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Experimental evaluation of three different configurations of constructal disc-shaped heat exchangers

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ABSTRACT

The aim of this work is to experimentally evaluate three different compact branched heat exchangers, measuring, for every single device, the thermal efficiency and the pressure drop. The generality of the analysis of phenomena is enhanced by a comparison of the performance of different refrigerant fluids. In the first configuration, the channels have been designed, varying the inner diameter, to allow for an average constant flow speed throughout the exchanger. In the second one, the flow Reynolds number inside of the channels has been maintained constant. The last configuration is built according to the constructal diameter variation, as indicated in Bejan Constructal Theory. The exchanger manufacturing process is described in detail. The test bench has been assembled using a hot source (Heating Plate with a power of 500 W) and a submersible pump, needed for the fluid recirculation, coupled with flowmeters, to control the mass flow rate within a specific range. The data obtained from several comparative tests have been analyzed, to determine the optimal solution for each refrigerant among the different exchangers.

1. Introduction

The aim of this work is the identification of the optimal configuration for a branched heat exchanger, using different refrigerant fluids. To evaluate the devices performance, the exchangers thermal efficiency and the pressure drop, in the different working conditions, have been measured. The branched configuration has been introduced by Adrian Bejan, in the "*constructal theory (CT)*" [1,2]. The scope of the author is to introduce a new trend in the conceptual design of energy systems. From Bejan point of view, the global performance, based on the "*constructal*" principle, is maximized by balancing and arranging the various flow resistances (the irreversibility) in a flow system, free to morph. The direction of this development is from large-scale applications toward micro-scales applications. The large-scale tree-shaped designs of electric power distribution systems and networks for natural gas and water are now invading small-scale designs such as fuel cells, heat exchangers and cooled packages of electronics. These flow configurations have several common properties: freedom to morph, multiple scales, hierarchy, non uniform (optimal according to CT) distribution of scales through the available volume, compactness and finite complexity. In alternative to the CT configuration, two other branched heat exchangers have been developed, with a particular geometry for the interior channels. The three configurations are similar, but differ in the internal channels geometry. Referring to Fig. 1, the heat exchangers are composed of two facing disks; on each disk, semi-circular excavations are obtained, to realize a circular-shaped channel when the two disks are coupled. The fluid enters through a hole on the upper disk and moving into the heat exchanger inner channels. From the center of the device, three channels depart; two branching levels are considered, for a total of six channels after the first bifurcation and twelve channels after the second. The twelve output channels are equally shared on the outer circumference, by obtaining a 30° overlapping exit. The comparison of three configurations was performed for three different flow rates: 2 L/min, 4 L/min and 10 L/min. To achieve a more reliable comparison, several tests were carried out for each heat exchanger and for each mass flow rate so that the validity of the final results could be evaluated statistically assuming that the flow will equally split in the two branches (Fig. 2).

2. Geometry description

The continuity equation, assuming that the flow will equally split in the two branches, can be written for the generic node:

$$m_i = 2m_j \tag{1}$$

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Nomenclature

Al	aluminum
c	water specific heat [J/kg·K]
CIPM	International Committee for Weights and Measures
D	diameter [m]
Fe	iron
ISO	International Organization for Standardization
GUM	Guide to the Expression of Uncertainty in Measurement
k	coverage factor
L	channel length [m]
m	mass flow rate [l/min]
Mn	manganese
N	measures number
NMI	National Metrology Institutes
p	pressure [bar]
P	power [W]
Re	Reynolds number
RMO	Regional Metrology Organizations
T	temperature [°C]
U(x)	expanded uncertainty
$u_c(x)$	combined standard uncertainty
W	fluid velocity [m/s]
x	generic measurement value

Greek symbol

Δ	difference
μ	dynamic viscosity [kg/m·s]
η	efficiency
ρ	density [kg/m^3]
σ_x	standard deviation

Subscripts

0	initial diameter, initial channel length
1	diameter or length before bifurcations
2	diameter or length after bifurcations
1, …, 12	measure points
amb	ambient
in	inlet
i	ith value
j	jth=ith + 1 value
m	average, medium
out	outlet

$$\rho W_i \frac{\pi D_i^2}{4} = 2\rho W_j \frac{\pi D_j^2}{4} \quad (2)$$

ρ is the fluid density, W is the mean velocity in the channel, D the channel diameter, “i” and “j“ represent the channel before and after the bifurcation. All tested configurations are characterized by the following common parameters:

- Disk diameter D = 150 mm
- Thickness disk s = 15 mm
- Initial channel diameter D_0 = 12.96 mm
- Initial length L_0 = 11.20 mm.

The value of length L_0 is obtained by scaling the model proposed in [2,11,12].

2.1. Configuration A

For the first configuration, a law of diameters variation such that the mean velocity of efflux remains constant in the branches, is adopted. From equation (2), being ρ and the velocity W constant, it is obtained:

$$\frac{D_j}{D_i} = \frac{\sqrt{2}}{2} \cong 0.707 \quad (3)$$

The same relationship to calculate the length variations has been used:

$$\frac{L_2}{L_1} = \frac{\sqrt{2}}{2} \cong 0.707 \quad (4)$$

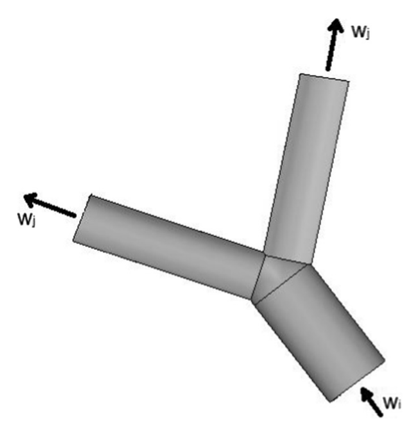

Fig. 2. Generic considered node.

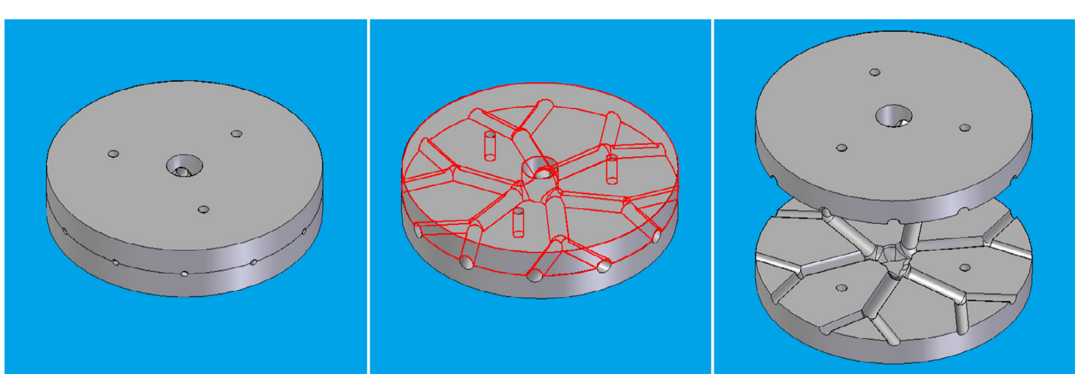

Fig. 1. Compact branched heat exchanger.