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The control of ice slurry systems: an overview

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Abstract

This article outlines some typical control strategies for the basic components of an ice slurry system. From this review it became apparent that the control of terminal units is not fundamentally different from the control of classical single-phase secondary cooling systems, except from the fact that it must be based on the use of local pumps and the ON–OFF operation of actuators to avoid ice plugging problems. The safe control of the ice generator can be ensured with a simple thermostat, although the resulting ice concentration control would be approximate. It was also demonstrated that any ice accumulation in the storage tank would not prevent the ice slurry system from functioning safely. As a final precaution, it was not recommended to operate an ice slurry generator at low solute concentrations and temperatures greater than $-3/-4$ °C due to the risk of plugging up the distribution loop and causing mechanical wear to the ice generator.

Keywords: Two-phase secondary refrigerant; Ice slurry; Survey; Control; Component; Safety

Régulation des systèmes á coulis de glace: vue d'ensemble

Mots clés: Frigoporteur diphasique; Coulis de glace; Enquête; Régulation; Composant; Sécurité

1. Introduction

The use of ice slurry systems is of great interest due to their wide range of refrigeration applications and high energetic performance. Although many authors [1–3] have described the advantages and drawbacks of ice slurry systems based on a thermal-hydraulic analysis, none of the past studies have dealt with the control of these systems.

Two main strategies exist for the control of ice slurry systems. The first approach involves the use of an ice slurry tank as a simple energy storage unit and neglecting ice segregation effects inside the tank. In this case, only the residual liquid phase at the bottom of the tank is pumped to multiple distribution points as normally done in classical secondary refrigeration loops. Many chilled water air-conditioning systems, especially in Japan [4], are based on this strategy.

The second strategy takes advantage of the additional latent heat of the ice crystals in the slurry for cold energy distribution to the terminal units. In this case, highly homogeneous ice slurry must be pumped to the secondary distribution loop. Naturally, the design of this system must also take into consideration the thermal and rheological properties of the slurry. Many systems used in supermarket display cabinets or food process applications are based on this principle [5,6].

The objective of this paper is to present some classical

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Nomenclature

C_p	heat capacity, kJ kg^{-1} K^{-1}
L	latent heat of fusion of ice, kJ kg^{-1}
$\dot{m}$	mass flow rate of secondary refrigerant, kg s^{-1}
T	temperature, K
X	ethanol/water mass concentration
X_i	ice mass concentration
Greek symbols	
Δ	variation in
Φ	refrigerating capacity, W
Subscripts	
0	primary
i	ice
in	inlet
out	outlet

control methods of ice slurry systems typically used in industry. As it will be shown in this paper, the control of ice slurry systems remains nearly as straight forward as the control of classical monophasic secondary coolants, despite of some ice slurry system-related particularities that exist.

2. General layout of ice slurry systems

Compared to classical secondary refrigerant loops that continuously supply cold energy, ice slurry systems rely on the use of storage tanks designed to store and supply the cold energy on demand thus cutting-off cooling peak demands. Depending on the type of application (the use of a monophasic residual liquid pumped from the bottom of a non-agitated tank or an ice slurry pumped from the middle of an agitated tank as illustrated with dotted lines in Fig. 1(a) and (b), respectively), the liquid or the ice slurry could be pumped from the storage tank to the terminal units using a classical flow loop setup (discharge and return lines).

A 'monotube dynamic®' type of arrangement could be used as shown in Fig. 1(b). This type of arrangement is best suited for applications that demand ice slurry to be delivered to the terminal units, since the temperature remains almost constant during the ice slurry melting process. The main difference between monophasic and ice slurry secondary loops is that in the second case the heat exchangers operating with ice slurry must be connected to small local pumps (classical centrifugal pumps are sufficient). Nevertheless, due to the risk of blocking up the system with plugs of ice, the use of three-way or throttling devices to control these terminal units should be avoided. Except these two differences, the control principle of an ice slurry system is similar to that of classical secondary loops. Consequently, a secondary refrigeration loop that was originally designed to operate with ice slurry may also be used for a monophasic coolant.

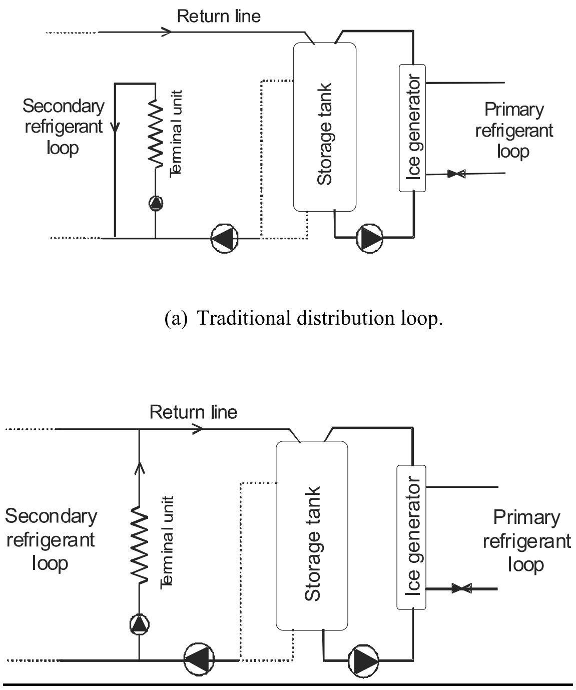
3. Control parameters

Fig. 1 shows that, regardless of the control strategy finally implemented, four main components must be regulated to ensure a proper control of the entire process: (i) the terminal units, (ii) the storage tank, (iii) the ice slurry generator, and (iv) the primary refrigerating unit.

3.1. Control of the terminal units

Despite the additional pumping requirements that ice slurry systems demand for the supply of ice slurry to the terminal units and assuming that heat exchangers are designed to operate with monophasic coolants as well as with ice slurry, the terminal units may be controlled reliably by a simple ON–OFF operation of the ice slurry delivering pumps. In this case, a simple thermostat measuring the process temperature (e.g. cold room, display cabinet) would be sufficient. Such control scheme is illustrated in Fig. 2. The terminal unit's delivering pump may also be used in conjunction with an electrical valve but such scheme is not mandatory.

If necessary, a defrost strategy similar to that adopted in monophasic coolants may be employed (e.g. the use of a



(a) Traditional distribution loop.

(b) "Monotube dynamic"® distribution loop

Fig. 1. Several possible arrangement designs for ice slurry systems.