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Technical Note

Sulfuric acid deposition characteristics of H-type finned tube bank with 10 rows

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ABSTRACT

The deposition rate and condensate mass fraction of sulfuric acid on heat exchanger surfaces play a decisive role on the local low-temperature corrosion of heat exchangers. Based on the prediction model of acid deposition, a three-dimensional numerical simulation was performed for acid deposition characteristics of H-type finned tube bank with 10 rows. The effect of six geometric parameters (spanwise tube pitch, longitudinal tube pitch, fin height, fin pitch, fin thickness and slit width) and Reynolds number are examined. It can be observed that the fin thickness and Reynolds number have the most significant effect on acid deposition. A large fin thickness will greatly increase the risks of fin corrosion, and it is not recommended for practical use. According to the calculation results, a correlation of *Sh* number of sulfuric acid vs fin geometries for the 10-row tube bundle is presented.

1. Introduction

Fin and tube heat exchangers are widely used in the waste heat recovery systems due to the small temperature difference in the heat exchangers and able to save volume of heat exchangers. So far, extensive researches have been reported on the heat transfer enhancement for the fin-side of the fin and tube heat exchangers, and various kind of fin-and-tube heat exchangers have been developed to satisfy industry requirements, such as wave fin, louver fin, slit fin, etc. Beecher and Fangan [1] tested 27 fin-and-tube heat exchangers with 21 of them having wavy-fin geometries. Wang et al. [2] tested 49 samples of louvered fin-and-tube heat exchangers with different geometrical parameters and developed their own correlations. Yun and Lee [3] experimentally investigated three kinds of slit fins and an optimal fin shape for home air conditioners was recommended. Kang and Kim [4] experimentally studied the effect of strip location of X-arrangement and found that a hybrid fin with plain fin at first row and strip fin at rear row was more effective to enhance heat transfer than that of whole strip fin at the same fan power. Han et al. [5] numerically investigated the fluid flow and heat transfer characteristics of finned tube heat exchangers by examining different oval and circular tubes. The above-mentioned studies only focus on the fluid flow and heat transfer performance of the fins, and the developed fins were employed on the clean operating condition.

In order to utilize the waste heat from the industrial gas, the fins are expected to very complicated environments, like corrosive gas and dust particles etc. H-type finned tube has excellent anti-wear and anti-fouling performance, which is very beneficial for the application in the waste recovery system. So far, many scholars have investigated the heat transfer characteristics of H-type fins. Zhang et al. [6] numerically investigated the air-side performance of H-type finned tubes. The effects of geometry parameters on the fluid flow and heat transfer performance were explored. Yu et al. [7] performed experimental tests to study the heat transfer and resistance characteristics at air-side of single or double H-type finned tube banks. Recently, Jin et al. [8] systematically investigated the effects of geometric parameters on heat transfer and pressure drop characteristics of H-type finned tube. Based on the calculation, correlations of *Nu* and *Eu* for the 10-row tube bundle were presented.

With the further improvement of waste heat recovery system efficiency, the reduction of exhaust temperature lead to serious low-temperature corrosion due to the condensation of acidic vapor on the heat exchanger surface. Some researchers sought to predict the condensation of sulfuric acid by using vapor–liquid equilibrium models [9,10]. In 2004, Valencia [11] performed a numerical simulation for the condensation of nitric acid, sulfuric acid and water vapor in the presence of air on a vertical water-cooled plate. Jin et al. [12] simulated the condensation of acid vapor in a circular tube channel. However, the dew points of the species were treated as constants in their study, and the model was simplified away from the actual geometry. In view of this, Han et al. [13] developed

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a new coupling method to compute the sulfuric acid condensation, and investigated the condensation characteristics on the H-type fin surface. The effects of the operating conditions on the condensation rate of sulfuric acid have also been considered.

In this study, a numerical study of sulfuric acid condensation on H-type finned tube surfaces is performed. The numerical method of Han's is employed in current simulation. The effects of seven parameters: fin thickness, slit width, fin height, fin pitch, spanwise tube pitch, longitudinal tube pitch and Reynolds number on condensation rate and acidic solution mass fraction are examined.

2. Model descriptions

2.1. Physical model

Fig. 1(a) is a schematic of the H-type fin heat exchanger with 10-rows tubes along the flow direction. The top and side views of the computational domain are shown in Fig. 1(b) and (c). Due to the geometry character of periodic and symmetric, the region sketched by dashed lines is selected as the computational domain, and the fin is located at the center of the flow domain in the *y*-direction. The geometry parameters of the heat exchanger are listed as follows: the tube outside diameter is $D_c = 38$ mm, the spanwise tube pitch is $S_1 = 108$ mm, the longitudinal tube pitch is $S_2 = 120$ mm, the fin height H is 73.4 mm, the fin pitch F_P is 16.87 mm, the fin thickness F_t is 2.5 mm, and the slit width W is 15 mm.

2.2. Governing equations and boundary conditions

The specific application in this investigation is a three-dimensional fluid flow with heat and mass transfer over the fin surface. The fin temperature distribution will be determined by solving the coupled problem of heat conduction within the fin and the heat convection between the fin surface and the fluid flow. The fluid is assumed to be incompressible and steady. The governing equations for continuity, momentum, species and energy can be found in many references and will not be presented here for simplicity. The RNG k–ε turbulence model is employed to consider the effect of turbulence flow.

Considering that the governing equations are elliptic, boundary conditions are required for all of the boundaries of the computational domain. At the inlet, a velocity boundary is imposed, in which the uniform velocity, temperature and species contents are defined. Symmetry conditions are imposed on the front and back while periodic conditions are imposed on the top and bottom of the domain. An outflow condition is set at the outlet plane. The tube walls are defined as a constant wall temperature, and a no slip condition is applied to the fin and tube surfaces. For turbulent flow, the turbulent intensity suggested in FLUENT User's Manual, $I = 0.16Re^{-1/8}$, is used in this study.

For the component transport and condensation of sulfuric acid and water vapor, the vapor–liquid equilibrium was applied to compute the species boundary conditions, which can expressed as follows.

$$\ln p_i = a_iA + b_iB + c_iC + \Delta H_i^v D + \Delta S_i^v E + \overline{C}_{pi}^l F + \overline{L}_i^l G + \alpha_i H + \ln \bar{a}_i(298) \tag{1}$$

The condensation rate of sulfuric acid and water vapor at the wall surface can be expressed as:

$$m_i = -\left(\rho D_{i,\mathrm{eff}} + \frac{\mu_t}{Sc_t}\right)\nabla y_i \tag{2}$$

To facilitate the statistics of the calculation results, the average condensation rate in the fin surface can be written as:

$$N_a = \frac{\sum m_i dA_i}{M_{H_2SO_4}\sum dA_i} \tag{3}$$

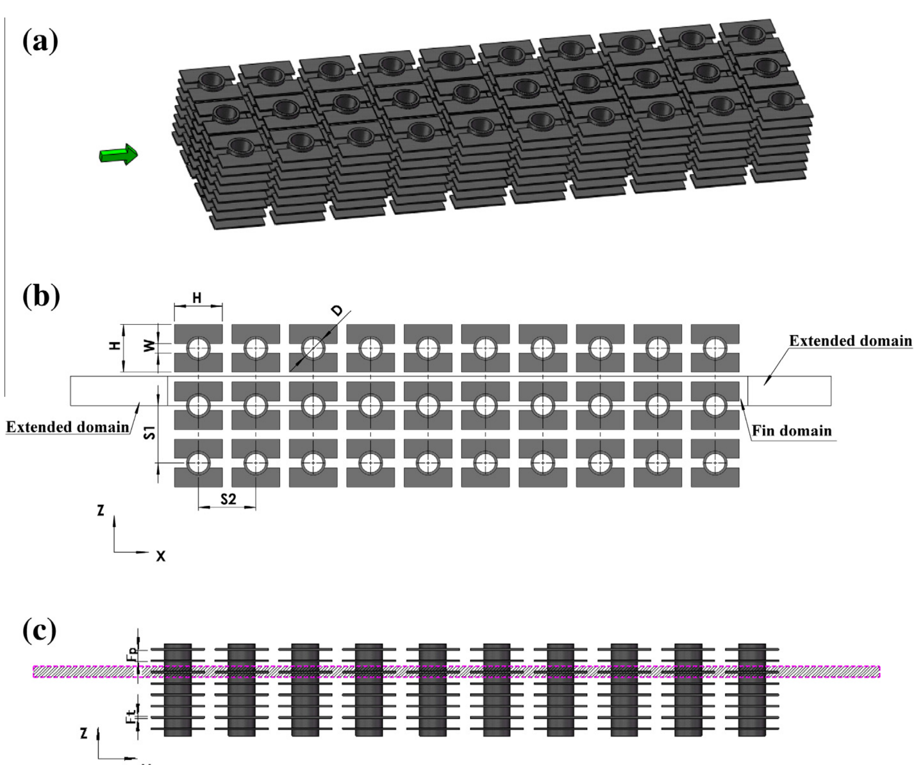

Fig. 1. Schematic configuration of an H-type finned tube heat transfer surface.