Flow Measurement and Instrumentation 46 (2015) 93–102

Contents lists available at ScienceDirect

Flow Measurement and Instrumentation

journal homepage: www.elsevier.com/locate/flowmeasinst

Development of measurement method of pressure distribution inside a compact and complex heat exchanger

Hyo Chang Cho [a], Byung Jun Na [a], Cheol Hee Ahn [a], Bo Sung Shin [b], Sang Hu Park [a], Changmin Son [a], Hyeong Soon Moon [c], Jeung Sang Go [a,*]

[a] *School of Mechanical Engineering, Pusan National University, Busan 609-735, Republic of Korea*
[b] *Department of Cogno-mechatronics engineering, Pusan National University, Busan 609-735, Republic of Korea*
[c] *Korea Institute of Industrial Technology, Busan 618-230, Republic of Korea*

ARTICLE INFO

Article history:
Received 12 June 2015
Received in revised form
7 September 2015
Accepted 15 October 2015
Available online 22 October 2015

Keywords:
Heat exchanger
Cross corrugated
Microchannel
Pressure tapping
Friction factor

ABSTRACT

To enhance the thermal efficiency of aero-engines, many works on numerical and experimental evaluation of cross corrugated heat exchangers for applications such as intercoolers and recuperators have been reported. However, numerical analyzes of unit cells or of corrugated flow passages in cross corrugated heat exchangers cannot be compared directly with experimental analyzes performed only at inlets and outlets. This paper presents results of the direct measurement of static pressure distribution in a corrugated flow passage: measurement was performed by embedding pressure tapping holes connected with microchannels into the corrugated plate, which had a thickness of 200 μm. Four corrugated plates were stacked and brazed to manufacture a real scale cross corrugated heat exchanger. The static pressure distribution was successfully measured inside the compact and complex heat exchanger. The friction factors for different Reynolds numbers were correlated for hydrodynamic performance evaluation. Finally, the friction factor was discussed with a consideration of the accuracy of the manufacturing of the cross corrugated heat exchanger.

1. Introduction

Aircraft gas-turbine engines operate on the simple Joule–Brayton cycle. The ideal cycle consists of isentropic compression in a compressor, isobaric heating in a combustor, and expansion in a turbine. Then, the total power or thrust can be obtained from the enthalpy–entropy diagram. To improve the efficiency of the gas turbine cycle, the gas entering the combustor can be heated to allow for less heat input or can be cooled down in the compressor for less work input. Similar to intercooling, reheating in the turbine can also enhance turbine efficiency by increasing the work done by the turbine.

To increase the overall efficiency of a gas turbine, heat exchangers such as recuperators and intercoolers are often considered to heat the combustor and compressor. When the thermal efficiency of a heat exchanger is considered in terms of minimum volume and light weight, a cross corrugated heat exchanger (CCHX, hereafter) is the most practical candidate to apply for the recuperator and intercooler. A CCHX has a high ratio of heat transfer surface to volume because it has a high ratio of heat transfer surface to volume, and rigorous hydrodynamic mixing resulted from corrugation [1,2].

Fig. 1 provides a schematic of the CCHX. Number of corrugated plates is stacked with an inclination angle between adjacent corrugated plate rows, β. Using the corrugated plates, the hot and cold sides of the heat exchanger are separated with a particular ratio of pitch-to-height. It has been determined numerically and experimentally that the thermal performance of the CCHX depends on the inclination angle and the ratio of pitch to height of the corrugated plates [3].

There is a limit to analyze the full model of the CCHX numerically. As introduced in the previous work [4], even one unit cell of the corrugated flow passage in the numerical domain is meshed with approximately millions grids to obtain insensitive solution to grid density and for one corrugated flow passage formed by a pair of upper and lower corrugated plates, at least more than 300 million grids are required for simulation. Therefore, most previous works have reported the hydrodynamic performance of unit cells and have possibly extended their analysis to the single corrugated flow passage [5]. Various geometrical parameters such as the inclination angle, pitch and height, and the Reynolds number have been examined. Also, various turbulent models have been studied and their results have been compared with data in the literature [4,6] and validated with experimental

* Corresponding author.
E-mail address: micros@pusan.ac.kr (J.S. Go).

http://dx.doi.org/10.1016/j.flowmeasinst.2015.10.008
0955-5986/

Nomenclature

A_s	upper and bottom wetted surface area of unit cell, m^2
A_{in}	inlet area of unit cell, m^2
D_h	hydraulic diameter, m
L	microchannel length, mm
L_c	length between two pressure tapping holes, mm
l_e	entrance length of the CCHX, mm
$\dot{m}$	mass flow rate, kg/s
p_i	initial pressure at the inlet of the microchannel, Pa
Re	Reynolds number
u_{avg}	average velocity through the unit cell, m/s
$\forall$	volume of the unit cell, m^3

Greek symbols

ΔP	difference of the measured static pressures along distance, Pa
β	inclination angle, °
μ	dynamic viscosity of fluid, kg/m s
ρ	density of fluid, kg/m^3
τ_m	microchannel time delay, s

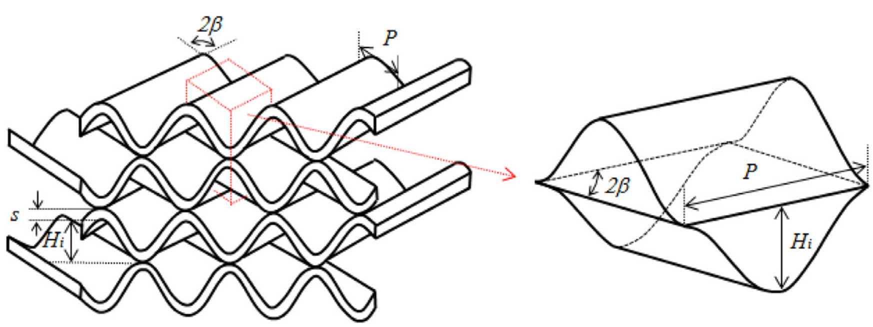

Fig. 1. Configuration of the stacked CCHX and unit cell in the corrugated flow passage.

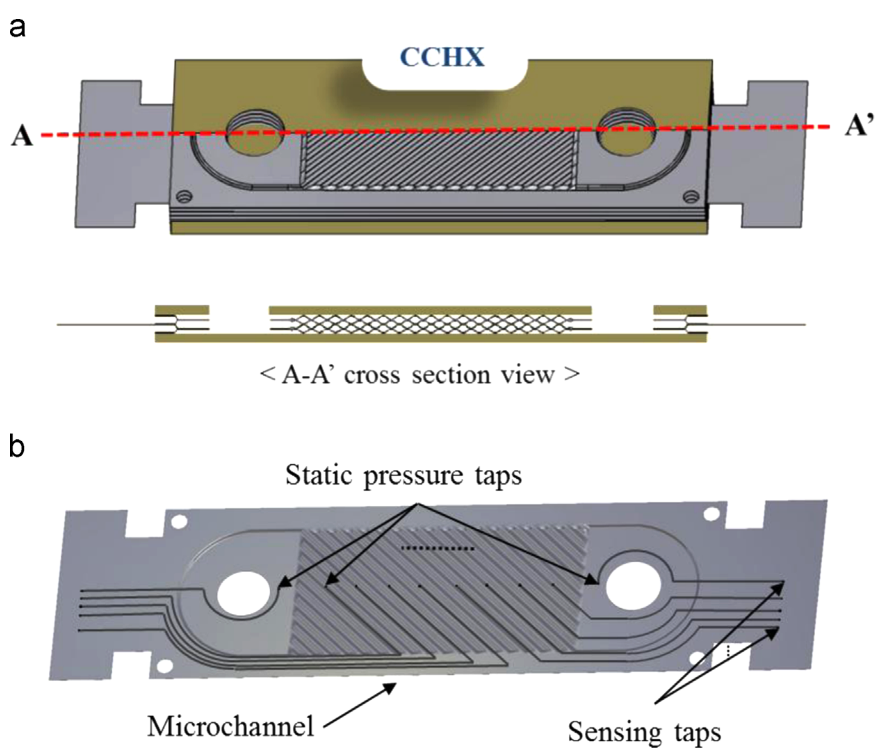

Fig. 2. CCHX with the microchannel-embedded corrugated plate.

data obtained for conventional cross-corrugated surfaces [7].

One alternative is to examine the hydrodynamic performance experimentally. However, the hydrodynamic performance can be evaluated only by measuring pressure at inlets and outlets because it is not possible to install bulky sensors in the corrugated flow passage of the compact and complex CCHX without disturbing the flow [8]. Instead, a large model with geometric similarity was used for the experiment. An inclination angle in the range of 30–79°, a ratio of pitch-to-height (P/H) in the range of 2.0–4.0, and a Reynolds numbers in the range of 500–5000 were considered [9].