters after SCR denitrification, this paper determines flue gas composition based on actual coal type and excess air coefficient. According to the structural dimensions of the rotary air preheater and flue gas composition, the internal temperature field can be precisely calculated. In existing power plant retrofit projects, the temperature at the junction between cold and hot sections is typically maintained at least 10°C above the ammonium bisulfate deposition temperature.

To verify whether the selection of heat transfer element heights is appropriate, determining the ammonium bisulfate deposition temperature is crucial. NH HSO formation is influenced by multiple factors including SO and NH concentrations in flue gas and unit operating load, but its deposition temperature is primarily affected by the concentration product of SO and NH within the air preheater [18].

[Figure 2: see original paper] shows the relationship between NH and SO concentration product and ammonium bisulfate deposition temperature. The empirical correlation is:

$$NH_4HSO_4 : 11.45\,\lg(= 0.4059[\lg()]^2)192.29$$

As shown in Figure 2, ammonium bisulfate deposition temperature decreases with decreasing concentration product of NH and SO . The NH concentration in the air preheater is primarily determined by ammonia slip rate in the SCR denitrification unit, which power plants can typically maintain below 3 mg/L. Therefore, determining SO concentration is essential for establishing the deposition temperature. SO concentration in flue gas depends mainly on coal sulfur content, while some SO converts to SO within the SCR unit due to catalytic action. However, this conversion is significantly affected by catalyst type and reaction temperature, so actual calculations can only define SO concentration within a range to determine the ammonium bisulfate deposition temperature.

4.1 Tri-Sector Preheater Calculation and Analysis

Due to implementation of the Standard [1], a 600 MW coal-fired power plant in Zhejiang underwent SCR denitrification retrofitting, and its associated tri-sector rotary air preheater (model 2-32VI(T)-2080SMRC) was correspondingly modified. The retrofit removed the original medium-temperature heat transfer elements, increased the cold section height, and adopted corrosion-resistant enamel-coated heat transfer elements.

compares the structural parameters before and after air preheater transformation. Using the structural parameters of this tri-sector rotary air preheater before and after denitrification retrofitting, along with inlet parameters for flue gas and air and leakage coefficients under design conditions (Boiler Maximum Continuous Rate, BMCR), Turbine Rated Load (BRL), and 75% BRL, this paper performed verification calculations using the proposed model. Results are presented in and , where design values are from comprehensive boiler thermal calculations and calculated values are obtained using the proposed model.

For the pre-retrofit rotary air preheater, shows that the maximum deviation between calculated and design values is less than 1% (BMCR condition, primary air outlet temperature). For the post-retrofit air preheater, demonstrates maximum deviations of less than 1%, confirming the accuracy of the proposed method for post-SCR tri-sector rotary air preheater calculations. The method simultaneously yields temperature distributions for internal fluids (flue gas, primary and secondary air) and heat transfer elements in a single computation.

[Figure 3: see original paper] illustrates the circumferential temperature distribution of heat transfer elements under BMCR design conditions after SCR denitrification. Here, h_{out} represents the temperature of heat transfer elements at the hot section outlet (air preheater top surface), *mid* denotes the temperature at the junction between cold and hot sections after retrofitting, and c_{out} indicates the temperature at the cold section outlet (air preheater bottom surface).

The temperature distribution shows gradual increase from 0-160°, gradual decrease from 180-290°, and continued but slowing decrease from 310-340°, consistent with tri-sector rotary air preheater structure. For this coal type, post-SCR SO concentration ranges from 1.58-2.37 L/L and NH concentration is 3 L/L. According to Figure 2, the NH HSO deposition temperature in this range is 190-200°C. Figure 3 shows the minimum temperature of hot section heat transfer elements is 210°C, meaning the hot section corrugated plate temperature exceeds the NH HSO deposition temperature. After structural retrofitting with enamel-coated corrugated plates in the cold section, low-temperature corrosion is mitigated, and the successful operation of this post-SCR rotary air preheater validates the heat transfer design calculations.

For design and retrofit of post-SCR air preheaters, the key focus is determining heat transfer element height and corrugation pattern. The above example demonstrates that the proposed heat transfer model can accurately determine the minimum temperature in the ammonium bisulfate deposition zone, providing theoretical guidance for selecting heat transfer element height and corrugation pattern.

4.2 Field Experiment and Calculation Comparison

To verify the operational performance of the post-SCR air preheater, the authors conducted field tests at the power plant. Under BMCR design conditions, synchronous testing methods were employed to measure inlet and outlet temperatures of flue gas and primary/secondary air. Using real-time flue gas flow rates, secondary air flow, primary air flow, and leakage coefficients provided by the plant, calculations were performed using the proposed model. Results are presented in .

compares calculated results with field test data. The close agreement between calculated and experimental values confirms the accuracy of the proposed method for temperature calculations in post-SCR air preheaters.

5. Conclusions

After SCR denitrification in power plants, highly viscous and corrosive ammonium bisulfate causes air preheater blockage and corrosion, affecting unit operation. This paper presents the following contributions:

1) Addressing the changed operating environment of rotary air preheaters after SCR denitrification, a heat transfer calculation model applicable to post-SCR conditions is proposed, building upon existing heat transfer research and incorporating the structural characteristics of rotary air

preheaters.

2) By considering changes in flue gas composition after SCR denitrification and temperature effects on physical properties, the model accurately determines not only outlet fluid temperatures but also the temperature fields of internal fluids (flue gas, secondary air, and primary air) and heat transfer elements. This provides theoretical guidance for retrofitting rotary air preheaters after SCR denitrification, enabling accurate and rapid selection of heat transfer element height, corrugation pattern, and rotor speed.
3) An empirical correlation between NH HSO deposition temperature and the concentration product of SO and NH in flue gas is provided, offering reference for determining heat transfer element heights after retrofitting.
4) Example calculations for tri-sector rotary air preheaters before and after SCR denitrification, along with field experiment comparisons, demonstrate that the proposed heat transfer calculation model offers broad applicability and high computational accuracy.

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