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Hydraulic performance of a microchannel PCHE

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ABSTRACT

A newly developed type PCHE (Printed Circuit Heat Exchanger), which has a longitudinal corrugation flow channel, was fabricated using etching and diffusion bonding to evaluate its hydraulic performance. The result of a three-dimensional numerical simulation are presented, conducted using commercial Computational Fluid Dynamics (CFD) software FLUENT in the lower Reynolds number range ($Re < 150$). The validity of the numerical results through comparison with the measured data obtained via experimentation with helium gas is demonstrated. The results of CFD prediction show fairly good agreement with experimental data. The local friction factors associated with different hydraulic diameters and inclination angles are discussed. The correlation of the friction factor is presented from numerical simulation results.

1. Introduction

Over the last century, heat exchangers have been used in a wide variety of applications. Typical among them are air-conditioning, heat recovery, refrigeration and industrial systems. Over time, the demand for compactness and high efficiency in heat exchangers has been consistently increased.

The PCHE (Printed Circuit Heat Exchanger) was invented in 1980, in Australia, and subsequently incorporated into refrigerators in 1985, by Heatric (UK). The PCHE is a highly-integrated plate type compact heat exchanger. The development of PCHE was an innovation in manufacturing technology with regard to photo-etching and diffusion bonding. In the fabricated PCHE, flow channels are etched chemically into metal plates and plates are then stacked using diffusion bonding. It is possible to construct a PCHE with a flow channel diameter that is much smaller than that of a standard plate heat exchanger by employing these techniques. This technology allows for an increase in the heat transfer coefficient, while simultaneously increasing the friction factor. Because smaller hydraulic diameters result in a greater pressure drop within the heat exchanger, the minimal flow channel size of PCHEs is somewhat limited by pressure drop characteristics, where the pressure drop of a PCHE is dependent upon the corrugation angle and the hydraulic diameter [1–3].

Researchers have expended considerable effort in attempting to understand the characteristics of hydraulic performance and to predict the pressure drop of a PCHE. Ishizuka et al. [4] performed an experimental study of the thermal-hydraulic characteristics of a PCHE employing zigzag flow channels. Ngo et al. [1,2] evaluated a PCHE imbued with an S-shaped fin configuration, similar to a sine wave, based upon 3D numerical simulations incorporating a CO_2 side and H_2O side. The thermal-hydraulic performance of this PCHE was then compared with the performance of an exchanger having a zigzag flow channel. Nikitin et al. [3] investigated the performance of a PCHE in an experimental supercritical CO_2 loop. Pra et al. [5] evaluated a wavy channel PCHE and compared their experimental data with calculated data obtained from CFD simulation. Kim et al. [6] performed a numerical analysis using FLUENT (6.3) to investigate the performance of a PCHE with airfoil shaped fins. In addition, these authors, using CFD, investigated the effect of the bending angle on pressure drop characteristics in zigzag PCHEs [7]. Finally, Kim et al. [8] investigated the performance of corrugated channel PCHEs using a helium test facility and CFD simulation. Although the preceding researches are very useful for investigating the performance of PCHEs, it is necessary to evaluate the hydraulic performance of them according to various channel sizes and configurations.

The research presented herein represents an effort to contribute to the evaluation and prediction of the hydraulic performance of PCHEs with respect to variations in hydraulic diameter and the corrugation inclination angle of the main flow relative to vertical direction. The experimental evaluation of certain geometries was conducted and compared with simulation results, while the

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remaining cases were evaluated solely by numerical methods. The calculation model focuses on the single cell, the smallest repeating unit of the channel, composed of two crossing ducts. Friction factor values were obtained for use in evaluating the hydraulic performance of PCHEs by experimental and numerical approaches. For reference, we will present the numerical correlation of the friction factor as obtained in the numerical simulation results.

2. Experimental approach

Although the experimental apparatus was designed to investigate the thermal and hydraulic parameters of helium gas on the PCHE, this paper focuses solely on the pressure drop characteristics.

2.1. Experimental procedure

The hydraulic performance of the PCHE was measured using the test apparatus depicted in Fig. 1. In this setup, helium flows into the hot side of the heat exchanger after passing through the helium compressor (Genesis Vacuum Technology, 2.1 Helium Compressor), enters the cold side after being cooled with liquid nitrogen and is then finally returned to the compressor. Four silicon diodes (DT-670-SD, Lakeshore) were attached to the inlets and outlets of the heat exchangers, and various mass flow rates were recorded. Two pressure transducers (SENSYS, PSHD 30 bar) and two low temperature pressure transducers (Kulite, CT-375 M, 30 bar) were attached to the hot inlet and cold outlet streams. The pressure drop was calculated based upon the differences in measured pressures of each stream. The mass flow rate was controlled using a mass flow controller (Bronkhorst: Helium, 4000 slpm). The pressure values and the mass flow controller's data were both collected using devices manufactured by National Instrument (SCXI-1000, SCXI-1125, SCXI-1328). Silicon diodes were connected to a Lakeshore Temperature monitor 213, and data was collected together with the pressure and mass flow information, in LABVIEW. In order to prevent heat loss during the course of the experiment, tests were conducted inside a vacuum chamber. Operating the apparatus at consistent initial conditions for a 1-h period, prior to the actual experiment, allowed us to ensure the experimental conditions had reached the desired steady state. After reaching steady state, an additional period of 10 min of operation was necessary for us to obtain steady state conditions at a given mass flow rate. The experimental results were drawn from the final 2 min of this 10 min period.

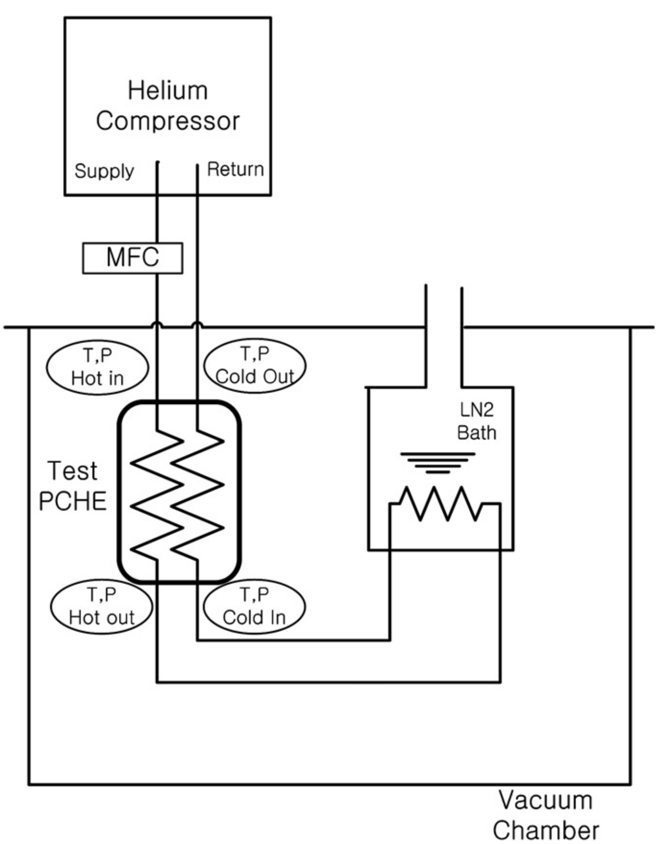

Fig. 1. Schematic of test apparatus.

2.2. PCHE specification

The PCHE used in this study was fabricated using chemical etching and diffusion bonding, with stainless steel plates of 100 μm thickness. The plate was etched at a 45° incline to a depth of 26 μm and a width of 55 μm (a semicircular shape); a depiction of the detailed pattern is presented in Fig. 2. The PCHE incorporates transverse bypass holes to avoid mal-distribution of the flow. 250- and 500-layer sections (125 and 250 layers per stream, respectively) of etched plating were stacked and diffusion bonded to form a complete PCHE, as shown in Fig. 3. The PCHE has core dimensions of 50 × 25 × 150 mm (250 layers) and 50 × 50 × 150 mm (500 layers). Table 1 summarizes other details of the fabricated PCHEs.

2.3. Results and discussion

The overall pressure loss of the PCHE observed during testing includes the pressure lost at the inlet and outlet of the exchanger, any friction lost in the channel, any form lost through the bypass hole and any loss stemming from an acceleration effect due to the change in density between the inlet and outlet.

The diameter of the headers and bypass holes is larger than the hydraulic diameter of the flow path channel. As such, with respect to our experiment, the pressure loss is very small at the header and bypass holes and the contribution of the acceleration effect is negligible.

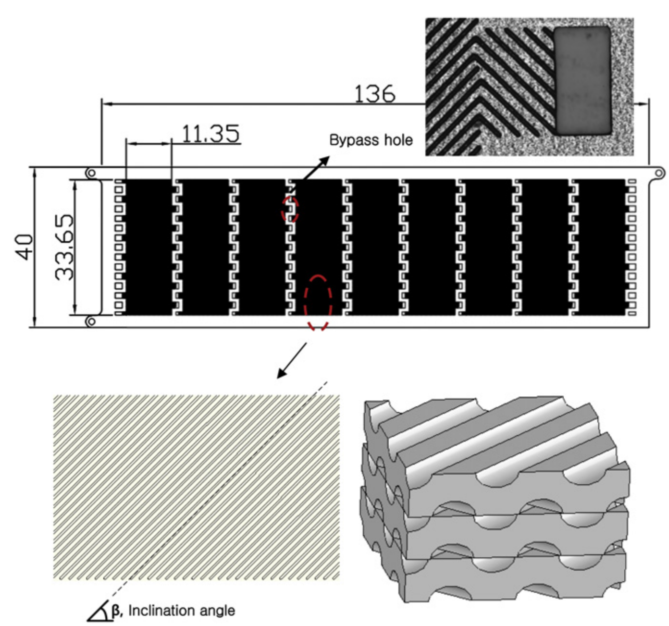

Fig. 2. Flow configuration of proposed PCHE.