euspen's 15th International Conference & Exhibition, Leuven, Belgium, June 2015
www.euspen.eu

An investigation on the role of thermal fins in the design of micro heat exchangers

Farzaneh Omidvarnia[1], Hans N. Hansen[1], Ali Sarhadi[2]

[1] *Technical University of Denmark, Department of Mechanical Engineering, Lyngby, Denmark.*
[2] *Technical University of Denmark, Department of Energy Conversion, Roskilde, Denmark.*

Abstract
The different dominant physical phenomena in design for micro and macro scale products result in different design considerations for both categories. In the current study, a few design concepts are proposed as micro heat exchangers. In addition, the influential parameters on design of a micro heat exchanger in comparison with the effective factors in designing its macro counterpart are investigated. Numerical simulations in the finite element software COMSOL are used to evaluate the thermal performance of both micro and macro heat exchangers. The result of the analysis reveals the fact that the presence of some features such as "fins" in micro heat exchanger is not as significant as it is in macro scale. The results of this study can be employed as guidelines in design of similar micro heat exchangers.

Heat exchanger, micro, size effect, thermal performance, design

1. Introduction

During the design process of micro products a number of issues appear which are inherent due to the down scaling or physical phenomena dominating in the micro range but negligible in the macro scale [1, 2]. In fact, some aspects in design for micro manufacturing are considerably different compared to the design procedure applied at the macro level. For instance, the application of micro scale heat transfer faces with some engineering challenges that demands great efforts to overcome them [3]. In this paper, the importance of "fins" in the functional performance of a micro fluidic heat exchanger compared to its macro counterpart is investigated.

2. Methodology

The thermal analysis of the selected ideas was carried out using finite element (FE) simulation of the conjugate heat transfer in COMSOL to evaluate the performance of each design. The water was considered as coolant flowing under a laminar flow regime in the heat exchanger. A convective heat transfer to the ambient air was considered for the surfaces of the heat exchanger and heat source.

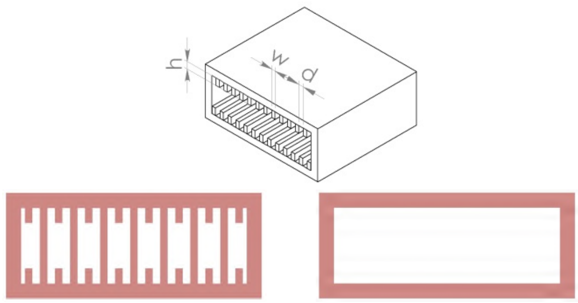
In the FE model, the heat transfer and fluid flow equations are solved simultaneously. The steady state form of the governing momentum, mass and energy conservation equations are expressed as [4, 5]:

$$\rho u.\nabla u = -\nabla P + \nabla.\left(\mu(\nabla u + (\nabla u)^T) - \frac{2}{3}\mu(\nabla.u)\,\mathrm{I} \right) + F \quad (1)$$

$$\nabla.(\rho\,\mathrm{u}) = 0 \quad (2)$$

$$\rho C_p u.\nabla T = \nabla.(\mathrm{k}\,\nabla T) + Q \quad (3)$$

where ρ, u, P, μ, F, C_p, k, Q are density, velocity vector, pressure, body force vector, specific heat capacity, thermal conductivity and heat source, respectively.



(a) (b)

Figure 1. The schematic picture of heat exchangers, with(a) and without fins (b). Details in Table 2.

Table 1 Thermal boundary conditions for both micro and macro heat exchangers

Inlet velocity of the coolant (m/s)	0.066
Heat source/heat exchanger Interface HTC (W/m^2.K)	2000
Heat source power per volume (W/m^3)	5.6×10^6
Inlet temperature of the coolant (water) (°C)	20
Convective heat transfer coefficient of the ambient (W/m^2.K)	10

Table 2 Geometrical dimensions and constituent material of the micro heat exchanger (a) with fins (b) without fins

Heat Exchanger type	(a)	(b)
Dimension (mm×mm×mm)	17×7×15	17×7×15
Wall thickness	1 mm	1 mm
Fin width (w)	0.8 mm	-
Fin height (h)	1.75 mm	-
Distance between fins (d)	0.6 mm	-
Material	Aluminium	Aluminium

Thermal boundary conditions for both micro and macro heat exchangers are given in Table 1. The geometrical dimensions and schematic picture of a micro heat exchanger with optimized fin dimensions is given in Fig. 1 and Table 2. The heat source is considered as a rectangular cube with the same dimensions of the heat exchanger (17×7×15 mm). In order to compare the role of fins in micro heat exchangers with its macro counterpart, a macro heat exchanger is assumed with scaling up the dimensions of the micro heat exchanger by 10 times. The dimensions of the heat source are also scaled up.

4. Result and discussion

The calculated heat source temperatures in a steady state condition for both micro and macro heat exchangers with and without fins are given in Table 3 (see also Fig. 2). As can be seen from Table 3, presence of the fins in micro heat exchanger reduces the heat source temperature from 44.1 °C to 41.0 °C (ΔT=3.1 °C), while the thermal effect of the fins on reduction of the heat source temperature is considerably higher in case of a macro heat exchanger (ΔT=140.9 °C). This can be explained by evaluating the convection heat transfer at the solid-fluid interface as expressed by Newton's law of cooling [6]:

$$q = -hA(T_s - T_\infty) \qquad (4)$$

Where h, A, T_s and T_∞ are convective heat transfer coefficient, solid-fluid contact surface, solid surface temperature and fluid temperature, respectively. Presence of the fins increases the contact surface to a ratio of 3.1:1(see Table 4) for both micro and macro heat exchangers. Therefore, difference in thermal performance of the fins for macro compared to the micro heat exchanger should be related to the other parameters, namely convective heat transfer coefficient (h) and temperature gradient ($T_s - T_\infty$). h increases with increasing the Reynolds number which is considerably higher in case of macro heat exchanger than that for the micro one ($\frac{\mathrm{Re}_{macro}}{\mathrm{Re}_{micro}} \approx 10$), hence h is larger for the macro heat exchanger. Moreover, due to small cross section of the fins in the micro heat exchanger, the fin's thermal resistance in the micro heat exchanger is considerably higher than that for the macro one which results in considerable temperature gradient between the base and the tip of the fins. This decreases the temperature difference between the solid surface and the fluid ($T_s - T_\infty$) and hence reduces the fin's thermal performance. Since adding fins to micro heat exchangers increases the manufacturing cost or in some cases makes the manufacturing process very challenging, the insignificant role of the fins on thermal performance of the micro heat exchangers can be considered as a useful point in design of micro heat exchangers to reduce the manufacturing cost considerably without major decrease in thermal performance of the micro heat exchangers.

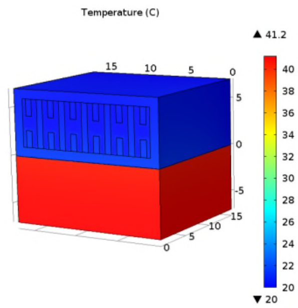


Fig. 2. Temperature profile plot of the heat source and micro heat exchanger

Table 3 Heat source temperatures in a steady state condition by cooling for both micro and macro heat exchangers (a) without fins (b) with fins

Heat Exchanger type	Heat source temperature (°C)	
	Micro	**Macro**
(a) Without fins	44.1	451.8
(b) With fins	41.0	310.9

Table 4. Solid-fluid contact surface for both micro and macro heat exchangers (a) without fins (b) with fins

Heat Exchanger type	Solid-fluid contact surface (mm^2)	
	Micro	**Macro**
(a) Withot fins	600	60000
(b) With fins	1860	186000

5. Conclusion

In the current study, the effect of fins on thermal performance of a micro heat exchanger compared to that for its macro counterpart was investigated. Thermal performance of the heat exchangers was evaluated using FE simulation in COMSOl and the final heat source temperatures of the micro and macro heat exchangers with and without fins were calculated. The results revealed that presence of fins in a micro heat exchanger only reduces the heat source temperature around 3.1 °C, while the reduction in heat source temperature for its macro scaled counterpart is around 140.9 °C. Based on the results, presence of the fins has an insignificant role on thermal performance of the micro heat exchanger while it can raise the manufacturing cost, considerably. This can be used as an interesting guideline in design of a micro heat exchanger to reduce the manufacturing costs while preserving its thermal performance. The effects of constituent materials and thermal boundary conditions on the thermal performance of the fins are proposed for future work.

References

[1] Alting L, Kimura F, Hansen HN and Bissacco G 2003 Micro Engineering. CIRP Ann - Manuf Technol **52** 635–657

[2] Vollertsen F, Biermann D, Hansen HN, Jawahir IS and Kuzman K 2009 Annals of CIRP **58/2** 566-587

[3] Tien CL, Chen G 1994 Challenges in micro scale conductive and radiative heat transfer *J. Heat Transfer* **116** 799-807

[4] Baer HD and Stephan K 2006 Heat and Mass Transfer (Springer; 2nd edition)

[5] Panton RL 2013 Incompressible Flow (John Wiley, 4 edition)

[6] Hattel J 2005 Fundamentals of Numerical Modelling of Casting Processes (Polyteknisk Forlag. Kgs. Lyngby) 79–126