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New printed circuit heat exchanger with S-shaped fins for hot water supplier

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Abstract

A new PCHE with an S-shaped fin configuration was applied to a hot water supplier in which cold water of 7 °C is warmed to 90 °C through heat-exchange with supercritical CO_2 of 118 °C and 11.5 MPa pressure. The fin and plate configurations were determined using 3D CFD simulations for the CO_2 side and H_2O side and the thermal–hydraulic performance of hot water supplier was evaluated. Compared with a hot water supplier that is currently used in a residential heat pump, the new PCHE provides about 3.3 times less volume; and lower pressure drop by 37% in the CO_2 side and by 10 times in H_2O side.

Keywords: Printed circuit heat exchanger; Supercritical CO_2; Hot water supplier; Waste heat recovery; Overall heat transfer coefficient; Pressure drop

1. Introduction

Compactness and efficiency improvement of heat exchangers are important, particularly for cost reduction, in all energy system: modern air-conditioning, heat pumps, refrigeration, and waste heat recovery systems for variety of residential, industrial, automotive and process industry applications. A Printed Circuit Heat Exchanger (PCHE) is a promising candidate for compact heat exchangers. Two technologies are applied to manufacture the PCHE: photo-etching and diffusion bonding.

Compactness of the heat exchangers is usually expressed by using the Colburn j factor, given as

$$j = \frac{D_h}{4L} Pr^{2/3} N, \tag{1}$$

where N = NTU (number of thermal units), and

$$N = (T_o - T_i)/\Delta T_{LMTD}. \tag{2}$$

Reduction of the hydraulic diameter engenders a decreased active length L or heat exchanger size at the same Colburn j factor, Pr and N conditions, as shown in Eqs. (1) and (2) (Hesselgreaves, 2001). The hydraulic diameter is easily reducible in PCHEs because photo-etching technology can mill small flow channels. Such reductions are not achieved easily in usual plate fin exchangers because plate fin manufacturing and brazing bonding costs increase with increase of fin density or reduced hydraulic diameter. For PCHE, hydraulic diameter reduction is not limited by the manufacturing cost increment, but by the pressure drop increment, which is roughly inversely proportional to the channel diameter. Although the pressure drop is not a constraint for application to high system-pressure plants, it will be the main barrier to the use of such heat exchangers. A previous study introduced a new PCHE with the S-shaped fins [1]. It reduces the pressure drop while retaining high heat-transfer performance, thereby extending the PCHE application field to lower-pressure plants.

The diffusion bonding technology maintains the parent material strength because of no flux, braze or filler exist in the heat exchanger core. This provides high capability of corrosion and temperature resistance.

The new PCHE was proposed for a recuperator of a carbon dioxide (CO_2) gas turbine cycle in the previous study that eliminates the drawback of high pressure drop in a

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Nomenclature

A	surface area of heat exchanger, m^2	T	temperature, °C
c_p	specific heat, J/kg K	t	wall thickness, mm
D_h	hydraulic diameter, mm	U	overall HTC, W/m^2 K
d_f	fin width, mm	V	volume, m^3
$d_y - d_f$	fins gap, mm	W	flow rate, kg/h
f	friction factor		
h	local HTC, W/m^2 K	*Greek symbols*	
j	Colburn factor	θ	fin angle
J	number of banking configurations	Δ	denotes difference
k	thermal conductivity, W/m K	σ	stress, MPa
L	active heat exchanger length, mm		
L_x, L_y, L_z	dimension in x, y, z directions	*Subscripts and superscripts*	
l_x	fin length in the x-direction, mm	CFD	computer fluid dynamics
M	number of simulation parts	c, h	cold, hot fluid, respectively
N	number of thermal units	i, o	inlet, outlet, respectively
Nu	Nusselt number	LMTD	log-mean temperature difference
n	number of fluid flow channels	m	Number of simulation parts
P	pressure, MPa	w	wall
Pr	Prandtl number	tot	total
Q	heat load, W		

conventional PCHE with zigzag flows [2,3] keeping the advantage of high heat transfer performance. The purpose of this study is to expand applicability of the new PCHE from the gas (CO_2)-gas (CO_2) heat exchanger of the recuperator for the CO_2 gas turbine cycle system to a gas (CO_2)-liquid (H_2O) heat exchanger or a hot water supplier for a residential use [4].

2. Analytical method

2.1. Flow channel configuration with S-shaped fins

The flow channel configuration is shown in Fig. 1. The fins with an S-shape are made from a sine curve. The fin angle θ is slope of the tangential line at the center of the fin measured from the horizontal line, as shown in Fig. 2. Points A and B are the peaks and trough of a sine curve and the distance from A to B is defined as the fin length;

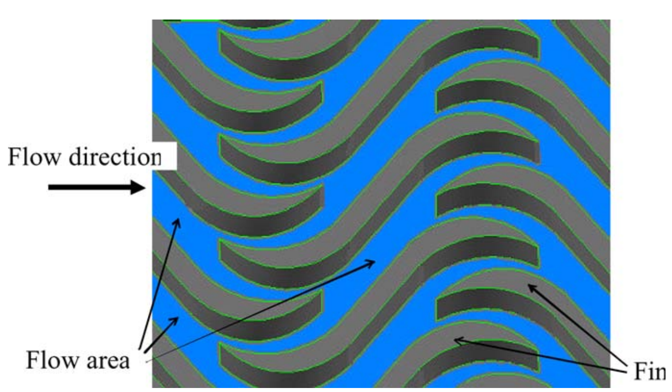

Fig. 1. Flow channel configuration.

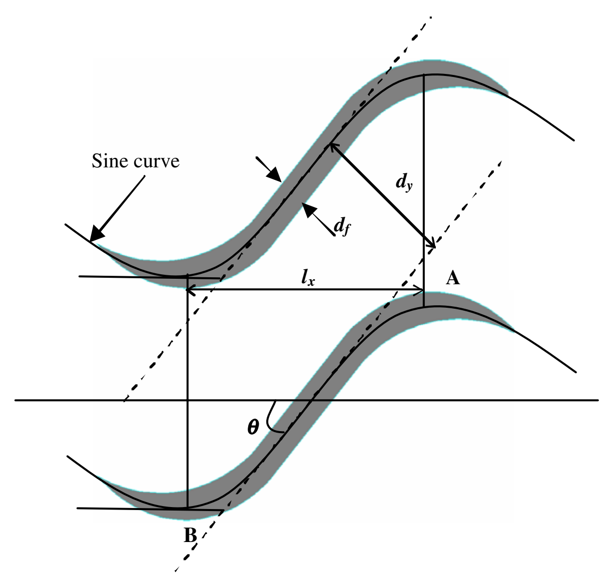

Fig. 2. Fin shaped in the models.

fin width is d_f, and the fin gap is determined as ($d_y - d_f$). The same pattern is repeated as illustrated in Fig. 1. The S-shaped fins are used for both sides of hot and cold channels.

2.2. Plate configuration model

Typical plate configurations used for three-dimensional computational fluid dynamic (3D-CFD) simulations are illustrated in Fig. 3 for a single-banking and a double-banking model. A cold plate and a hot plate are stacked alternatively, so-called single-banking. One cold plate and