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Research Paper

Cellulose/PET humidifying elements having horizontal air and vertical water channels

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HIGHLIGHTS

- New material and shape of the humidifying element were developed.
- The new material consists of 50% cellulose and 50% PET.
- The parallel channel configuration was devised to reduce excessive pressure loss.
- The new element outperforms the widely-used glasswool element.

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ABSTRACT

New material and shape of a humidifying element were developed, which outperformed the widely- used criss-cross glasswool element. The new material consists of 50% cellulose and 50% PET. A parallel channel configuration was devised to reduce excessive pressure loss caused by the decreased height (5.0 mm) from that (7.0 mm) of the criss-cross configuration. For the same criss-cross configuration, the humidification efficiency of the cellulose/PET element was 26% higher than that of the glasswool element. For the same cellulose/PET material, humidification efficiency of the parallel channel configuration was 14% higher than that of the criss-cross configuration. As for the pressure drops, those of the glasswool element were 2–52% higher than those of the cellulose/PET element. For the same cellulose/PET material, the pressure drop of the parallel channel configuration was 14% higher than that of the criss-cross configuration. Data were compared with the predictions by existing correlations and those by the proposed model.

1. Introduction

In modern buildings, humidity control is an essential constituent of the building management. Humidity is commonly controlled using humidifiers mounted in air handling units. Of the two types of humidifiers (steam injection or spray-type), spray-type is widely used due to low initial and operation costs [1]. A spray-type humidifier is shown in Fig. 1. For a spray-type, the humidifying element is soaked with water sprayed from the top, and humidifies the air which passes through the element channels. The element is commonly made by stacking corrugated sheets horizontally in an alternate manner to form criss-corrugated channels. Typical criss-cross channel is shown in Fig. 2. It is important that the element is fully wetted and soaked by water as quickly as possible.

The literature reveals several studies on moisture transfer in humidifying elements. Franco et al. [2] numerically and experimentally investigated the effect of corrugation angle on heat or moisture transfer from the dry or wet corrugated channel. Numerical results successfully predicted the dry channel data, whereas they showed large discrepancy for the wet channel data. Malli et al. [3] experimentally investigated the effect of channel length on moisture transfer and pressure drop, and showed that both moisture transfer and pressure drop increased as channel length increased. Barzeger et al. [4] experimentally investigated the effect of corrugation depth, and showed that both moisture transfer and pressure drop increased as corrugation depth increased. Kim [4] tested eight samples having different corrugation angles and corrugation depths, and confirmed the results of Franco et al. [2] and Barzeger et al. [4] that the moisture transfer increased as the corrugation angle or the corrugation depth increased. Numerical models for moisture transfer in humidifying elements have been proposed by Wu et al. [6], Fouda and Melikyan [7], Sheng and Agwu Nnanna [8] and Kim [9].

Many kinds of materials had been searched for a humidifying element. They include both organic and inorganic materials. Inorganic materials include glasswool, ceramic, PVC sponge, wire

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Nomenclature

A	area (m^2)
A_c	cross-sectional area (m^2)
A_{fr}	frontal area (m^2)
D_h	hydraulic diameter (m)
f	friction factor
H	corrugation height (m)
h_D	moisture transfer coefficient (kg m^{-2} s^{-1})
j_m	colburn j factor of mass transfer
k	thermal conductivity (W m^{-1} K^{-1})
k_D	diffusion coefficient (m^2 s^{-1})
L	length (m)
$LMTD$	log mean temperature difference (K)
$\dot{m}$	mass flow rate (kg s^{-1})
Nu	Nusselt number
P	pumping power (W)
P_c	corrugation pitch (m)
P_w	wetted perimeter (m)
Pr	Prandtl number
Re	Reynolds number
Sc	Schmidt number
Sh	Sherwood number
V	velocity (m s^{-1})
W	humidity ratio
x^+	non-dimensional entrance length

Greek symbols

α	apex angle (deg)
δ	mass diffusivity (m^2 s^{-1})
Δp	pressure drop (Pa)
μ	viscosity (Pa·s)
η	humidification efficiency
ν	kinematic viscosity (m^2 s^{-1})
ρ	density (kg m^{-3})
σ	contraction ratio

Scripts

a	air
c	core
ent	entrance
exp	experimental
in	inlet
m	middle
max	maximum
o	outside
out	outlet
pred	prediction
s	surface or saturation
w	water or moisture

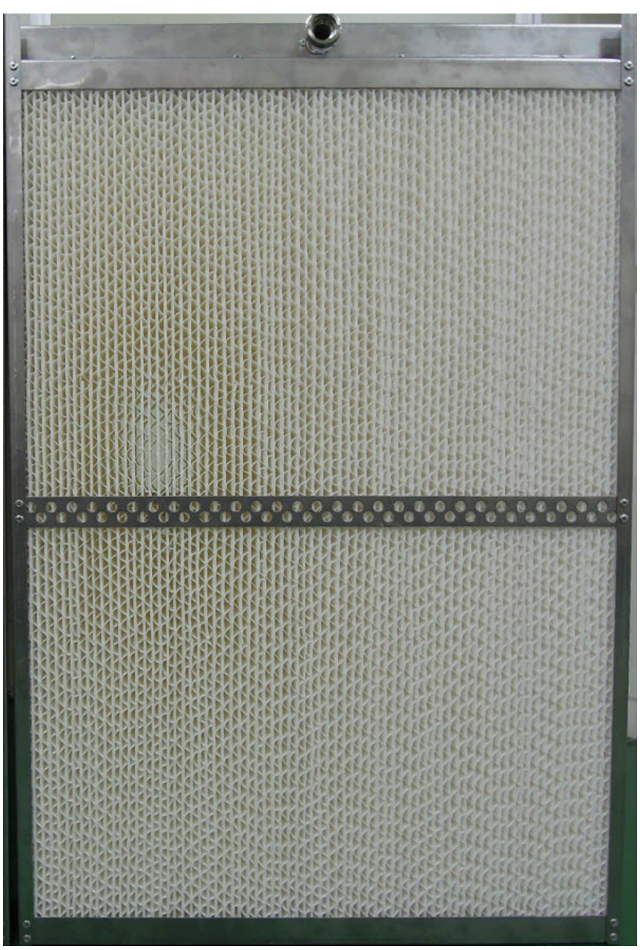

Fig. 1. Photo of a spray-type humidifier.

mesh, etc. Organic materials include kraft fiber, aspen fiber, coconut fiber, etc. [10–14]. Of the many materials, glasswool has been successfully commercialized [15], and is widely used in air-handling units. Recently, a humidifying element made of cellulose/PET composite has been proposed by Kim [5]. He showed that the new element yielded higher humidifying efficiency and lower pressure drop compared to those made of glasswool. The larger surface area per volume ratio and the smaller surface roughness of the cellulose/PET were attributed for the reason.

The foregoing literature survey reveals that existing studies are limited to humidifying elements having criss-cross channels. Generally, a criss-cross geometry induces large pressure drop due to an intense flow mixing. If the element channels are made parallel to the air flow, only frictional pressure loss consists of the channel pressure drop (no profile drag), and the pressure drop may significantly be reduced. Reduced pressure drop will also increase the water carryover velocity. For the parallel geometry, however, the humidification efficiency may be reduced. This problem can be solved by increasing the surface area (or by reducing the channel pitch).

In this study, new humidifying elements having parallel channels were made, and tests were conducted to investigate the moisture transfer characteristics. One concern of the parallel geometry is the water supply to downstream parallel channels. To resolve this issue, separate water channels having vertical corrugation were mounted next to the corresponding horizontal air channels. To increase the moisture transfer rate, the air channel pitch was reduced to 5.0 mm from previous 7.0 mm. The water channel pitch was 2.0 mm. Samples were made of cellulose/PET composite, which contains cellulose 50% and PET 50%. Data are compared with theoretical models.

2. Experiments

2.1. New humidifying elements

A photo of the new humidifying element is shown in Fig. 2 (c) and (d). The water flowing down the vertical corrugated chan-