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Numerical analysis with experimental comparison in duct flow using optimized heat sinks

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ABSTRACT

In many industrial applications, heat must be transferred in the form of either an energy input into the system or removal of energy produced in the system. In this study, heat transfer and flow characteristics of hexagonal finned heat sinks which optimized according to the Taguchi experimental $L_{18}(2^1*3^7)$ design method in channel flow was analyzed numerically. Ansys-Fluent Icepak module was used in CFD analysis. The analysis carried out for two hexagonal finned optimized heat sinks in 3 different fin heights and 5 different flow velocities. Nusselt number increased with increasing Reynolds number for OH-1 and OH-2 heat sinks with all fin heights. Also, results showed that the friction factor decreased with increasing Reynolds number for all fin heights. According to CFD results, Nu-Re and f-Re variations were obtained and compared with experimental results. The experimental results and the numerical results were quite consistent.

1. Introduction

Electronic systems which have multiple heat-generating parts will have cooling problems. It is especially hard for computer motherboards to achieve needed heat diffusion rates limited interior spaces are densely packed that pose an obstacle to the free circulation of the cooling air (Zhang, Huang, Li, & Chua, 2002). These components behave as strong regional heat sources which should cause high local superheating with heavy power consumption. For this reason effective heat transfer is required for a safe long-lived operation (Niceno, Dronkers, & Hanjalic, 2002).

Today, not only investment costs but also operating costs and lifetime must consider when designing a heat sink. So efficiency of heat sink is the most important parameter. The heat sinks having high effectiveness enhance heat transfer. Thermal conditions must be taken into consideration for effective heat transfer. If this condition is not satisfied, the maximum junction temperature exceed the allowed temperature by the producing company. So device performance, lifetime and safety may be reduced (Remsburg, 2001).

The heat transfer enhancement methods are classified as active and passive methods in the literature. Those which require external power to maintain the enhancement mechanism are named active methods. On the other hand, the passive enhancement methods are those which do not require external power to sustain the enhancements' characteristics.

At the passive methods, various geometries are designed for effective heat transfer. In general, increment the heat sink surface area reduces the junction temperature of the system. Today, heat sinks are produced for consumer requests in high-tech countries.

CFD (Computational Fluid Dynamics) is a branch of fluid mechanics that based on numerical analysis and algorithms to solve problems that involve fluid flows.

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Experimental and theoretical methods are two basic approaches to the design of engineering systems. In the first of these, heat and flow characteristics are determined experimentally for produced heat sink model in wind tunnel. In the second one, heat and flow characteristics are obtained by numerical solutions of governing differential equations. Today, engineers use effectively both experimental and CFD analysis.

Tahat et al., studied heat transfer with orthogonal pin-fin which were arranged staggered and in-line in steady-state condition. They determined optimum length between the fins in spanwise and streamwise directions with the given conditions. Nusselt-Reynold variations were investigated with pin-fin pitch (in both directions). Also, they designated that the average heat transfer coefficient increases with increasing Reynolds number (Tahat, Kodah, Jarrah, & Probert, 2000).

Tanda et al., were performed heat transfer and pressure drop with arrays of diamond-shaped elements in rectangular channel. In this studies, the average Nusselt correlations were found to depend on the Reynolds number for each fin configurations. Heat transfer was enhanced by a factor of until 4.4 for uniform mass flow rate and by a factor of until 1.65 for uniform pumping power over diamond-shaped elements (Tanda, 2004).

Lee and Garimella investigated laminar convective heat transfer for uniform wall temperature and axially uniform wall heat flux thermal boundary conditions in the entrance region of rectangular micro channels. They have compared their correlations with other conventional and available experimental correlations. They indicated that their theoretical results are in good agreement with the others (Lee & Garimella, 2006).

Yakut et al., conducted a pioneering experimental study to determine optimum design parameters of hexagonal fins using Taguchi experimental design method (Yakut, Alemdaroglu, Sahin, & Celik, 2006).

2. Materials and methods

In this study, heat transfer and fluid flow characteristics were determined numerically in channel flow for 2 optimized hexagonal finned heat sinks which are coded Optimum Hexagonal-1 (OH-1) and Optimum Hexagonal-2 (OH-2) respectively. ANSYS Icepak was used for numerical analysis. The analyses were performed for 3 different fin heights and 5 different flow velocities for each model. According to CFD results, Nu-Re and f-Re variations were presented and compared with experimental results which are previously obtained (Gureşçi, 2014).

Geometry and mesh of hexagonal finned heat sinks which were optimized according to the Taguchi experimental $L_{18}(2^{1}*3^{7})$ design method (Ross, 1989) in channel flow were created.

Two different models which are optimized previous studies (Yakut, Alemdaroğlu, Sahin, & Celik, 2006) are used in numerical analysis. The heat sinks were optimized using Taguchi experimental-design method. Optimization criteria are used "the bigger the better" for Nusselt number and "the smaller the better" for friction factor and thermal resistance. Optimization of the heat sinks was based on the channel hydraulic diameter and taking into consideration three objectives. Optimum results were obtained at 150 mm fin height, 14 mm fin span, 20 mm fins distance in cross-stream, 20 mm fins distance in downstream and 4 m/s fluid velocity when Nusselt number calculated for the hexagonal finned heat sinks. The analysis were carried out for 3 different fin heights (100, 150, 200 mm) and 5 different flow velocities (1.2, 2.3, 3.5, 4.2, 4.6 m/s) for each model. Nu-Re and f-Re variations were obtained from the CFD results and the compared with experimental results which are previously obtained (Yesildal, 2007) (see Figs. 1 and 2; Table 1).

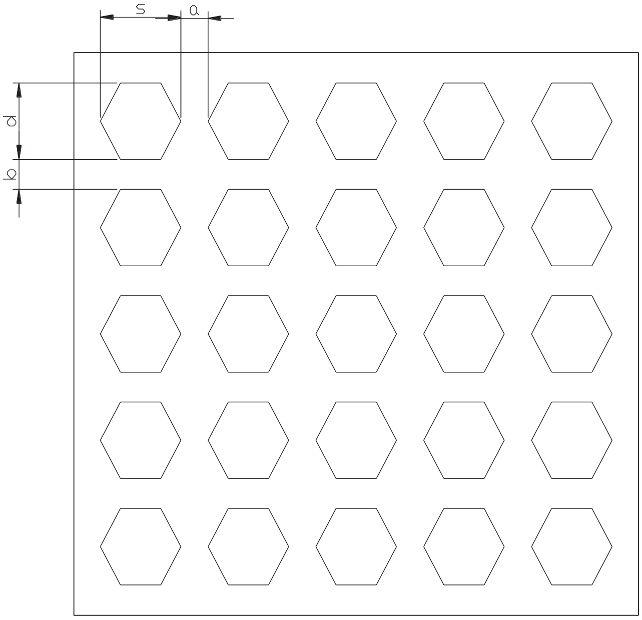

Fig. 1. The general characteristics of the heat sinks.

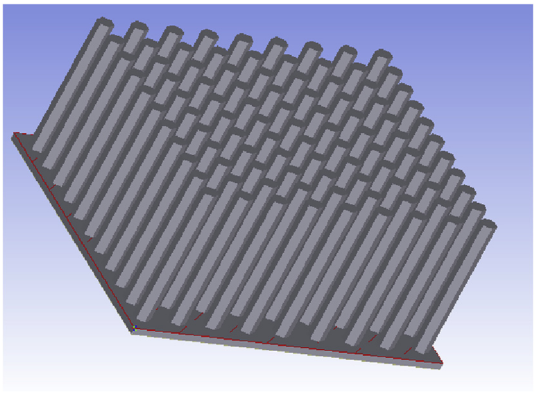

Fig. 2. The perspective view of the hexagonal test model.

Table 1
Parameters in experimental and numerical analysis.

Parameters		Optimal Heat Sink	
		OH-1	OH-2
A	Fin span, d[mm]	14	14
B	Distance between fins along cross-stream, a[mm]	20	20
C	Distance between fins along downstream, b[mm]	20	10

2.1. Calculations of the heat transfer and friction factors

The steady-state rate of the heat transfer through the air can be expressed as follows:

$$Q_{total} = Q_{conv} + Q_{rad} + Q_{cond} \tag{1}$$

$$\dot{Q}_{conv} = \dot{m}C_p(T_{out} - T_{in}) = \frac{V^2}{R} = VI \tag{2}$$

The heat transfer from the test section by convection can also be expressed as;

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