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ENHANCED ELECTRONIC COOLING USING FIN HEATSINK: A COMPARATIVE ANALYSIS

AHMED M. BUKAR[a], ABDULRAHMAN S. ALMERBATI[a,b]

[a] Mechanical Engineering Department, King Fahd University of Petroleum and Minerals (KFUPM), Dhahran 31261, Saudi Arabia
[b] Interdisciplinary Research Center for Sustainable Energy Systems (IRC-SES), King Fahd University of Petroleum and Minerals (KFUPM), Dhahran 31261, Saudi Arabia
*Correspondence: g202203340@kfupm.edu.sa ;Tel.+966503638505

Electronic devices consistently produce undesired thermal energy. The growing demand for these devices in various applications necessitates innovative cooling solutions to mitigate thermal losses. The main challenge in electronic cooling is the full development of the thermal boundary layer. This study aims to optimize the conventional rectangular plate-fin heatsink by redeveloping a new thermal boundary, which involves morphing the fin configuration and distribution while maintaining a constant fin volume. We used numerical simulation in COMSOL Multiphysics to analyze and compare conventional rectangular plate-fin heatsink performance with two optimized configurations: the bifurcated longitudinal split fin and hybrid plate-pin fin heatsinks. The methodology involves assessing the thermal and flow performance in the form of the average heatsink baseplate temperature and the average pressure drop across the heatsink. We investigated these under a constant heat flux of 5903 W/m^2 and varying air velocities between 4 and 12 m/s. The results showed that using five bifurcated plate fins and hybrid plate-pin fins lowers the temperature of the heatsink base plate by 25% and 47%, respectively, compared to conventional rectangular plate fins when the air velocity is 8 m/s. However, these optimized configurations increased the pressure drop across the heat sink.

Keywords: Constructal design; Fin heatsinks; Thermal management; Electronic cooling.

1. INTRODUCTION

Electronic devices consistently produce undesired thermal energy during their operation, and with electronic systems increasingly becoming more advanced, the challenge of providing an effective and dependable heat dissipation system has grown burdensome [1,2]. The proficient cooling of high-power electronic devices facilitates the downsizing and acceleration of electronic systems, making them more robust. One significant environmental factor that has an impact on built-in circuit performance is temperature. Overly elevated temperatures of operation typically interfere with the equipment's ability to function effectively [3]. Therefore, an innovative and effective cooling system is required to solve the overheating challenge and achieve efficient heat dissipation to prevent such failures. One of the main challenges in the thermal management of electronic chips is the full development of the thermal boundary layer, which greatly reduces the heat transfer coefficient along the flow channel. The existing research indicates that there is potential for increased heat transfer coefficients in a newly formed boundary layer along the flow channel by changing the fin shape and distribution [4,5].

Extensive research efforts over the years have been dedicated to the investigation of heat transfer within vertical [6] and horizontal [7], [8] channels containing heated obstructions, leading to a comprehensive body of literature on this subject. In this study, the performance of the rectangular plate fin (RPF) heat sink is optimized by changing the configuration and the distribution of the plate-fin heat sink. Two optimizations are proposed: bifurcated longitudinal split fins (BLSF) and hybrid plate-pin fins (HPPF).

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2. MODEL DESCRIPTION

The proposed approach enhances the efficiency of the traditional RPF heatsink by altering the type and distribution of the fins while maintaining constant fin volume. Figure 1(a) shows the heatsink with a BLSF. The main objective of this design is to control the thermal boundary layer by dividing the plate fin (n_2) at a specific length (L_1), splitting the remaining half into two (n_3), and then replanting it to the base plate. The primary design factor is the specific length (L_1) at which the plate fin divides, enabling it to morph in percentage of the overall fin length (L) represented by equation (1). Figure 1(b) illustrates the arrangement of the HPPF heatsink. The primary design concept entails decreasing the thickness (t_f) of the plate fin to embed a pin onto the plate fin's surface, thereby converting a specific proportion of the plate fin's volume into the pin. As the thickness of the plate fin (t_f) decreases, the height of the pin (H_p) increases while keeping the pin diameter (d_p) constant.

$$L^* = \frac{L_1}{L}, \tag{1}$$

$$T^* = \frac{T_b - T_{in}}{T_{in}}, \tag{2}$$

$$\Delta P = P_{out} - P_{in}. \tag{3}$$

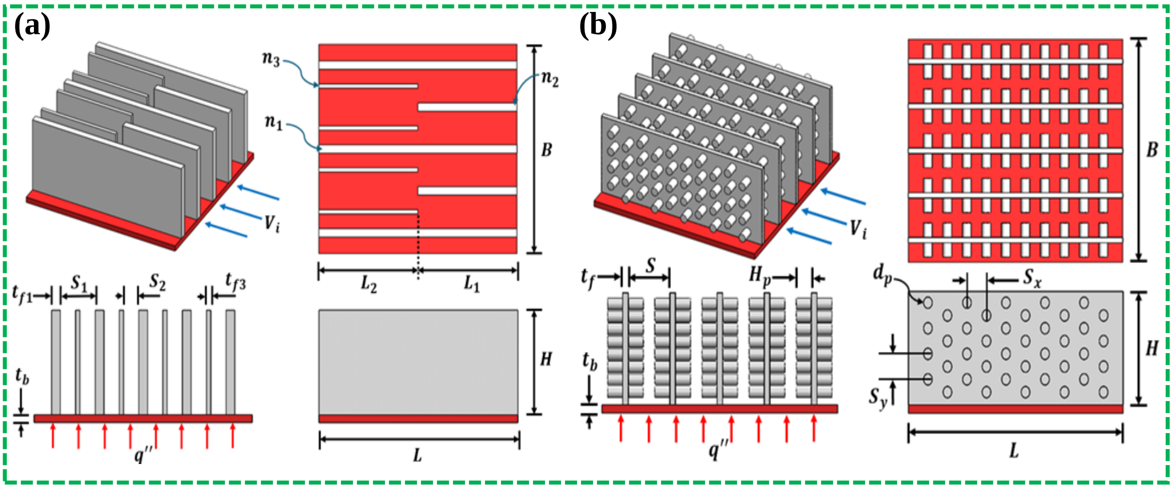

Fig. 1 – Model description of (a) BLSF heatsink, and (b) HPPF heat sink.

3. NUMERICAL METHOD

The numerical simulations were performed utilizing commercial CFD software, COMSOL Multiphysics. The simulations were conducted on a three-dimensional domain, considering both steady-state and turbulent flow conditions. The geometric model is constructed, boundary conditions are established, mesh independence tests are carried out, and the numerical model is validated with experimental work during the pre-processing phase. The processing stage involves solving the governing equations for fluid flow and heat transfer. The post-processing stage entails examining the simulation results to assess the hydraulic and thermal performance metrics of the heat sink configurations in terms of dimensionless baseplate temperature and pressure drop given by equations (2) and (3), respectively. Where subscript *b*, *in* and *out* represents baseplate, inlet and outlet.

4. RESULTS AND DISCUSSION

Figures 2(a) and 2(b) show the effect of bifurcation length (L^*) in BLSF. As the bifurcation length increases, both the plate temperature and the pressure drop increase. The optimum L^* is at the closest point to the inlet (0.1). Figures 2(c) and 2(d) show the effect of pin volume in HPPF. As the pin volume increases, the plate temperature decreases while the pressure drop increases. Hence, the optimum pin volume is 50% and 10% in terms of thermal, and hydraulic performance respectively. This is because as the pin volume increases, the flow obstruction increases, thus, increasing the pressure drop.

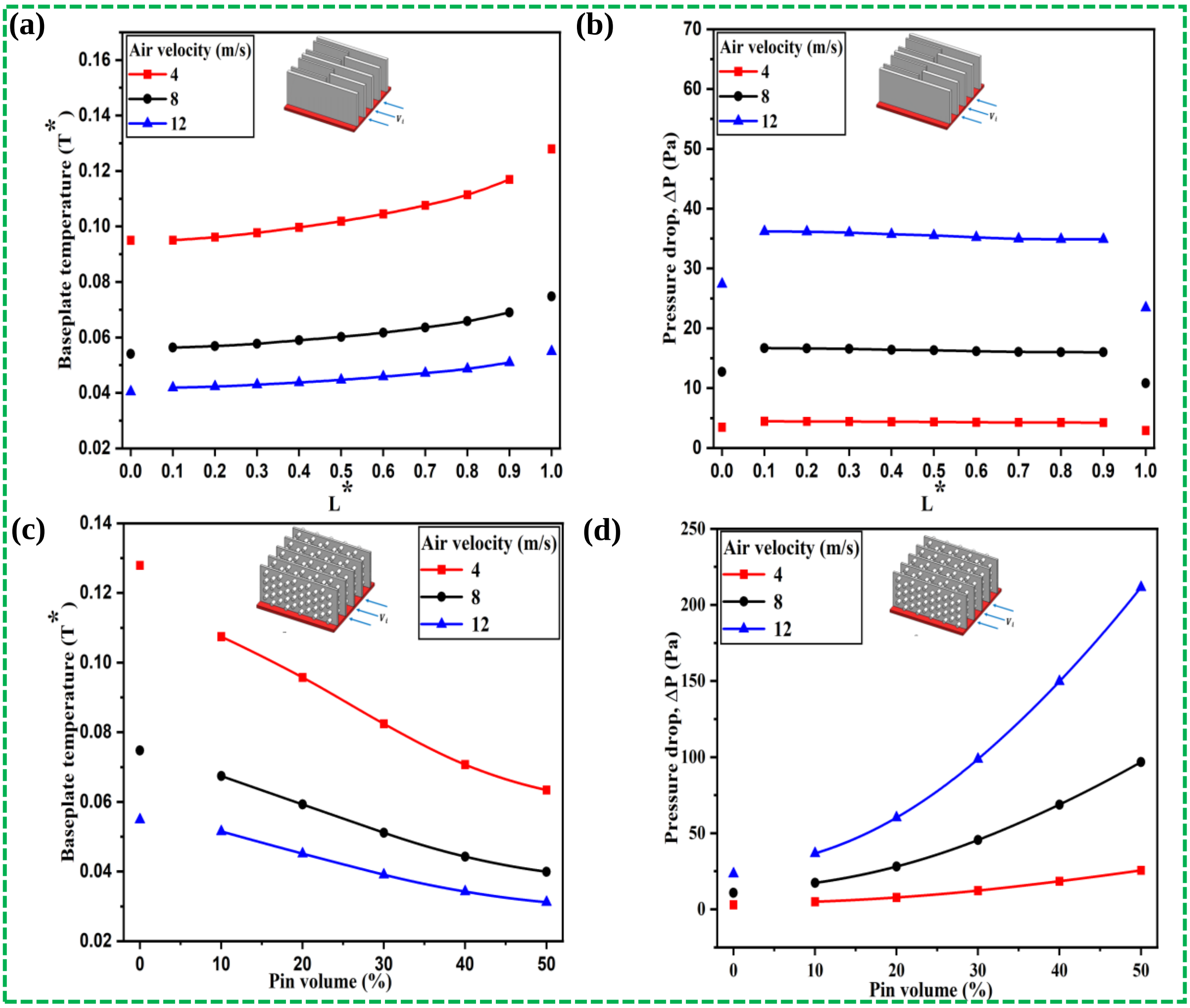

Fig. 2 – Effect of bifurcation length of BLSF on: (a) temperature, (b) pressure drop, and effect of HPPF pin volume on (c) temperature, (d) pressure drop.

5. CONCLUSION

In this study, we numerically showed the effect of optimizing the rectangular plate fin heatsink. The best configuration, which has a lower baseplate temperature, was found to be HPPF as shown in Figure 3(a). In contrast, the optimal configuration in terms of pressure drop is the conventional RPF heatsink, as shown in Figure 3(b). HPPF and BLSF resulted in a 47% and 25% reduction in baseplate temperature compared to the

RPF heatsink, respectively. The findings of this study are not limited to electronics cooling but also photovoltaic modules and similar applications.

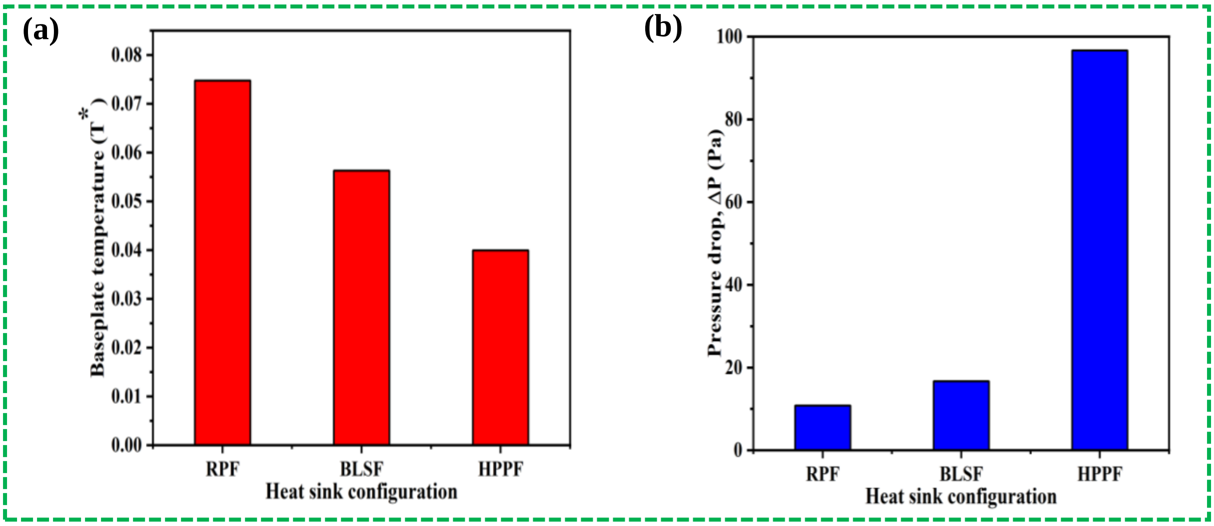

Fig. 3 – Comparison of (a) temperature and (b) pressure drop between RPF, BLSF, and HPPF.

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