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Selection and optimization of pin cross-sections for electronics cooling

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Abstract

Pin fins are widely used as elements that provide increased cooling for electronic devices. Increasing demands regarding the performance of such devices can be observed due to the increasing heat production density of electronic components. For this reason, extensive work is being carried out to select and optimize pin fin elements for increased heat transfer. In the present paper, a procedure is described to select heat exchanger surfaces with pin fins in accordance with their location in a performance diagram. Such a diagram provides performance comparisons of pin fins with respect to two operating parameters: the heat transfer rate per unit base surface area and the power input for the same area. It is shown that elliptical cross-sections offer the best performance compared with all other investigated cross-sections for pin fins. The present work demonstrates that the heat exchanger performance plot allows also the selection of the best elliptical cross-section design within the initial design set (design set obtained numerically) in analogy with the Pareto-optimality approach. However, the real optimal geometry of the elliptical cross-section is deduced from commercial optimization software, modeFRONTIER. It is shown that by subsequent use of the virtual solutions from the response surface modelling (RSM) of that software and their validation with Star-CD, a complete "Pareto-frontier solution" can be obtained.
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Keywords: Pin fins; Heat transfer rate; Power input; Selection; Optimization

1. Introduction and aim of the work

One of the primary goals in the design of modern thermal systems for cooling of electronic components is the achievement of more compact and, hence, efficient heat transfer devices. This requires the employment of surfaces with high heat transfer coefficients and high area compactness. Particular attention has to be paid to the selection/design of heat transfer surfaces if the required energy-carrying fluid turns out to be a gas. It is well known that gases have heat transfer coefficients that are about 100 times lower than those of liquids. This is usually compensated with larger heat transfer areas and it is the aim of the work of engineers to have the surface area reduced by enhancing the heat transfer coefficients. The present paper relates to work in this direction.

To outsiders, the design of efficient heat exchangers appears more like an art than an engineering science. If the designer looks into the literature, finds a number of investigations that relate to the optimization of heat transfer by suitable elements mounted on surfaces. Elements of different shapes and different sizes are used for heat transfer enhancements and the concentration of elements per unit area varies from experiment to experiment. The final results of individual measurements are generalized by plotting the results in the form of Nusselt numbers, *Nu*, and friction factors, *f*, as a function of Reynolds numbers, *Re*. Similar dimensionless numbers, namely Colburn factor, *j*, and friction factor, *f*, were employed by Kays and London [1] for presenting heat transfer and pressure drop data. Diagrams of this kind are only useful for scale-up or scale-down investigations, i.e. the same Nusselt number only applies for geometrically similar heat enhancement

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Nomenclature

A	surface area
a	large elliptical axis
b	small elliptical axis
c_p	isobaric specific heat capacity
d	diameter
e	power input
$\dot{m}$	mass flow rate
P	pressure
ΔP	pressure drop
$\dot{Q}$	heat transfer rate
$\dot{q}$	volume or area reduced heat transfer rate, W/m^3 or W/m^2
Re	Reynolds number
r	elliptical axis ratio
S	pin distance
T	temperature
t	thickness (NACA profile)
U_i	velocity components
U_∞	free stream velocity
$\dot{V}$	volume flow rate
X	pin distance
x	abscissa (NACA profile)
x_i	Cartesian coordinates
y	ordinate (NACA profile)

Greek symbols

δ_{ij}	Kronecker-delta
η	fan efficiency
ν	kinematic viscosity
ρ	density
τ_{ij}	viscous stress tensor

Subscripts

a	big elliptic axis
b	base surface area reduced parameter, small elliptic axis
f	fluid
h	hydraulic
in	inlet
L	streamwise direction
out	outlet
s	solid
T	transverse direction
t	total
v	volume reduced parameter, constant volume

elements. Hence Nusselt number elements of different shapes or of different number concentration per unit area are not comparable. The Nusselt number of one element can be larger than that of a second element but can still yield lower overall heat transfer when realized in a particular heat exchanger configuration. The appropriate comparison of various elements for heat transfer enhancement should consider their overall performances, namely their heat transfer and pressure drop characteristics. For that purpose Kays and London [1] suggested the plotting of heat transfer coefficient h normalized to unit heat transfer surface area versus pumping power e normalized to the same area. In the study Sahiti et al. [2], that method was for practical reasons modified by reducing of the heat transfer coefficient to the bare surface area, whereas subsequently [3] it was demonstrated that the most reliable performance prediction can be obtained by comparison of the heat transfer rate per unit heat exchanger volume $\dot{q}_v$ versus the power input per same volume e_v (Fig. 1). Hence heat transfer capability versus effort is plotted, both normalised with the same volume. In this way, elements for heat transfer enhancement that lie higher than others are better in their performance and should be chosen for a particular heat exchanger design. The original data provided by Kays and London [1] were converted by the authors to yield the diagram shown in Fig. 1.

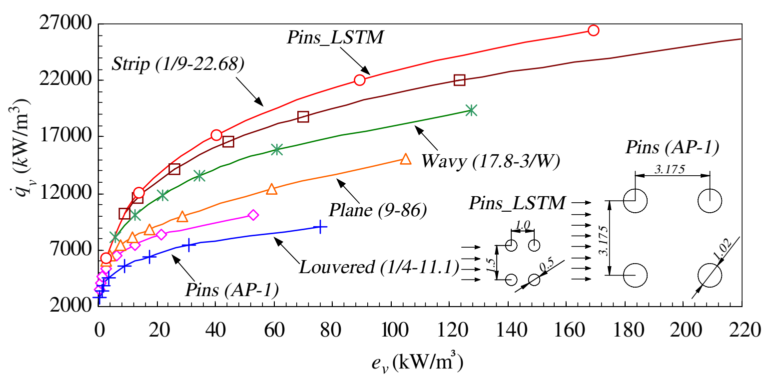

Fig. 1. Performance plot of plate and pin fin heat transfer surfaces.

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