



NUMERICAL SIMULATION OF FLOW AND HEAT TRANSFER IN MICRO HEAT EXCHANGERS

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ABSTRACT

Pin fin arrays have been used for turbine blade cooling applications in the trailing edge where they can fulfill a structural as well as a heat transfer function. A recently proposed concept involves covering the outer surface of turbine blades with an array of very short pin fins and adding a coating on top that is exposed to external gases [1]. The coating completely enshrouds the turbine blade, leaving a micrometer-sized gap bridged by the pin fin array, and preventing contamination of the coolant by the high temperature gases outside. Cooling air bled from the compressor stage flows through the gap, protecting the blade surface.

A preliminary computational study using a commercial CFD program (Fluent™) was undertaken to provide support and future guidance to the experimental evaluation of the concept under way at LSU. The problem was modeled as periodic flow with conjugate heat transfer through an array of cylindrical pin fins bounded by parallel flat plates. The energy input from the external gases was modeled by a uniform heat flux perpendicular to the fin axis applied to the top endwall, while the bottom endwall was assumed to be adiabatic.

To validate the computational model, simulations were run to compare previous experimental work with various types of pin fin arrays performed by Chyu [2] and Metzger [3]. Good agreement with published friction factor and Nusselt number results therein inspires a level of confidence in the current computational model.

The computational study investigated the effects of varying Reynolds number and Prandtl number on the friction factor and heat transfer characteristics of the basic flow configuration. Table 1 displays that, for the range of Reynolds numbers in the present study, the heat transfer enhancement increases with increasing Reynolds number. However, this increased enhancement comes with rises in the friction factor as flow becomes more turbulent. Friction factors and Nusselt numbers can be incorporated into a single quantity that contains information about the pressure

penalty paid for increased heat transfer, known as the thermal performance factor (TPF):

$$TPF = Nu \cdot f^{-?}$$

Table 1 indicates a maximum TPF that falls within the range of Reynolds numbers used.

Simulations were also performed to evaluate the effects of modification of the fin array geometric parameters—changing the fin height (H/D), and the streamwise (L/D) and spanwise fin (W/D) array density. Results presented in Table

Table 1: Results of increasing Reynolds number on friction factor and Nusselt number (normalized by corresponding flat channel values), and associated TPF

Re	f/f_{flat}	Nu/Nu_{flat}	TPF
675	0.3974	1.79	2.43
1350	0.2950	13.49	20.26
2025	4.0011	17.66	11.12
3038	7.5495	22.72	11.58

Table 2: Results of changing geometry parameters (base case: L/D = W/D = 5; H/D = 2.5) on friction factor and Nusselt number (normalized by corresponding flat channel

		f/f_{flat}	Nu/Nu_{flat}	TPF
H/D	1.25	15.7	7.9	3.16
	2.5	4.6	10.3	6.20
	5	3.0	16.6	11.47
L/D	2	5.3	12.3	7.06
	5	4.6	10.3	6.20
	8	4.8	8.8	5.19
W/D	2	29.8	23.0	7.42
	5	4.6	10.3	6.20
	8	1.9	6.2	4.95

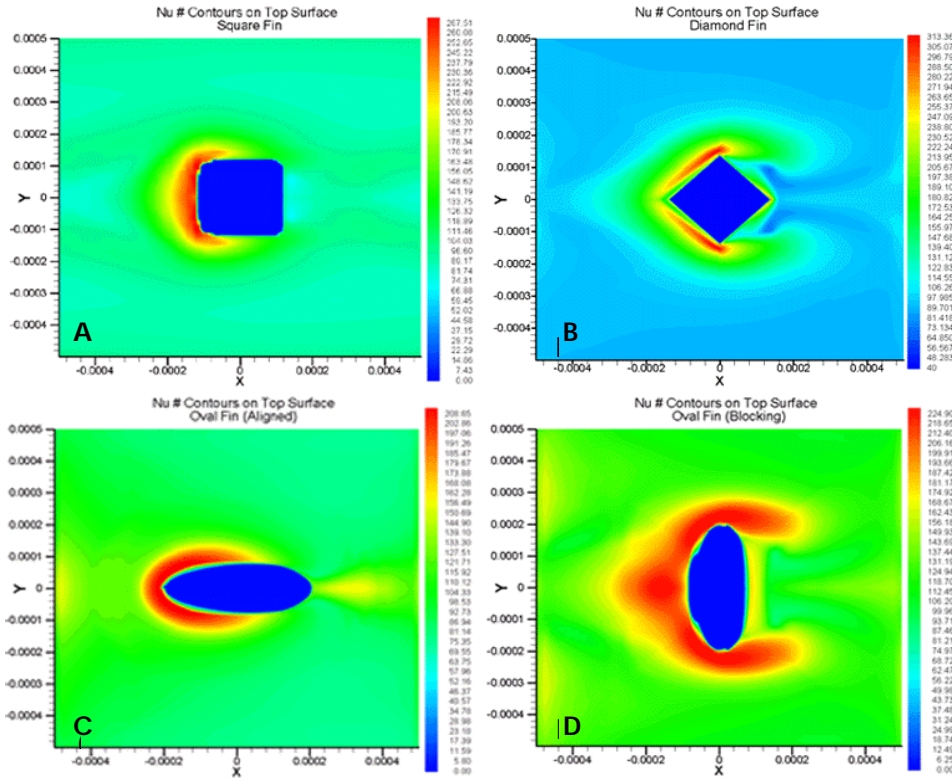


Figure 1. Nusselt number contours on top surface of channel for different pin shapes for $L/D = W/D = 5$, $H/D = 2.5$ arrays and Reynolds number = 3×10^4 , and associated performance factors

2 indicate that from a heat transfer viewpoint, larger H/D values are desired—this seems to reflect the rising effectiveness of the fluid to remove energy as the fin height, and thus, the channel height is increased. Heat transfer can also be increased by decreasing L/D and W/D , which means increasing the fin array density. However, as Table 2 demonstrates, increasing fin density comes with severe pressure penalties. Nusselt numbers are more responsive to W/D changes than L/D , possibly because the wake of the flow (L/D) isn't as important as the shear layers that form around the fin region. Taken overall, the best performance will be obtained from closely spaced arrays with large height to diameter ratios—essentially, the current results are predicated a move toward transverse flow across closely spaced tube bundles. This observed trend matches well with [4], where it was noted that the heat transfer enhancement using pin fin arrays of intermediate H/D is lower than that for classic tube bundles operating at the same Reynolds number (until very high Reynolds numbers are reached).

While the pin fin arrays mentioned so far consist of cylindrical pin fins, it is by no means certain that a circular cross section produces the most effective heat transfer enhancement. The computational study was extended to investigate the effects of a variety of fin shapes at a Reynolds number of 3000. The table associated with Figure 1

illustrates performance factors for square, diamond and elliptical fins oriented parallel and perpendicular to the flow. In terms of TPF, the last case offers a viable alternative to cylindrical pin fin arrays.

The results presented allow optimal choices of promising geometric parameters and fin shapes to be made for further experimental study.

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