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Study on performance of wave-plate mist eliminator with porous foam layer as enhanced structure. Part II: Experiments

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HIGHLIGHTS

- A wave-plate mist eliminator with porous foam as enhanced structure is designed.
- Separation efficiency and pressure drop are investigated experimentally.
- Validity of earlier simulation is verified by comparing with experiment results.
- Phenomenon of the suppression for re-entrainment by foam layer is discussed.

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ABSTRACT

In this paper, a new kind of wave-plate mist eliminator using open-celled porous silicon carbide foam layers as enhanced structure has been firstly proposed. The effects of foam layer geometry parameters (foam layer thickness, porosity, PPI) on droplet performance (separation efficiency and pressure drop) were experimentally investigated. Re-entrainment mechanism influenced by flooding state in the foam layer was also discussed. Downstream droplet diameter distribution under the re-entrainment conditions were also investigated by color-developing method. The results show that the sample with smaller foam pore size has larger volume mean diameter of secondary droplets in the outflow, due to its weaker liquid drainage ability. Comparisons between the experiment and our earlier numerical simulation demonstrate the average relative errors of the separation efficiency and the pressure drop are within 10%, meanwhile trends relating demister performance to foam geometry parameters are the same between the two sets of results, indicating the validity of the simulation method. In addition, two empirical correlations were obtained by fitting the experimental data, which can be used for predicting separation efficiency and pressure drop in the selected experiment conditions.

1. Introduction

Wave-plate mist eliminators have the advantages of high processing capacity and low flooding tendency, making them widely used in chemical industry processes with the circumstance of large gas flow or liquid load. For example, in seawater desalination they are used to recover valuable products, or in natural gas industry they are installed to increase the purity of the gas stream. Wave-plate eliminators are also key equipment in Wet Flue Gas Desulfurization (WFGD) System of the coal-fired power plants, functioning as slurry and particulate separators to prevent downstream equipment corrosion or pollutant discharge (Wang et al., 2008a). In response to the severe air pollution in north China, Chinese Ministry of Environmental Protection revised the national standard of *Emission Standard of Air Pollutants for Thermal Power Plants* (GB13223-2011) in 2011. In order to adapt the increasingly stringent air pollution discharge standard, large amounts of coal-fired power plants have reconstructed their WFGD system to integrate the function of desulphurization and dust remove. Therefore, there is an urgent need of mist eliminators with excellent performance, namely low pressure drop, high separation efficiency and large critical air velocity.

Investigation on mist eliminator performance usually has two acknowledged methods, namely experiment and numerical simulation. Although the numerical simulation method has the advantages of time and expense saving, the importance of the experiment still cannot be neglected since it reflects real service condition. Most of the earlier researches adopted experimental

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Nomenclature

d	equivalent unit cell diameter d in Eq. (5), mm
d_p	pore diameter of foam, mm
d_s	strut diameter, mm
d_t	diameter of the sampling tube inlet, m
$D_{(3,2)}$	droplet surface mean diameter, mm
$D_{(4,3)}$	droplet volume mean diameter, mm
D_{50}	droplet median diameters, mm
Eu	Euler number, dimensionless
h	characteristic film thickness, mm
M	total mass of the droplet collecting part, g
n	foam thickness, mm
PPI	pores per liner inch
Q_g	gas flux, $m^3\ s^{-1}$
Re	Reynolds number, dimensionless
S	plate spacing, m
S_V	surface-to-volume ratio, mm^{-1}
u	velocity, $m\ s^{-1}$
V	strut volume of foam, mm^3
V_0	total volume of foam, mm^3
We	Weber number, dimensionless
Δp	pressure drop, Pa

Greek symbols

ε	real porosity of foam
σ	surface tension coefficient, $N\ m^{-1}$
η	separation efficiency
ρ	density, $kg\ m^{-3}$
δ	average relative error
χ	foam tortuosity in Eqs. (5-7)

Subscripts

g	gas
in	inlet
p	foam pore
s	foam strut
f	liquid film
T	sampling tube

Abbreviations

WFGD	Wet Flue Gas Desulfurization

method to investigate the overall separation efficiency of the demisters. As early as 1950, an experimental facility had been built to test the effectiveness of various eliminators by Chilton (1952). This research revealed that the demister consists of stagger arranged wooden slats with 2.75 in. channel width and 120°turning angle had favorable droplet mass removal efficiency about 95%. Partly because the warm and damp environment in cooling tower greatly reduces the service life of the wooden demister, asbestos-cement demister was developed as a substitute in the later 1960s (Gardner and Lowe, 1974). Foster et al. (1974) investigated the performances of wooden lath and the corrugated asbestos-cement demisters. Their research gave a theoretical analysis about the relationship between the overall separation efficiency and the turbulence effect. Visualization photography method was also adopted to define the separation points and show the wake region shapes. Wang et al. (2008b) experimentally studied the effects of operating conditions and demister's geometry on overall separation efficiency and pressure drop.

Grade removal efficiency is another important index which can reveal the demister's removal ability for tiny droplets in specific diameter ranges. Earlier investigations usually combined the color-developing method and the microphotography counting method to evaluate the grade removal efficiency (Martin and Barber, 1974; Ushiki et al., 1982). Lately, it can be deduced by testing the droplet size distribution using laser interferometer (Koopman et al., 2014; Layton et al., 1997; Monat et al., 1986; Verlaan, 1991).

The effect of demister geometry parameters on pressure drop was experimentally studied by Banitabaei et al. (2012). Dimensional analysis demonstrates that the ratio of place spacing to bend wavelength equal to 0.24 gave the minimum pressure drop coefficient. Jøsang and Melaaen (2000) experimentally investigated the air velocity distribution in the demister channel by using Laser Doppler Anemometry.

Re-entrainment also greatly influences the performance of wave-plate mist eliminator at high air velocity. Theoretical analyses on re-entrainment mechanism have been conducted by Jøsang (2002) and Verlaan (1991), respectively. Azzopardi and Sanaullah (2002) experimentally studied re-entrainment in horizontal wave-plate separators by using grey scale image analysis. In their research, critical Weber number for inception of re-entrainment was also deduced according to the selected vane geometry.

In the WFGD system of coal-fired power plant, the in use mist eliminators still have the problem of insufficient removing ability for tiny droplets. These unremoved tiny droplets combine with gypsum slurry might be emitted into the atmosphere to produce the gypsum rain. In order to solve this existing problem, we have proposed a wave-plate mist eliminator using porous foam layers as enhanced structures. Such space grid structure with three dimensional network provides more interception points for the droplets, meanwhile, its open-cell structure also has favorable penetrability for gas phase. These characteristics make the porous foam a potential enhanced structure is applicable to the working condition of high liquid/gas ratio. In this article, we fabricated wave-plate mist eliminators with porous foam enhanced structure according to the earlier design in our simulation research. The effects of the foam layer geometry parameters (foam thickness, n; volumetric porosity, ε; pores per linear inch, PPI) on demisters' performance (separation efficiency η and pressure drop Δp) were verified by conducting a series hydrodynamic experiments. In addition, the re-entrainment phenomenon and the influential factors on the critical air velocity (the highest permitted velocity without re-entrainment) were also analyzed.

2. Experimental details

2.1. Experimental apparatus and procedure

The sketch of the experiment apparatus was depicted in Fig. 1. The experimental apparatus was designed and built at the Institute of Metal Research Chinese Academy of Sciences. It was set up as a vertical counter-current tower with total three parts of atmospheric air duct, circulating water system and sampling/measuring system. The atmospheric air duct with dimension of 250 mm × 250 mm square section and 3250 mm total height was mainly fabricated from transparent polymethyl methacrylate material to assure visually accessible. Guide plates were arranged to homogenize the flow field at the inlet of the vertical part of the duct. Demisters used in the experiments were placed in the