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Experimental analysis on pressure drop and heat transfer of a terminal fan-coil unit with ice slurry as cooling medium

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ABSTRACT

This paper is concerned with the experimental analysis of a standard terminal fan-coil unit with ice slurry as coolant. The ice slurry was produced from an ethylene glycol 10 wt% aqueous solution. The pressure drop measurements are presented as a function of volumetric flow rate, ice concentration and Reynolds number. The experimental friction factors are obtained and discussed. The fan-coil capacity was experimentally determined for chilled water and melting ice slurry with inlet ice fractions around 5, 10, 15 and 20 wt%, considering in each case three different fan rotation velocities. The fan-coil capacity is higher with melting ice slurry than with chilled water by factors between 3.7 and 4.9. The heat transfer analysis realizes that the air side thermal resistance controls the heat transfer process. Experimental results for the melt off rate of ice in the fan coil and the superheating at the fan-coil outlet are shown and discussed.

Analyse expérimentale de la chute de pression et du transfert de chaleur d’un ventilo-convecteur dans un système employant un coulis de glace pour le refroidissement

Mots clés : Conditionnement d’air ; Expérimentation ; Coulis de glace ; Ventilo-convecteur ; Transfert de chaleur ; Chute de pression

1. Introduction

Phase change slurries consist of dispersed particles of a phase change material in a continuous carrier fluid. Egolf and Kauffeld (2005) defined ice slurry as ice particles with an average characteristic diameter equal or smaller than 1 mm dispersed in an aqueous solution. The range of operating temperatures of ice slurry is restricted to temperatures below 0 °C and it depends on the freezing point depressant substance and its concentration in the solution. Glycols

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Nomenclature

A	area (m^2)
C	volume fraction
d	diameter (m)
F	correction factor
f	friction factor
h	heat transfer coefficient ($W\ m^{-2}\ K^{-1}$)
i	specific enthalpy ($kJ\ kg^{-1}$)
k	thermal conductivity ($W\ m^{-1}\ K^{-1}$)
L	length (m)
m	mass flow ($kg\ s^{-1}$)
ΔP	pressure difference (Pa)
q	heat transfer rate (kW)
R	thermal resistance ($K\ W^{-1}$)
Re	Reynolds number
T	temperature (K)
ΔT	temperature difference (K)
U	overall heat transfer coefficient ($W\ m^{-2}\ K^{-1}$)
V	volume flow rate ($m^3\ s^{-1}$)
v	velocity ($m\ s^{-1}$)

Symbols

η	fin efficiency
ρ	mass density ($kg\ m^{-3}$)
φ	ice mass fraction
μ	dynamic viscosity ($kg\ m^{-1}\ s^{-1}$)

Subscripts

a	air
ai	air inlet
ao	air outlet
c	coolant
ci	coolant inlet
co	coolant outlet
cw	condensed water
d	dry
eff	effective
eq	equivalent
exp	experimental
i	inlet, inner
ic	ice
is	ice slurry
so	solution
LMTD	logarithmic mean temperature difference
o	outer
ov	overall
s	sensible
t	tube
w	water

(ethylene glycol, propylene glycol, etc), alcohols (ethanol, methanol, etc) and salts (NaCl, $CaCl_2$, etc) are the substances commonly used in practice as depressant for ice slurry generation. Ice slurry can be generated using several methods. Egolf and Kauffeld (2005) and chapter 5 in Kauffeld et al. (2005) provide an overview of the currently known methods of ice slurry production. However, in most industrial applications ice slurry is produced by cooling a solution of water with a freezing point depressant flowing over a refrigerated surface.

Ice slurry is an efficient heat carrier due to the latent heat of ice crystals. The high heat transportation capacity of ice slurry and its low operating temperatures make it an excellent alternative to conventional single-phase coolants in indirect refrigeration systems. Nowadays, indirect cooling systems are spreading out due to regulations for the use of synthetic refrigerants and the possibilities that these systems provide for thermal energy storage. Ice slurry, up to certain ice fractions, can be easily pumped through distribution pipe networks and heat exchangers. Therefore, ice slurry can effectively provide the same cooling load with much lower volume flow rates, offering significant savings in pumping cost and size of equipment.

These outstanding features of the ice slurry are bringing about an increasing interest in this technology, which has been successfully employed in many applications (Davies, 2005). The applications of ice slurry can be grouped into direct applications and its use as a secondary fluid in indirect cooling systems. Most of the direct applications are related to the processing and preservation of food products such as fish, dairy, etc. Other direct applications such as in medicine, pigging, fire fighting, etc, are being considered. Ice slurry as a secondary fluid has been employed in air conditioning systems, commercial refrigeration and industrial production processes.

Ice slurry-based air conditioning systems usually present two different arrangements: with only an ice slurry circuit and with both ice slurry and chilled water circuits. In the former, the ice slurry is pumped from the storage tank directly to the air-handling units. In the latter, the ice slurry circulates between the storage tank and a heat exchanger where chilled water is produced, then, the chilled water is distributed by a second circuit to the air-handling units.

An arrangement with direct distribution of ice slurry to the air-handling units would result in a sizeable reduction of heat exchangers due to its lower and almost constant operating temperature, which would provide a larger temperature difference than chilled water. Additionally, ice slurry provides the option of reducing cooler air temperature and, consequently, the volume flow rate needed for a given cooling load. As a result, the investment and operating costs of the air-handling system are reduced. However, it should be borne in mind that if air at low temperature is distributed in a conditioned space, draft will be avoided. If fan-coils are considered as terminal air cooler units, besides the benefits associated with the downsizing of the usually complicated distribution networks, a significant size reduction of the terminal units may be attained thus resulting in a lower investment cost.

However, it should be borne in mind that frost formation will occur on the finned-coil surfaces due to its low operating temperatures (below 0 °C), which will affect the fan-coil performance. On the other hand, it should not be forgotten that the generation of ice slurry requires more energy consumption in the primary refrigeration plant than the production of chilled water. The pros and cons cited above, as well as the overall energy consumption and investment costs