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Research Paper

An experimental study and numerical investigation on fluidized defouling of non-clean water heat exchanger wall

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HIGHLIGHTS

- A set of defouling system using sand as defouling particles was designed.
- The sand has been realized fluidization and recycling.
- The defouling system can effectively remove dirt and rust on heat exchanger wall.
- The optimum parameters were researched of the defouling system.

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ABSTRACT

The solid-liquid fluidized defouling technology was applied to prevent and remove fouling of non-clean water heat exchanger. The simulation results show that with the increase of flow rate the maximum erosion rate firstly decreases and then increases, and the maximum erosion rate increases quickly with the increase of sand total flow rate. The shear stress on the pipe wall is high enough to remove fouling. Meanwhile a set of defouling system using sand as defouling particles was established in this paper. The experimental results show that the sand with the diameter of 2 mm could be fluidized if the non-clean water flow rate reaches 0.87 m/s. The recycling efficiency of the sand was almost 95%. The fluidized defouling technology could effectively remove dirt and rust on non-clean water heat exchanger wall. In addition, the heat transfer coefficient increased by 25.6% after the defouling system continued to run for 24 h when the sand particle volume fraction was 6% compared with fouled heat exchanger. In order to reduce erosion and assure the defouling efficiency, the optimum parameters were set as follows: the volume fraction of sand was 4% and the flow rate was 0.87 m/s.

1. Introduction

Use of non-clean water source heat pump has significant benefits of energy saving and environmental protection. However, fouling is one of the main problems of heat transfer which can be described as the accumulation on the heat exchanger tubes, the fouling problem in heat exchanger has not been solved effectively [1]. The fouling deposits increases overall thermal resistance, which may result in problems of deterioration of the heat performance, corrosion of heat exchanger wall, obstacles to fluid flow, etc., leading to an increase in operating costs. The fouling deposits on the heat exchanging wall further affects the average temperature and heat transfer coefficient [2,3]. Therefore, how to prevent fouling on the heat-exchanger wall is an imperative problem.

To remove the fouling effectively, it is therefore necessary to predict the type, intensity, growth characteristic and behaviors of fouling. A neural network based fouling model has been developed using historical plant operating data by Radhakrishnan et al. [4], they found that the defouling model is adequately accurate, which the predictive model can be used to develop a preventive maintenance scheduling tool. Arsenyeva et al. [5] described the asymptotic behaviour of water fouling, the fouling deposition rate and the fouling removal rate. Bai et al. [6] conducted an experimental investigation on the dynamic growth characteristics of surface water fouling and its main components. They had also founded a fouling prediction model, which was developed and validated based on elaborating with fouling principle under specified water conditions. The deposition rates of fouling on different metal materials may be different. Besides, the fouling deposition on four different metal surfaces (copper, aluminium, brass, and stainless steel) was investigated. Kazi et al. [7] found the fouling deposition

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Nomenclature

DPM	discrete phase model	G_T	production term of turbulent kinetic energy caused by the flow of the main body
ρ	density of solid liquid two phase flow, kg/m^3	ψ	modifying factor of Prandtl number
ρ_1	fluid density, kg/m^3	σ_t	turbulent prandtl number, 0.9
Γ	diffusion coefficient	C_μ	constant, 0.09
u	velocity m/s	C_1	constant, 1.14
μ_1	the turbulent viscosity coefficient, Pa·s	C_2	constant, 1.92
α_1	voidage	σ_k	constant, 1.92
$f_{dx}\, f_{dy}$	drag force caused by solid-liquid two-phase flow in direction of X, Y	σ_ε	constant, 1.92
G_p	turbulent generated term of sand		

raise with the increasing thermal conductivity of the metal, or the total surface energy. Moreover, the fouling behaviors might be affected by different factors including fluid velocity, hardness, alkalinity, solution temperature, and wall temperature. Zhenhua et al. [8] conducted an experiment to investigate the fouling process of calcium carbonate on the heat transfer surface. The experimental result showed the fouling rate and asymptotic fouling resistance increased and the induction periods were shortened with decreasing fluid velocity, hardness, alkalinity, solution temperature and increasing heat transfer surface temperature, which has certain guidance for us to prevent fouling deposition. The existence of fouling will inevitably lead to changing of heat transfer coefficient. Experimental measurement of fouling resistance in the heat exchanger was investigated by Milanovic et al. [9]. They observed the change in fouling resistance was a linear function of time, which is important to design certain equipment to defoul based on the changes of fouling resistance.

In order to realize the sustainable and efficient heat transfer and conversion, it is necessary to overcome the fouling problem, some of the articles recently published concern addition and surface treatment. The mechanisms of adhesion, available literature about surface effects on deposit formation, as well as available technologies to produce low-fouling surfaces were researched by Zhao and Muller-Steinhagen [10]. Kazi et al. [11] found the addition of gum arabic additive could be designed aid for economic and enhancement of heat exchanger performance. On the other hand, in industry, the cleaning methods of non-clean water heat exchanger are mainly based on batch cleaning after machine stops. There are huge investments of manpower and materials or damage of heat exchange equipment. Online fluidization defouling technology has multiple functions of anti-scaling and heat transfer enhancement, which has the advantages of non-pollution, small investment and online cleaning [12–14]. Shen et al. [15] developed a novel Dry-Expansion Shell-and-Tube Evaporator (DESTE) with a de-fouling function. The evaporator performance was experimentally and numerically evaluated. However, it is different from the defouling system that will be described below.

In this paper, the fluidized defouling technology was studied by experimental and numerical investigation. Using sands as defouling particles. The erosion rate of pipe wall and shearing stress was investigated by numerical methods. In addition, an industrial non-clean water heat exchanger was chosen to be experimental defouling objects. Combined experiment, the optimal working parameters and defouling ability of fluidized defouling were discussed. The experimental results show that the online fluidization defouling technology can effectively solve the non-clean water heat exchanger fouling problem. The technology is simple and feasible, and has no pollution to the environment.

2. Numerical investigation on solid-liquid two-phase flow of heat exchanger pipe

2.1. The physical mode

In order to simplify analysis processing, the physical mode is shown in Fig. 1, it is a heat exchanger pipe with inner diameter of 100 mm and 1 m in length. It has inlet and outlet, the import is also the entry of the particle injection. The particle property is listed in Table 1.

2.2. Mathematical model

This paper mainly uses sand as material particles, in a single control equation on the basis of adding sand to liquid phase flow and heat transfer of the original phase correction, the mathematical model is shown as follow:

Continuity equation:

$$div(\alpha_1 u) = 0 \tag{1}$$

Momentum equation:

$$div(\alpha_1 \rho u \phi) = div(\alpha_1 \Gamma grad\phi) + S \tag{2}$$

Energy equation:

$$div(\rho u T) = div(\alpha_1 \psi \Gamma_T gradT) + S \tag{3}$$

where ρ is density of solid liquid two phase flow, $\rho = \alpha\rho_s + (1 - \alpha)\rho_l$, ρ_s is density of particles, ρ_l is density of fluid, α is the volume fraction of particles. ϕ, Γ, S are shown in Table 2.

Fig. 1. The physical model.

Table 1
Type and property of particles used in the experiment.

Number	Type of particle	Diameter of particle/mm	Density of the particle/kg/m^3
1	Sand	1.5	1500