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Dynamic modelling and experimental study of an ice generator heat exchanger using supercooled water

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Abstract

Since confirmation of the contribution of the refrigerants to ozone depletion and global warning, many solutions have been carried out to reduce their direct and indirect impact on the environment. One of them consists in using secondary refrigerant fluid (SRF) to reduce the amount of refrigerant flowing in the refrigerant loop. The new two-phase SRF present some advantages, and this paper presents a process using supercooled water to produce such fluid.

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1. Introduction

Due mostly to climate changes, the field of air-conditioning and the refrigerating industry knows a significant growth and must face new challenges such as energy improvement of the processes, and limitation of the environmental impact. Since the fluids traditionally used in refrigeration industry contribute to increase the greenhouse effect, it is thus necessary to replace them and to develop new technologies. These latter must satisfy several objectives: in particular to increase energy efficiency and to use less refrigerant. Our study is in this context. One of the areas of current research is the settling of cold distribution network using a secondary refrigerant fluid allowing decreasing the amount of refrigerant. One of the alternatives to classical single-phase fluid is the use of ice slurries. These two-phase fluids (liquid/solid) present some advantages:

- high cooling capacity due to the latent heat of fusion of the ice,
- lower energy demand for the pumps,
- better temperature stability,
- storage possibilities.

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Nomenclature

A	heat exchanger area (m^2)
C_p	specific heat capacity ($J\,kg^{-1}\,K^{-1}$)
L	evaporator length (m)
L_f	heat of crystallization ($J\,kg^{-1}$)
$\dot{m}$	mass flow rate ($kg\,s^{-1}$)
T	temperature (K)
U	internal energy (J)
X_{ice}	ice fraction
α	heat transfer coefficient ($W\,m^{-2}\,K^{-1}$)
ΔT_s	supercooled degree (K)

Subscripts

h	hot
c	cold
wi	internal wall
we	external wall
l	liquid
m	melting

Several technologies to produce ice slurries exist nowadays [1]. The most widely used is the scraper type system. The ice is mechanically extracted from the evaporator wall of a refrigeration system and then mixed with the liquid. The main disadvantage is the high amount of extra mechanical work required by the scraper, decreasing the global energetic efficiency of the whole system. Another way consists in evaporating water under vacuum conditions (near the triple point of water). This method suffers from implying high volume flows due to low evaporation and sublimation pressures. The supercooling concept presented in this paper consists in lowering the temperature of a stream of water below the normal freezing point before provoking the crystallisation outside of the heat exchanger in a storage tank. The advantage of this technique is to use simple technology and not to need extra energy to operate [2].

However, the main disadvantage is that the crystallization can occur in the evaporator of the refrigerant machine, and can stop the process. In order to study the phenomena, a pilot has been built and experimented. The results as well as the description of the machine are presented in the beginning of this paper. To help understanding the behaviour of the exchanger and in particular when this latter is submitted to unsteady conditions, a numerical model has been built. It is presented in a following part, where the obtained simulated results are compared to experiments. The model reveals finally quite accurate and could be used to predict the behaviour of the heat exchanger.

2. Supercooled water and ice slurry production

It is well known that any substance does not crystallize upon cooling to the melting temperature but at a lower one. Considering a sample of liquid being cooled as in Fig. 1, it can be observed that the liquid state remains below the melting temperature. The liquid is then called supercooled. It is an unstable state, and in supercooled liquid, the probability of crystallization [3] growth up with the difference between the melting temperature (at T_m) and the sample temperature (at T). This difference is called supercooled degree and is defined as:

$$\Delta T_s = T_m - T \tag{1}$$

This temperature difference can reach relatively important values: from a few degrees to a few tens of degrees when a few micrometer volume is considered as for instance in the clouds or emulsions [4].

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