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EXPERIMENTAL ANALYSIS OF HEAT TRANSFER AND PRESSURE DROP FOR TUBE-IN-FIN HEAT EXCHANGERS USING ICE SLURRY IN HVAC SYSTEM

P. Bharathidasan*, N. Azhaguvel

Department of Mechanical Engineering, Roever College of Engineering & Technology, Elambalur, Perambalur 621212, Tamil Nadu, India

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Abstract

Ice slurries can be used both for cold storage in place of chilled water or ice and as a secondary refrigerant since, up to certain concentrations, they can be pumped directly through distribution pipe works and heat exchangers. For ice slurries to become more widely accepted, however, more engineering information is required on fluid flow and heat transfer characteristics. This paper reports on the results of experimental investigations of heat transfer and pressure drop of 14 % ice fraction, 16% ethylene glycol, and 70% water by volume flowing in a tube-fin exchanger. And the airflow rate is varied from between 1 m/s to 3 m/s. In this flows range, due the ice fractions caused around a 5% in the pressure drop. The overall heat transfer capacity of the heat exchanger was found to increase by more than 26% with melting ice slurry flow compared to chilled water flow. In a practical application, for a given thermal load this would lead to between 70% and 80% reduction in flow rate and pressure drop compared to chilled water cooling systems.

Keywords: Heat transfer, Pressure drop, Ice slurry

Introduction

Ice slurries are increasingly applied as the working fluid in secondary cooling systems in supermarkets, in air-conditioning and in other applications. Ice slurries consist of a water solution with small (0.01 mm-0.1 mm diameter) ice particles. By addition of a substance that depresses the freezing point, ice slurries can be produced from just below 0ºC down to –20ºC or at even lower temperatures. Heat transferred to ice slurry melts a small amount of ice instead of increasing the temperature without phase change. Cold is stored and transported at high density and pipe diameters and storage vessels can be small. Until now the main disadvantage has been the expensive ice slurry generator needed for producing the ice slurries.

One of these alternative technologies is the potential production and use of ice slurries in conventional cooling processes. Ice slurry is a mixture of ice crystals, water and an additive such as glycol, salt or alcohol to lower the freezing point. The size of these crystals can vary between 100 μm and 12 mm [Egolf and Sari, 1999, Sellgren, 1986]. Ice slurries have very good thermo physical and transport properties. They behave almost like liquids and can be pumped through pipes or stored in tanks. The energy capacity of ice slurries per unit volume is greater than that for chilled water due to phase change of the ice particles. Because of their large energy capacity, for a given cooling load, ice slurries can reduce the required cooling flow rate significantly compared to chilled water flow [Metz and Margen, 1987]. Therefore, pipe dimensions, pumping energy, heat exchanger size and operating costs could be substantially reduced. Another advantage of ice slurry systems is that the fluid can be completely safe and harmless to the environment. These advantages make ice slurry systems very attractive from both the technical and economic viewpoints.

Several experimental methods to measure the density and ice concentration of ice slurries have been reported but research is continuing to develop on-line methods for ice concentration measurement [Dickey et al., 1989, Kauffeld et al., 1999, Fournaison, 2001]. Correlations for the calculation of the physical properties of ice slurries are either based on semi-empirical methods that rely on the determination of the ice content of the ice slurry from on-line density measurements, along with measurements of the melted slurry at its melting temperature, or the assumption that the slurry is an immiscible multiphase mixture. The properties of the mixture are then determined based on the weight fraction and the property of each component of the mixture [Wasp et. al. 1975, Guilpart et al., 1999].

The majority of thermo physical property correlations found in the literature are based on the assumption that ice slurry is a suspension of pure ice crystals in a residual liquid phase [Bell et al., 1999]. An extensive literature survey of the thermo physical and transport properties of ice slurries was carried out. Properties studied include density, viscosity, thermal

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* Corresponding Author, *Email*: bharathi91221@gmail.com, Mob: +91 9443169492

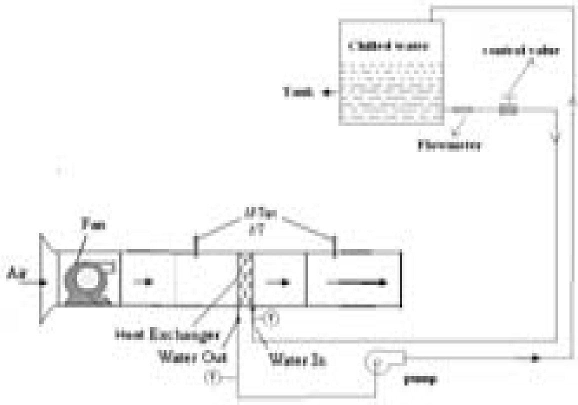
conductivity, enthalpy and specific heat. The literature survey also includes past experimental work and technologies used for ice slurry production and distribution [Bellas, 2002]. Experimental investigations have shown that this assumption may lead to significant errors in the calculations and more experimental work is needed to develop more accurate correlations for ice water mixtures based on different freeze depressant fluids [Thomas, 1965]. Only very few investigations on the flow and heat transfer characteristics of melting ice slurries in plate and tubular heat exchangers have been carried out [Gupta and Frazer, 1990] carried out experimental investigations on the pressure drop and heat transfer for 6% ethylene glycol/water ice slurry at ice fractions between 0% and 20%and flow rates between 0.180 m3/h and 2.16 m3/h in a plate heat exchanger. The heat exchanger compared of 12 copper plates with nominal gap of 2.1 mm and heat transfer area of 0.134 m^2. The size of the ice crystals was measured to be between 0.125 mm and 0.625 mm. They reported an increase in the overall heat transfer coefficient with increased flow rate but a decrease in the overall heat transfer coefficient with increased ice fraction. The pressure drop in the heat exchanger was reported to remain constant upto 20% ice fraction and increase rapidly at concentrations above this value. Results for the higher concentrations, however, were not presented but the authors attributed the rapid rise in pressure drop to the choking of the flow by ice particles.

The heat transfer and pressure drop results obtained by different investigators indicate that the behavior of ice slurries is a function of a number of parameters which include the mixture viscosity, Reynolds number, ice crystal size and ice fraction. The influence of these parameters, however, is not fully characterized and as yet there are no widely accepted correlations for the calculation of heat transfer coefficients and pressure drop in tube-fin heat exchangers. This paper reports to the overall effort to increase heat transfer and minimize pressure drop in tube-fin heat exchangers in ice slurries HVAC system.

Experiments

The wind-tunnel test facility employed is shown in Figure 1. The system was designed to draw room air over the finned side of the coils while circulating chilled water through the tubes. Following the air path after leaving the test section air and differential pressure ports.

Figure 1. Schematic diagram of experimental test apparatus.



A frequency controller (0-60Hz) was used to modulate the power to the blower. It was built in accordance with ANSI/ASHRAE Standard 41.2-1987. The range of airside frontal velocity u_{in} varied from 1–3 m/s. The temperature and pressure at the inlets and outlets of both waterside and air side of the heat exchanger were measured with an RTD temperature sensor. During the experiment, u_{in} was changed to desired values until steady-state conditions prevailed. Special attention was paid to relatively low-Re a flow that is typical in low-noise air conditioning applications.

Data acquisition

The data acquisition system is comprised of instrumentation, a set of hardware Instrumentation consists of several transducers namely: four temperature sensors, Pitot tube and a flow meter. Temperatures were measured using T-type [copper-constantan] thermocouples attached to shielded, grounded, single-strand thermocouple extension wire. The instrumentation accuracy is summarized as follows a standard an accuracy of the entire thermocouples ±1 °F. And a digital manometer is used to measure the pressure drop across the heat exchanger of an accuracy of ±0.002 inH2O. The digital manometer used to measure the differential pressure across the test section. The water flow rate was calculated by measuring the number of pulses and the sample time. A gauge repeatability and reproducibility study was performed to provide information on wind tunnel performance by using ratios of measurement variation and parameter temperature, pressure, velocity, etc.

Ice fraction measurement

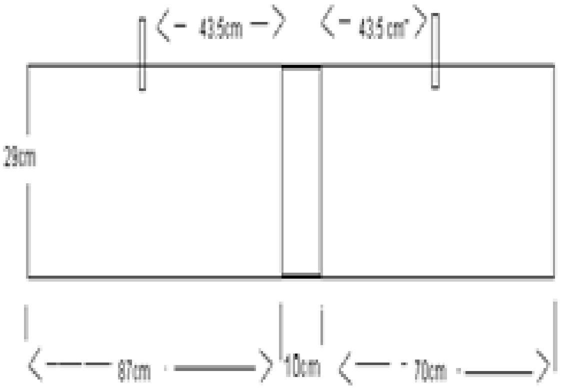
The ice volume fraction was tested manually, using a coffee press (a mesh filter) to separate the solid and liquid phases of the slurry as described by Evans et al. This technique has been found to produce quick and repeatable results (to within 3%) for this type of ice slurry. The fine crystals of the slurries used for this work had a large surface area, which made the gravity filtration techniques used by other researchers inappropriate since the fluid takes a very long time to drain off the crystals and the technique leads to gross over-estimation of the ice fraction.

Methodology

Procedure

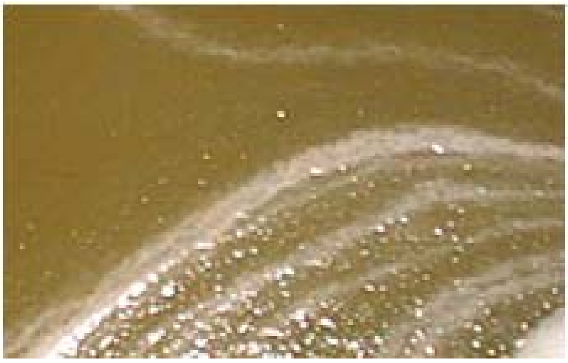
The goal of the Variable Air test is to determine the airside heat transfer and the pressure drop of coil over a range of airflow rates. The test heat exchanger was a commercially available aluminium fin, copper-round-tube heat exchanger with two row two-pass cross-counter flow circuiting. Cold water in an inlet header was evenly distributed into 20 tubes in Row 2 at a flow rate of 0.07 kg/s. A chilled water system at temperature of 8°C is passed into the tube-fin heat exchanger and allows the system to attend the steady state condition before to measure the temperature and pressure. The atmosphere air is passed over the coil in a counter flow direction and the velocity of air is varied by adjusting the fan speed using rheostat, the temperature and pressure at the inlets and outlets of both water side and air side of the heat exchanger were measured. The air volumetric flow rate was measured downstream of the heat exchanger. The energy balances between air and watersides were used to ascertain the performance of the test apparatus. Similarly the experimental work carried for the ice slurry system for the mixture of 14 % ice fraction, 16% ethylene glycol, and 70% water by volume flowing in a tube-fin exchanger. And the airflow rate is varied from between 1.0 m/s to 3 m/s. In this flow ranges, due the ice fractions caused around a 5% in the pressure drop. The heat transfer capacity of the heat exchanger was found to increase by more than 30% with melting ice slurry flow compared to chilled water flow.

Figure 2.duct dimensions used for experiment



In a practical application, for a given thermal load this would lead to between 70% and 80% reduction in flow rate and pressure drop compared to chilled water cooling systems.

Figure 3. Photograph view of ice slurry in tank



Data reduction

To obtain the total heat transfer can calculate by using the following equation

$Q = m\, c_p \Delta t = V\rho\, c_p \Delta t$

For an ice slurry system, it is more suitable to apply the relation:

$Q = m\, \Delta h = V\rho\Delta h$

Both sensible heat and latent heat of melting are included in the enthalpy difference, Δ**h**. In these relations, **m**, is the fluid mass flow rate, **V**, is the volumetric flow rate, Δ**t** is the temperature change between the fluid entering and exiting over the test section , **ρ** is the fluid density and **c_p** is its specific heat. The heat transport ability of ice slurries in equilibrium is proportional to the enthalpy difference, Δ**h**, obtained for a certain temperature change between the fluid entering and exiting. It is much higher for ice slurry than for mono-phase aqueous solutions, as there is a benefit from the latent heat of melting of ice crystals, which reduces the fluid flow rate required for a given cooling capacity and also the temperature change. This heat transport ability depends partly on the specific heat of the fluid, but more on the ice fraction of the ice slurry that enters the test section, on the amount of ice that melts (Melinder, 2003b).

This apparent specific heat includes sensible heat of the fluid and latent heat of melting of the ice. And the following relation can calculate the pressure drop.

$\Delta P = P_{in} - P_{out}$

Where ΔP is the pressure drop between inlet and outlet of the airflow rate.

Results and Discussion

Figure 4, shows the variation of pressure drop with airflow rate is varied from between 1 m/s to 3 m/s. It can be seen that ice slurry pressure drop is slightly higher than chilled water pressure drop. The ice slurry pressure drop increases with flow rate. Increasing the flow rate from 1 m/s to 3 m/s produced between 5% and 7% increases in pressure drop over a chilled water system. Comparison of Pressure drops for chilled water and ice slurry system. It can be seen that ice slurry pressure drop is slightly higher than chilled water system.

Figure 4.comparison between ice slurry and chilled water a variation of heat transfer with the frontal velocity

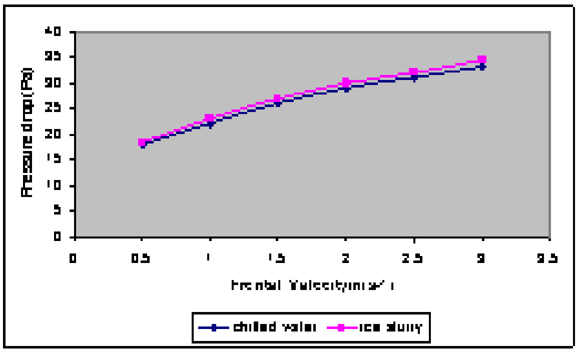


Figure 5.comparison between ice slurry and chilled water a variation of pressure drop with the frontal velocity.

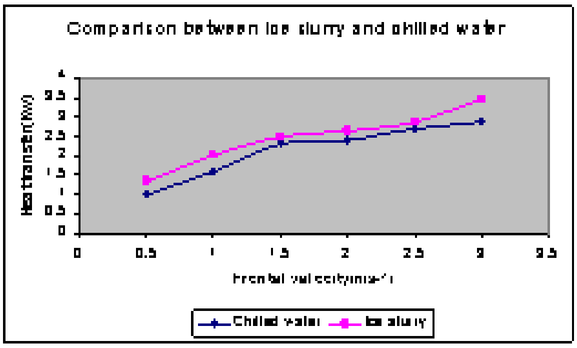


Figure 5, shows the variation of heat transfer with airflow rate is varied from between 1 m/s to 3 m/s. It can be seen that ice slurry pressure drop is higher than chilled water pressure drop. The ice slurry heat transfer increases with flow rate. Increasing the flow rate from 1 m/s to 3 m/s produced between 26% increases in heat transfer over a chilled water system. It can also be observed that the heat transfer increases rapidly with flow rate. The pressure drop increases exponentially with the flow rate. The effect of melting ice slurry on heat transfer in the heat exchanger for the ice fractions between 14% can lead to a more heat transfer while compared to chilled water system and there by increase the heat transfer capacity of the system. This can lead to significant reductions in both the size of the heat exchangers and pumping power.

Conclusions

The experiments performed for a 14 % ice fraction, 16% ethylene glycol, and 70% water by volume in a tube-fin exchanger. These results can be summarized as follows:

- The pressure drop was found to increase with increasing flow rate
- The heat transfer capacity of the tube-fin heat exchanger of ice slurry was found to increase by more than 26% compared to chilled water. And the pressure drop of ice slurry to be 5% more than the chilled water system.

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