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ScienceDirect
Chemical Engineering and Processing 47 (2008) 229–236
Chemical Engineering and Processing
Process Intensification
www.elsevier.com/locate/cep

Experimental study of constructal distributor for flow equidistribution in a mini crossflow heat exchanger (MCHE)

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Received 18 October 2006; received in revised form 16 January 2007; accepted 21 February 2007
Available online 3 March 2007
With contributions of Nicole Henriet and Raymond Sedano.

Abstract

This paper examines experimentally the effects of constructal distributors or collectors, built on a binary pattern of pores, on flow equidistribution in a multi-channel heat exchanger. Thermal performance and pressure drop have been determined with different assembly configurations of constructal distributors, conventional pyramid distributors and a mini crossflow heat exchanger (MCHE). Experimental results show that the integration of constructal distributors/collectors could homogenize the fluid flow distribution and consequently lead to a better thermal performance of the MCHE, but it also results in higher pressure drops. Among all tested assembly configurations, the configuration where the inlet is equipped with a conventional pyramid distributor, and the outlet is equipped with a constructal collector (Apec) shows a relatively better thermal performance as well as low pressure drops under experimental conditions considered.
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Keywords: Flow maldistribution; Mini crossflow heat exchanger (MCHE); Constructal distributor; Conventional pyramid distributor; Thermal performance; Pressure drops

1. Introduction

In most theoretical calculations of thermal performance and pressure drop evaluation of multi-channel heat exchangers, it is assumed that the flow is uniformly distributed over different channels or tubes. In fact, this assumption is questionable under operating conditions in real-world engineering, and people have noticed the problem of decreased thermal performance due to flow maldistribution over the entrance or exit face of heat exchangers [1–3]. In recent years, a lot of work has been realized by numerical modelizations to simulate the flow distribution, for it is not easy to get flow uniformity in reality. Ranganayakulu and Seetharamu [4,5] developed a mathematical equation using finite element analysis to generate different types of fluid maldistribution models both in crossflow tube-fin and plate-fin compact heat exchangers. Lalot et al. [6] found that the ratio of the maximum to the lowest velocity in the inlet of the counterflow heat exchanger is about 4, with a model of crossflow electrical heater. Results indicated that flow maldistribution caused a loss of heat exchange effectiveness up to 25%. From the above discussion and a number of other related research works [7–9], one may conclude that the fluid maldistribution is especially detrimental in micro or mini-scale heat exchangers and finding effective methods to solve this problem is a real challenge to optimize the global performance of heat exchangers.

Beside a number of factors such as manufacturing tolerance, channel surface roughness, fouling, etc. that cannot be avoided due to manufacture accuracy limitation, the configuration of inlet distributors (as well as outlet collectors) significantly affects the velocity distribution of the exchanger core. Various methods have been proposed with the purpose of obtaining a uniform distribution, including the employment of a uniformly perforated grid [6], a baffle [7] or a second header [10]. The aim of equidistribution is reached at the cost of a high pressure drop and of flow dispersion, both undesirable from the engineering point of view. It is also reported [6] that it is pos-

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doi:10.1016/j.cep.2007.02.028

sible to modify the geometrical dimension of the distributor to homogenize the velocity distribution. This, to some extent, points toward a completely different design concept of a novel constructal distributor with its specific internal geometrical structures.

The so-called "constructal theory", developed by Bejan and his co-workers from 1996 on, is a quite general theory of multi-scale shapes and structures in nature and engineering [11–13]. In "constructal" terms, the distributor or collector problem is topologically one of connection between a point and a surface. The "point" is here the single inlet tube or pore, and the surface is the entrance surface of a heat exchanger fed by the distributed flow. Some detailed work concerning the design and scaling laws of fluid distributors by the constructal approach are presented in earlier papers of Luo and co-workers [14–16] and it has been proved qualitatively by high-speed camera pictures that the constructal distributors could approach fluid equidistribution.

Our work will start with an aluminum MCHE on which inlets and outlets for the two fluids may be equipped with novel designed constructal distributors. Conventional pyramid distributors that have equal external shape but without any interior structure were also used for comparison. Measuring both pressure drops and thermal flux transferred at different flow-rates gives the global evaluation of heat exchanger performance. The objective of the optimization is to increase the thermal performance while pressure drop increases as little as possible.

2. Devices

2.1. Constructal distributor versus conventional pyramid distributor

In recent years, the laser polymerization (stereolithography) technology [17–19] has been introduced in the fields of chemistry and chemical process engineering for the fabrication of prototypes with polymer material. The constructal distributors used in our experiment were manufactured at the "Département de Chimie Physique des Réactions" (DCPR), a laboratory of the ENSIC-group in Nancy, using stereolithography, with a photosensitive epoxy resin (RP Cure 400 AR) manufactured by RPC S.A. (Marly, Switzerland, now 3-D Systems). The design is defined by using a CAD tool and the program is fed to the computer controlling the laser machine.

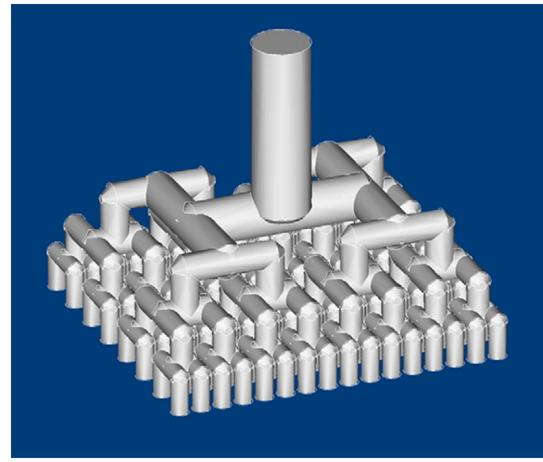

Fig. 1. Structure and geometrical dimensions of the constructal distributor with 7 scales and 128 outlets. The side of the square is 56.5 mm.

Fig. 1 gives the internal pore structure of this constructal distributor of the present investigation. The main geometrical dimensions are given in Table 1. The pore space has the structure of a sequence of seven generations of T- or Y-bifurcations or divisions. The resulting channels are indexed from 0 to 7, including the inlet channel (index 0). The latter is split perpendicularly into two opposing channels (index 1), and each of these is again split into two channels (index 2), such that channels of indices 1, 2 and 3 are coplanar. The ends of pores 3 are elbows (downcomers), which descend into 2 new planes successively, containing pores of indices 4 and 5 in one plane and pores of indices 6 and 7 in the other. Since there are seven generations of bifurcations, there are $2^7 = 128$ final outlet channels, opening on the outlet face of this "pyramid". The present distributor was designed to distribute equally an input flow on the square inlet surface of the MCHE with a "resolution" of approximately 4 outlet ports per cm^2, corresponding to a theoretical outlet surface of 32 cm^2 (side = 56.5 mm).

To determine the channel diameter of each scale, the factor 1.26 ($2^{1/3}$) is applied approximately. It is determined by an optimization that specifies the total flow-rate and accounts for both viscous dissipation and total pore volume [16], and is sometimes referred to as "Murray's law" in literature.

Table 1
Dimension parameters of the constructal distributor

Layer	Scale, *k*	Number of channels, *N*	Channel diameter, *d* (mm)	Horizontal length, *l* (mm)	Vertical downcomer (mm)
	0	1	8		25
First	1	2	6.3	12	
	2	4	5	12	
	3	8	4	6	6.3
Second	4	16	4	3	
	5	32	3.15	6	4.725
Third	6	64	2.5	1.5	
	7	128	2.5	3	5
Total		255		43.5	41.025

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