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Research paper

Predicting the flow distribution in compact parallel flow heat exchangers

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HIGHLIGHTS

- A flow network can accurately simulate the flow in compact heat exchangers.
- The tube to header area ratio (AR) is a good indicator for flow mal-distribution.
- As AR increases, flow mal-distribution (FMD) becomes sensitive to increasing *Re*.
- As AR increases, FMD becomes sensitive to decreasing pipe length.
- Friction dominates FMD, but as AR increases inlet losses affect early channels.

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ABSTRACT

This paper presents a computationally efficient flow network model to predict the flow distribution in compact multi-channel parallel flow heat exchangers. Compact U-type and Z-type heat exchangers with nine parallel channels were used as test case on which the model was validated to within 4–8% in terms of non-dimensional flow distribution ratio. The model was used to perform a sensitivity analysis of flow mal-distribution with changes in operational and geometric boundary conditions. The results show that the tube to header area ratio is an important global parameter for controlling mal-distribution. As the area ratio increases, flow mal-distribution becomes more pronounced and more sensitive to increased Reynolds number and decreased parallel pipe length.

1. Introduction

This paper presents a flow network model to simulate flow distribution in compact parallel flow heat exchangers. The model is fast to solve and equips the designer with a useful tool to investigate the sensitivity of the head losses and flow mal-distribution from the components that make up the heat exchangers.

Parallel flow heat exchangers have multiple applications such as evaporators and condensers in refrigeration units, solar energy collectors and cooling systems for electronics and nuclear reactors amongst others [1,2]. Flow mal-distribution in a heat exchanger can significantly reduce performance [3] and is therefore of interest for research. A number of papers focus on measuring techniques [1–5] or numerical simulation such as Computational Fluid Dynamics (CFD) [6]. Flow mal-distribution can be caused by a combination of heat exchanger manifold geometry, design features and operating conditions [7]. Therefore, despite these approaches providing detailed information and insight into the fluid behaviour, iterative improvement of the heat exchanger design is time consuming and costly.

A design method that is fast and can accurately predict the flow distribution in compact heat exchangers is required, and is therefore the subject of this paper. Flow network models to predict the flow distribution in pipe networks are well established [8]. However compact heat exchangers often involve developing flows and therefore applying correlations from fully developed flows would result in significant errors. The pipe network approach was adapted to include appropriate minor losses and entrance effect friction factor correlations, enabling the flow network model to become an accurate design tool for compact heat exchangers. This paper is therefore organised in the following manner: A description of the heat exchanger geometry considered as a case study is provided in Section 2, thus setting the geometrical boundary conditions for this problem. Section 3 describes the iterative network model and

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Nomenclature

A	area (m^2)
AR	tube/header area ratio
β	flow ratio
$\overline{\beta}$	average flow ratio
C_F	correction factor
D	diameter of parallel pipes
D_h	hydraulic diameter (m)
DR	diameter ratio
Δ	head/flow ratio
dQ	change in flow rate (m^3/s)
f	Darcy friction factor
f_{app}	apparent friction factor
g	acceleration due to gravity (m/s^2)
h_f	head loss (m)
K	loss coefficient
L	pipe length (m)
L_e	entry length (m)
N	number of parallel pipes
ν	kinematic viscosity (m^2/s)
P	wet perimeter (m)
Q	flow rate (m^3/s)
Re	Reynolds number
s	non uniformity factor
V	velocity (m/s)

Subscripts

i	channel designation
in	inlet pipe
j	loop designation
k	time step iteration
m	manifold
SE	sudden enlargement
PR	pressure recovery

Section 4 describes the head loss coefficients for the various components. Finally Section 5 validates the model by comparing simulated results with experimental results found in the literature [1]. Finally Section 6 investigates the sensitivity of the flow distribution due to the various components that make up the compact heat exchanger.

2. Parallel flow heat exchangers

Parallel flow heat exchangers consist of an inlet and an outlet manifold joined by a series of parallel branches. The heat exchanger is typically referred to as an U-type or a Z-type, depending on the flow direction. The heat exchangers investigated here each consist of two square manifolds joined by 9 parallel circular pipes as shown in Fig. 1a and b. The heat exchangers had a tube to header flow area ratio varying between 0.022 and 0.144, which was defined as:

$$\mathrm{AR} = \frac{N\pi D^2}{4A_m} \tag{1}$$

In which N is the number of parallel pipes and D the diameter of the parallel channels. A_m is the manifold area defined as:

$$A_m = H^2 \tag{2}$$

The dimensions of the heat exchangers are given in Fig. 2 and Table 1.

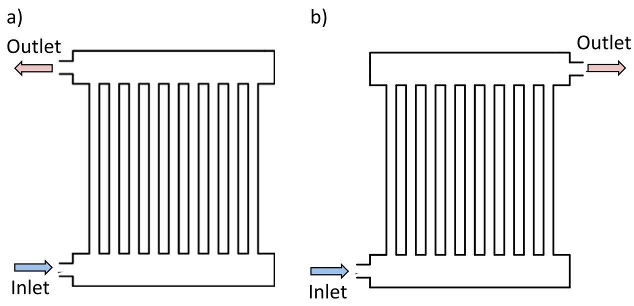

Fig. 1. Schematic showing the heat exchangers with a) U-type and b) Z-type flow directions.

3. Numerical modelling

3.1. The iterative flow network model

The head loss h_f along a pipe varies with flow rate Q as described by the Darcy–Weisbach equation and can be computed directly using:

$$h_f = \frac{fLV^2}{2gD} = \frac{fLQ^2}{2gDA^2} \tag{3}$$

In a flow network such as that in a parallel flow heat exchanger, the total head loss between inlet and outlet is equivalent to the sum of the pressure drops along any path connecting the inlet and the outlet. This is the same whatever path is chosen. The head loss is therefore dependent on the flow distribution. The flow along any one branch is determined by its resistance relative to neighbouring branches and therefore the flow distribution in the network must solved iteratively.

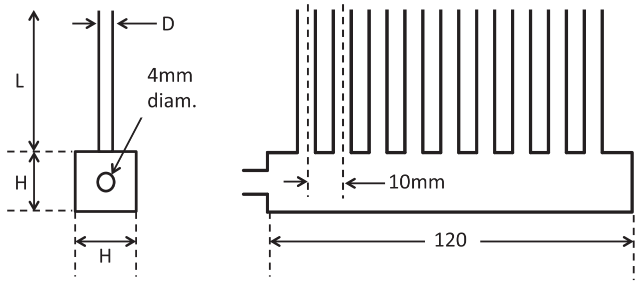

Fig. 2. Geometrical dimensions of the heat exchanger investigated, to match Ref. [1].

Table 1
Geometrical dimensions of the simulated heat exchangers.

Test case	D [mm]	H [mm]	L [mm]	Flow [lpm]	Area ratio
1	2	7	300	2	0.064
2	3	7	400	2	0.144
3	2	12	300	2	0.022
4	3	12	400	2	0.049