INTERNATIONAL JOURNAL OF REFRIGERATION 60 (2015) 261–269

Available online at www.sciencedirect.com

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Method for defrosting heat exchangers using an air-particle jet

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A R T I C L E I N F O

Article history:
Received 1 May 2015
Received in revised form 27 July 2015
Accepted 19 August 2015
Available online 28 August 2015

Keywords:
Defrosting
Cryogenic heat exchanger
Jet
Particles

A B S T R A C T

We report test results on a method for defrosting heat exchangers in which solid particles accelerated by an air jet impinge on heat exchange surfaces. This study was motivated by the development of a cryogenic heat exchanger for a hypersonic aircraft engine. We conducted experiments to remove frost from a single-row heat exchanger cooled with liquid nitrogen as the refrigerant. In the experiments, particle-jet defrosting was conducted for 1 s at intervals of 50–300 s over total experimental durations of 600 s. The experiments were performed using different intervals between defrost cycles, different particle diameters, and different numbers of particles. The effects of these parameters on the performance of the heat exchanger were evaluated by measuring pressure losses and heat transfer rates. The results show that the method prevents buildup of frost and is more effective than defrosting with only an air jet.

Méthode de dégivrage d'échangeurs de chaleur en utilisant un jet de particules d'air

Mots clés : Dégivrage ; Echangeur de chaleur cryogénique ; jet ; Particules

1. Introduction

Frost formation on cooling tubes in heat exchangers not only decreases the amount of heat transferred but also increases pressure losses. Therefore, many countermeasures to frost formation have been proposed. One of the most popular methods is to defrost by adding heat, which is the method currently used in heat pump systems. In this method, the frost on heat exchangers is melted by stopping the operation of the heat pump or reversing its operation. However, this method reduces the efficiency of the system; moreover, the heat exchanger must stop its operation during defrosting.

Recently, our group has developed a cryogenic heat exchanger for hypersonic aircraft engines (Fukiba et al., 2008). This heat exchanger cools intake air to improve engine

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http://dx.doi.org/10.1016/j.ijrefrig.2015.08.017

Nomenclature

c	specific heat at constant pressure [J kg^{-1} K^{-1}]
c_p	pressure loss coefficient
m	mass flow rate [kg s^{-1}]
T	temperature [°C]
u	flow velocity [m s^{-1}]

Greek

Δp	pressure loss [Pa]
ρ	density [kg m^{-3}]

Subscripts

in	inlet
out	outlet

performance. The refrigerant in the heat exchanger is liquid hydrogen, which is the propellant of the engine. During development, we recognized that frost formation on the heat exchanger has serious adverse effects on the engine system. Because of this, our group has been investigating frost formation and possible countermeasures. In previous studies, we proposed three defrosting methods: first is by using an antifreeze solution (Harada et al., 2001; Kimura and Sato, 2006), second that reduces frost using an obstacle placed ahead of the cooling tube (Sato et al., 2014), and third that uses an air jet (Fukiba et al., 2009). We found that defrosting using methanol as the antifreeze suppressed frost formation; however, this method requires devices for ejecting the methanol. This system also raises safety issues because methanol is combustible. Jiang et al. (2014) also investigated a heat pump system with a defrosting device that used an antifreeze solution. They pointed out that recycling the antifreeze solution degraded effectiveness because the concentration of the solution decreased.

In our previous study of reducing frost using an obstacle located in front of the cooling tubes (Sato et al., 2014), we succeeded in decreasing pressure losses and increasing the heat transfer rate under frost-forming conditions. However, that method only reduced the adverse impact of frost formation and did not completely solve the problem. In another study, we proposed a new method to remove frost by impinging an air jet directly on the cooling tubes (Fukiba et al., 2009). In this method, the jet was impinged for a short duration (e.g., 0.1 s) at intervals of 10–50 s. Our study revealed that this method was successful when the velocity of the main airflow was low (about 1 m s^{-1}) and the temperature of the cooling tubes was cryogenic (about −190 °C). However, all frost could not be removed under other conditions in which the frost was strongly attached to the cooling tubes.

In the present study, we propose a new defrosting method in which we add solid particles to the air jet. The purpose of the solid particles is to improve the performance of the jet. Aihara et al. investigated defrosting methods using solid particles in the form of a fluidized bed (Aihara et al., 1989, 1996, and, 1997). They constructed a fluidized bed using glass particles with diameters of 1 mm. Cooling tubes were placed inside the fluidized bed and frost was successfully removed. Takeuchi et al. proposed a new heat exchanger that had circulating solid particles inside; they developed a 10 kW heat exchanger and conducted a field test (Takeuchi et al., 1990). In their experiment, the heat exchanger successfully operated without frost formation; however, some problems must be overcome to use the heat exchanger in practice. One is the difficulty in designing a compact version of the heat exchanger. Another is the large amount of power needed to fluidize the particles; this leads to a large decrease in overall efficiency. In this study, we do not propose that particles will be constantly fluidized; instead, the jet containing the particles will be ejected at intervals of several tens or hundreds of seconds, and the duration of each jet will only be approximately 1 s. The power necessary for this defrosting method is expected to be dramatically reduced compared to that in the previous fluidization method.

In this study, a single-row heat exchanger was defrosted using the proposed method. The refrigerant in the heat exchanger was liquid nitrogen. Results from tests of the proposed method are presented in this paper. We also investigated how the effectiveness of the method is influenced by the interval between applications of the jet, the number of particles, and their diameters.

2. Experimental setup

2.1. *Development trajectory*

The validity of the particle-jet defrosting method was demonstrated through experiments using a single-row heat exchanger. The single-row heat exchanger used in this study is shown in Fig. 1. The heat exchanger was composed of five stainless steel tubes, each with a diameter of 6 mm. The tube pitch was 12 mm. The manifolds for refrigerant were located at the top and bottom of the heat exchanger, and they were set outside the flow channel. The cross-section of the flow channel was 60 × 60 mm. Airflow inside the channel was controlled by an air conditioner to 20 °C ± 1 °C and 50% ± 3% relative

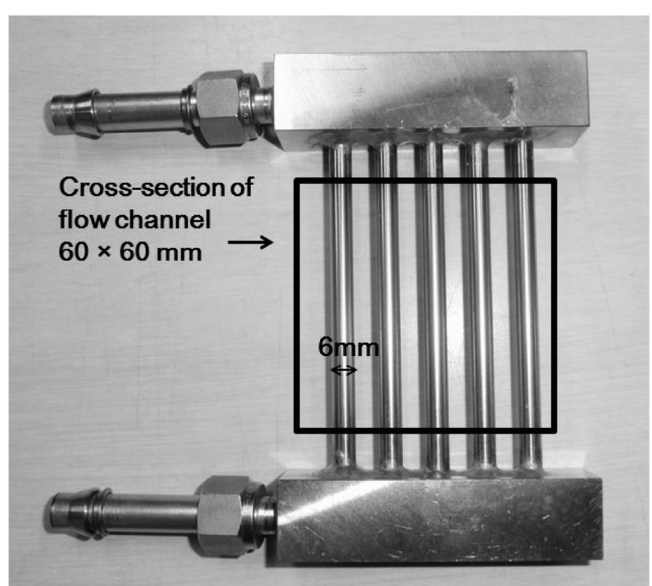

Fig. 1 – Heat exchanger used in this study.