The Ice Slurry Technology after Some Years of its Introduction

La tecnologia delle miscele acqua-ghiaccio ad alcuni anni dalla sua introduzione

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ABSTRACT

In this short review paper two definitions of ice slurry are presented. Furthermore, ice slurry systems and the most relevant components of ice slurry systems are described. Such equipment are ice slurry generators (different physical principles), storage tanks, mixing elements, pumps, piping systems, consumers, e.g. display cabinets in super markets, etc. The direct contact ice slurry generator is an efficient low-cost machine, which at present is experimentally and theoretically investigated. A nearly complete list of the advantages and disadvantages of ice slurry systems in comparison with direct expansion systems is given. Advantages to the environment, for the case that the ice slurry technology is applied, are addressed. Furthermore, the article lists existing and possible future applications of the ice slurry technology.

1. INTRODUCTION

Phase change materials (PCM) have for decades been considered as effective storage materials. They can reduce the size of a water storage tank by a factor two to ten, depending on the material applied and the operation temperature range of the system. The reason for the high energy density is the latent heat of phase change. At a constant temperature - the freezing temperature - a high amount of energy is required to build up a regular crystalline structure, leading to the solid phase. In the opposite process of melting, the crystal is destructed and energy released at the same temperature, now called the melting temperature. In technical applications mostly mixtures are applied. They show a temperature glide (continuous transition) in the enthalpy density function.

If a PCM is finely dispersed in a carrier fluid, a phase change slurry (PCS) is obtained. The particles need to be stable and should not lead to high stratification effects in the system, caused by the buoyancy force. A comprehensive review on phase change slurries, e.g micro emulsions, shape-stabilized paraffins, clathrates, microencapsulated phase change slurries, etc. was published by Inaba[1]. In April 2003 in Switzerland a first international conference and business forum on the new field of PCS was organized and a proceedings published[2]. In PCS the storage medium, with its high thermal energy density and temperature stabilization by the phase change, is also used for the transportation of cold or hot.

Ice slurry is the oldest and most applied substances of the overall class of phase change slurries. This article briefly highlights its state-of-the art.

2. DEFINITIONS

In earlier times the Romans used natural occurring ice slurries, e.g. snow water mixtures, crushed ice, flake ice, etc. to cool their food. In the last century the technical invention of creating ice slurries artificially occurred. At the beginning they were water with large ice particles with a characteristic diameter of one to several centimeters. They were mainly applied to cool coal and silver/gold mines. A new production of fine-crystalline ice slurries then made it possible to apply the technique in small-scale systems, e.g. for the cooling of display cabinets in supermarkets (see Figure 1).

It is difficult to define "ice slurries". In a review article, Egolf and Sari tried to classify and define ice slurries in the following manner[3]:

Definition 1 : *An ice slurry consists of a number of solid ice particles in a fluid and, therefore, is a colloidal suspension with two phases.*

Definition 2 : *A fine-crystalline ice slurry is an ice slurry with ice particles with an average (characteristic) diameter, which is equal or smaller than 1 mm.*

Definition 2 is a little arbitrary, but still very useful. This article addresses only fine-crystalline ice slurries, as they are produced for example with mechanical scraper-type ice slurry generators. In this method the created ice particles have a characteristic diameter of approximately 200 μm.

3. PRODUCTION METHODS

The most applied techniques at present are the mechanical ones. Usually in a cylindrical double wall evaporator a refrigerant is evaporated. In the inner domain a water additive mixture leads to the creation of ice crystals on the wall, which then are mechanically removed. As the crystals drop into the fluid, the number of ice particles per volume and, therefore, also the ice concentration increases.

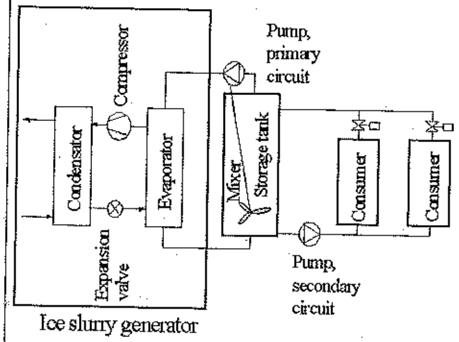

Figure 1. A schematic drawing of an ice slurry system, e.g. of a supermarket, is shown. The left part shows the ice slurry generator.

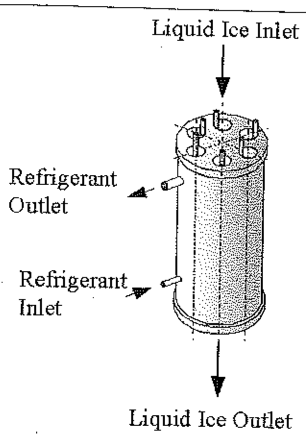

Figure 2. The principle of an ice slurry generator with rotating slabs allows a high ice production rate per unit volume.

A list of physical principles of ice slurry generators is the following :

- mechanical-scraper type ice slurry generator with :
  - o Rotating knifes
  - o Rotating cylindrical slabs
  - o Rotating brushes
  - o Screws in cylinders.

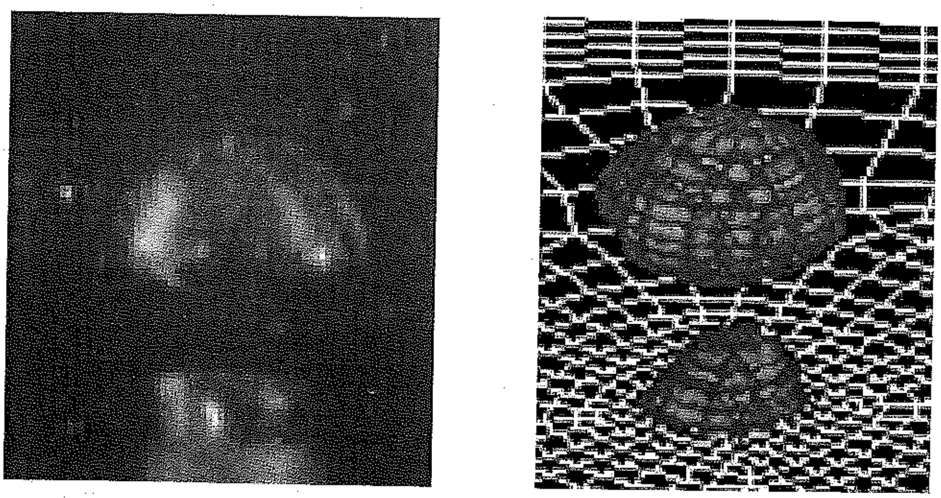

Figure 3 - At the University of Applied Sciences of Western Switzerland a direct contact ice slurry generator of type COLDECO is investigated. In a process of a direct injection of refrigerant (gas) into water/additive, at low mass flows evaporating drupples (droplet and bubble) occur. On the left a photograph of an experiment (a) and on the right a numerical simulation with Fluent ® (b) is shown. The evaporating cooled down drubbles lead to the ice slurry creation in their near environment.

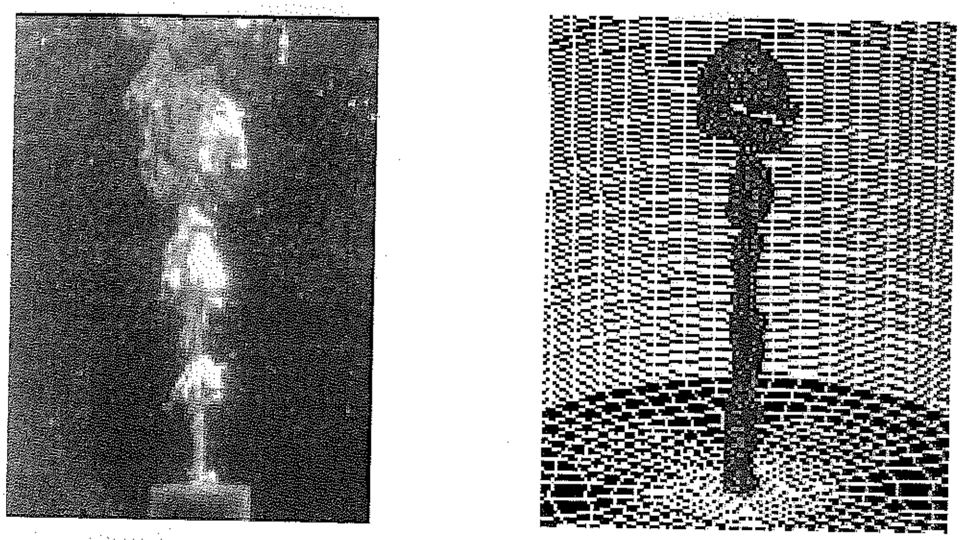

Figure 4 - For practical use the direct-injection method is operated with higher mass flows, leading to a splitting up and coalescence of drubbels in the turbulent flow field. When the mass flow is further increased, the system goes from the drubbel regime to the jet-like flow regime.

Other ice slurry generators in investigation are :

- Vortex-flow type (turbulent eddies of the fluid remove the ice particles from special treated surfaces with small adhesion)
- The direct-injection or direct-heat exchange type (the refrigerant or a cooled down immissible fluid is directly injected into the water, where it creates ice particles; *see figure 3 and 4)*
- The fluidized bed ice generator (by the flow levitated steel or glass spheres hit the ice crystals and remove them from the wall)
- Ice generators using supercooled water with different types of nucleation initiation :
    - By a momentum decrease (flow perpendicular to a cold wall)
    - By an ultra sound field
    - By bubble nucleation.

4. APPLICATION IN REFRIGERATION SYSTEMS AND ENVIRONMENTAL BENE-FITS

Because of long-time experiences, conventional direct evaporation systems usually show low costs and are technically very reliable. But they use the same fluid for the production and the transportation of cold from the central refrigeration unit to the end users (e.g. display cabinets). As a result these systems contain large masses of refrigerant and in the case of permanent or accidential leakages may lead to high losses with drastic consequences for the environment. Furthermore, high system contents of refrigerants lead to higher costs, because normally new replacements of HCFC's and CFC's are several times more expensive.

In indirect systems the production of cold and its transportation are separated. The cold is transferred in a heat exchanger from the primary to the secondary circuit. Like this each of the two occurring fluids can be adapted and optimized for their special application. Only with indirect systems ammonia (R717) or Propane (R290) may be used. The difficult search for alternatives, as a result of the phasing out of artificial refrigerants, has led to an intensive development of the ice slurry technology.

5. ADVANTAGES OF THE ICE SLURRY TECHNOLOGY

The advantages of ice slurries and ice slurry systems, which are listed in this section, are valid in a comparison with direct evaporation systems or/and indirect refrigeration systems containing brines as a secondary refrigerant :

- High cooling capacity given by the latent heat
- Smaller tube diameters of the piping system (A)
- Less energy demand of pumps (B)
- Higher humidity in the display cabinets. No humidification necessary. Higher product quality occurs
- No heating for defrosting necessary. A smaller energy demand results
- Existing display cabinets may be used in a renovation with an alteration of a conventional to an ice slurry system
- High thermal capacity of system may bridge small falling out of electricity supply
- Applying a storage technology, it may be taken advantage of the cheaper electricity during night
- Higher safety by stored cold in storage tanks
- Natural refrigerants are allowed for primary circuits (e.g. ammonia, propane, etc.)
- Smaller filling mass of primary circuits
- Higher heat transfer rates in heat exchangers, because of the phase change
- If a cooling demand of an existing system has to be extended, then the electrical supply does not have to be enlargened, because the cold production can be extended to 24 h
- The supply power of cold is many times larger in an ice slurry system than in a conventional storage system (e.g. an ice on coil system).

The system design engineer may choose between (A) and (B) or take partial advantage of both effects. High heat transfer rates are possible, because the ice particles are very finely dispersed in the fluid. *Figure 5* shows numerous ice particles in an ice slurry, and *Figure 6* the related surface A of the total amount of ice particles in one kilogram of ice slurry.

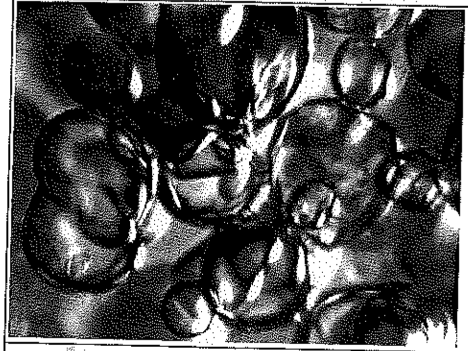

Figure 5 - A microscopic photograph of an ice slurry is shown in this figure (from Ref. 3). After their creation the ice particles slightly grow as a function of time, leading to a time behaviour of some physical properties.

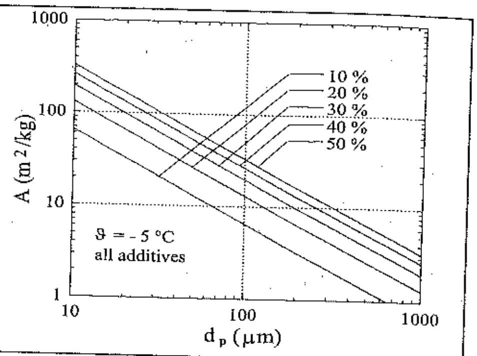

Figure 6 - The total surface areas A of all the particles in one kg ice slurry, for different ice mass fractions, are presented. These results are valid for spherical particles with a diameter d_p.

6. DRAWBACKS AND LIMITS

Ice slurry systems also show some significant disadvantages, which are listed below :

- Additional heat exchanger between primary refrigerant sytem and the secondary transportation system for cold
- Additional pump
- Additional energy demand for pump to charge the storage tank and for an operation of the mixing element
- Not adapted for the use in air conditioning and climatisation systems. It is thermodynamically not useful and not economic to cool down below zero degrees Celsius to fullfil a cooling task only at 12-14 °C.

The last disadvantage has recently led to the development of other PCS, e.g such with an application of paraffins. With such substances the melting point can be exactely adjusted to the particular application, e.g in air conditioning systems or in thermal solar systems, etc.

7. CURRENT APPLICATIONS

Ice slurry systems are favorable to be applied in the following domains :

- Refrigeration in super markets
- Cooling in dairies and cheese productions
- Cooling in breweries

- Fast food cooling
- Cooling of planes on airports (transport of cold over long distances to the docks)
- Cooling of pharma park (analogeous to technoparks, but for pharmaceutical research)
- Direct immersion of food (e.g. shrimps). A better food quality occurs by a fast freeezing process.

8. POSSIBLE FURTHER APPLICATIONS

Future applications are expected in the following domains :

- Plastics production: the temperature stabilization leads to more homogeneous temperature profiles in the plastic extruders. This will increase the product quality
- Cooling of chemical processes
- Immediate stopping of a chemical process by a direct injection of ice slurry into the reactor to absorb as much heat as possible, because of safety reasons
- Mixing of concrete with ice slurry in a quantity so that after the melting of the ice particles exactly the right mass of water is added to the concrete. The latent heat will be used to absorb the reaction heat. Especially in the construction of road and train tunnels, the technical cooling system may be reduced in size or even economized.

9. SYSTEMS DESIGN AND CALCULATION

The "Working Party on Ice Slurries" of the International Institute of Refrigeration has organized five workshops and published proceedings of the submitted articles. The contributions cover all important topics from physical properties and their time behaviour to fluid dynamics (e.g pressure drop calculations of piping systems), heat transfer (Nusselt functions) for laminar and turbulent flows, ice generation, storage, mixing, piping, etc. *Special contributions* will be published in a Special Issue on Ice Slurries of the Int. J. of Refr.[5]. All the useful and available practical knowledge will be comprised in a *IIR Handbook on Ice Slurries*[6], which will be published at the end of the year 2004.

10. FUTURE PROSPECTS

It is expected that in the near future in some countries the regulations in the refrigeration domain will limit the content of primary refrigerants in refrigeration systems, if they are not natural refrigerants. That will immediately create a higher necessity of an application of secondary refrigeration systems and, therefore, also a higher importance of the ice slurry technology.

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