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Experimental and numerical evaluation of the performance of a novel compound demister

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HIGHLIGHTS

- A novel compound demister with some advantages was proposed.
- The performance was evaluated by experimental and numerical methods.
- At low gas velocities or for small droplets, the compound demister is superior to the wave-plate demister.
- At high gas velocities, the compound demister shows higher resistance to droplet re-entrainment.

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ABSTRACT

A novel compound demister that combines an upstream tube bank and downstream wave plates was proposed in this work for application in multistage flash (MSF) desalination process. Its performance was evaluated by experimental and numerical methods. Compared with the individual tube-bank and wave-plate demisters, the compound demister is found to have the highest separation efficiency (>95%) with much less fluctuation for a wide range of gas velocities. At low gas velocities (≤4 m/s) or for removing small droplets (<20 μm), the separation efficiency of the compound demister is much higher than that of the wave-plate demister mainly because of the large separation capability of the tube bank. At high gas velocities (>4 m/s), the compound demister shows higher resistance to droplet re-entrainment that occurs at inlet gas velocity of approximately 7 m/s compared with the tube-bank demister. This is due to the compensation from the wave plates in the compound demister that separate secondary droplets generated by tubes. The compound demister possesses higher dry pressure drops than either the tube-bank or wave-plate demister, but is acceptable for industrial application. All these advantages make the compound demister a promising candidate for droplet removal in the desalination process.

1. Introduction

Desalination is one of the major processes to generate fresh water for various daily human usages and industrial applications, requiring different levels of quality and quantity [1,2]. Among the various desalination technologies, the microfiltration (MF) and multistage flash (MSF) are the most widely applied ones [3]. The MF technology is increasingly popular with the development of the membrane technology. It would be more competitive with the use of cheap membranes made of raw materials like kaolin and $CaCO_3$ [4], anorthite [5], ZrO_2 [6], natural alumino-silicates [7], and natural hydroxyapatite obtained from cortical bovine bones [8]. Despite the popularity of the MF technology, the MSF process still occupies a large portion of the global installed capacity as it is deemed as the most reliable thermal desalination technology [3]. It also has the advantage of larger daily production capacity than other technologies [9], and possesses great economic potential if driven by renewable energy [10]. In the MSF process, demisters are adopted to remove the entrained saline droplets from the fresh water vapor in order to maintain the level of salinity in the generated fresh water. Those demisters mainly include filters [1], vanes [11], wave plates [12] and wire mesh [13]. Among these devices, wave-type demisters [11,12,14–17] and wire mesh demisters [13,18] are the most widely adopted. Their performance is, however, largely dependent on demister configurations and operating conditions such as gas velocity and droplet size.

For wave-type demisters, increasing droplet size or gas velocity leads to higher separation efficiency [19–22]. Nevertheless, they cannot effectively remove inlet mist under conditions of low gas velocities or small droplets [21–23]. For example, the separation efficiency of a wave-plate demister was higher than 90% for 30 μm droplets when the inlet gas velocity was over 5 m/s; but it dropped significantly to

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Nomenclature

A_{sn}	area of the inlet of the sampling nozzle, m^2
C_D	drag coefficient
D_d	droplet diameter, m or μm
D_t	diameter of tubes, mm
Eu	Euler number
H_1	length of the wave-plate part, mm
H_2	length of the tube-bank part, mm
H_3	depth of the horizontal demisters, mm
h	length of certain part of the wave plate, mm
k	turbulent kinetic energy, m^2/s^2
L	channel width, mm
l	characteristics dimension of the flow, m
M_{in}	mass flow rate of liquid sampled at the inlet of demisters, kg/s
M_{out}	mass flow rate of liquid sampled at the outlet of demisters, kg/s
M_{noz}	mass flow rate of liquid from the spray nozzle, kg/s
M_{ap}	mass flow rate of liquid collected by the air passage before demisters, kg/s.
M_d	mass flow rate of liquid collected by the demisters, kg/s
p	pressure, Pa or MPa
Q_{sn}	volume flow rate at the inlet of sampling nozzle, kg/s
S_1	tube spacing, mm
S_2	row spacing, mm
St	Stokes number
T	temperature, K
t	time, s
$U_{g,cr,1}$	minimum gas velocity for possible detachment of liquid film, m/s
$U_{g,cr,2}$	minimum gas velocity to suspend a droplet, m/s
$U_{g,cr,max}$	maximum critical gas velocity, m/s
$U_{g,in}$	gas velocity at the inlet of demisters, m/s
$U_{g,max}$	predicted maximum gas velocity in the demisters, m/s
u	flow velocity, m/s
$u_{g,sn}$	gas velocity at the inlet of the sampling nozzle, m/s
We_d	droplet Weber number
w_i	mass fraction of a small group of droplets
Y	relative distance, mm

Greek symbols

α	bend angle, °
ΔP	pressure drop, Pa
ε	turbulent dissipation rate, m^2/s^3
η	separation efficiency
η_i	separation efficiency for a small group of droplets
μ	dynamic viscosity, Pa·s or μPa·s
ρ	density, kg/m^3
σ	surface tension of water, $N\cdot m^{-1}$ or $mN\cdot m^{-1}$

Subscript

d	droplet
g	gas phase

<50% at the inlet gas velocity of 3 m/s [21]. When the droplets' diameter was above 37.5 μm, the separation efficiency of the wave-plate demister was over 90% at an inlet gas velocity of 4 m/s; but it dropped sharply to <40% when the droplets' size decreased to <25 μm [21]. Similar phenomena have also been observed in the literature [15,20,24,25].

Compared with wave-type demisters, wire mesh demisters generally have much higher separation efficiency at low gas velocities and for fine droplets [23], despite similar dependence of the droplet separation efficiency on operating conditions (e.g. gas velocity and droplet size) [13,18,26–28]. For example, for 10 μm droplets, the separation efficiency of the wave-plate demisters in [20] was <20% at inlet gas velocity of 2 m/s; but the separation efficiency of the wire mesh demister in [29] could achieve >90% under the same conditions.

For both types of demisters, it is also noticed that increasing the gas velocity to a certain higher value may result in the decline of separation efficiency because of droplet re-entrainment [13,19,30–32]. For example, increasing the gas velocity to above 7 m/s [33] would lead to a decrease in the separation efficiency of the wave-plate demisters due to the apparent occurrence of re-entrainment. For some wave-type demisters with multiple bends in [19,34], the re-entrainment will not occur until the gas velocity increases to as large as over 8 m/s. In contrast, wire mesh demisters are more vulnerable to flooding and re-entrainment [13]. It was reported that droplet re-entrainment might occur at a gas velocity of as low as 4 m/s for a wire mesh demister, causing a sharp increase of pressure drop to above 1000 Pa [13].

From the above literature review, although most of the wave-type demisters have relatively higher resistance to droplet re-entrainment, they have difficulties in achieving high separation efficiency under conditions of fine droplets and/or small gas velocities. By contrast, the wire mesh demisters can obtain high efficiency under these conditions, but are much more vulnerable to droplet re-entrainment than the wave-type demisters. In summary, both types of demisters could hardly operate with high stable efficiencies under a wide range of industrial conditions.

In this work, a novel compound demister was proposed to take advantage of the merits of the wave-type and wire mesh demisters, which has not been reported in the literature. A staggered tube bank, simplified from the wire mesh demisters, was adopted in the compound demister aiming at removing fine droplets at higher efficiencies. Wave plates were arranged downstream just after the tube bank to mitigate potential flooding and re-entrainment. Both experiments and numerical simulation were carried out to evaluate the performance of the proposed compound demister. The effects of gas velocity and droplet size on the separation efficiency and pressure drops of the compound demister were investigated. Its performance was compared with that of the individual tube-bank demister and wave-plate demister. The mechanisms of droplet re-entrainment in the compound demister were also discussed. The results show that, compared with the individual demisters, the compound demister has higher and more stable separation efficiency under the conditions investigated. Further comparisons with findings in the literature reveal that, under the same conditions of fine droplets and low gas velocities, the compound demister has higher efficiency than most of the wave-type and wire mesh demisters [18,20,21]. The results also show that the compound demister has higher resistance to droplet re-entrainment than the wire mesh demisters in the literature [13,35].

2. Experimental and simulation methods

2.1. Experimental

2.1.1. Demisters

The compound demister tested in this work is presented in Fig. 1. It consists of an upstream tube bank and downstream wave plates. The tube bank consists of 4 lines of staggered tubes that are made of stainless steel, while the wave-plate part includes six plexiglass wave plates that form five channels. The tubes are vertically embedded into the plexiglass channel. The two-dimensional sketches of single units of the three demisters investigated are presented in Fig. 2. To make the comparison between different demisters reasonable, the individual tube-bank demister and wave-plate demister were designed to have the same geometric parameters as their counterparts in the compound demister. The configurative parameters of single units of the investigated demisters are given in Table 1. The geometric parameters of the wave plates are obtained from the optimal configurative results reported in