The thermal-hydraulic design of the microchannel heat sink

Design, Architecture

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A set of modeling simulations have been carried out in order to obtain the optimal thermal design of the heat sink by reducing the number of fins and simultaneously inserting pins inside channels. Basically, the pin size added is smaller than the size of the fin size removed. Therefore, removing one fin and adding one pin with at least the same thermal-hydraulic performance leads to saving the substrate material. Hence, the addition and subtraction of material will be taken into the account of enhancement estimation. It is worth to be mentioned that the number of pins in each channel is dependent on the ratio of ξ = (Nf, new fins/10).

The value of S (the pitch distance between the beginning of the channel and the pin center) is kept constant throughout the study (S = 5×10-3 m), while the width of the channel (Wc) is varied taking in the account the design of the channel and location of pins as shown in Table 6. In addition, the value of the pin height and fin length are kept unchanged (1. 125×10-3) and (50×10-3) m, respectively. Three values of fin number ratio are examined in this study, namely ξ = 1. 0, 0. 9, and 0. 8 respectively. Because the channel width (Wc) increases with decreasing the value of ξ, one pin is added to the channel in one position. It is necessary to calculate the volume of the fins, which are subtracted from the overall volume of the heat sink substrate and also estimating the total volume of pins added to the heat sink at the same time. It can be said that the fins removed from the heat sink are assumed income and material saving, while the pins added to the heat sink is considered as losses material. For this reason, the volume of fin reduction is denoted by minus signal whereas the pin volume is denoted by plus signal.

Mathematically, the volume of fins removed from the original volume of the substrate material is estimated as V_(f, removed)=(10-N_f)×V_f (m3) Where Vf is illustrated in Table 7. The number of channel is calculated from Nc= Nf - 1 Material reduction=|(V_(original-) V_new)/V_original |×100 (%) Where Vf and Vp represent the fin volume and pin volume, respectively. It should be noted that the case of ξ = 1. 0 is simulated with and without the pin. While for ξ = 0. 9 and ξ = 0. 8 only one pin is adopted in each channel. Now, a set of simulations is curried out for three values of Reynolds numbers (Re = 100, 500, and 1200). Before analyzing the CFD results, it is necessary to highlight that thermal optimization and material saving is represented in terms of thermal resistance, pressure drop, and pumping power.

The thermal resistance is reduced when one pin is added to the flow channel compared to the smooth one. Thus, the thermal resistance of the channel with the pin is lower than that without pin while the number of channels is the same for the three values of Reynolds number. With one pin in each channel, one fin has been removed by keeping the fin thickness constant (enlarge the flow channel width), the thermal resistance comes back to increase but it still lower than the original case. By removing the second fins, the thermal resistance becomes equal to that of the original smooth-fin microchannel. From the above demonstration, it became clear that the best flow rate behavior is at Re = 1200. For more clarification, the results at that value of flow rate have been enlarged as in subfigure (b) to be more explicit.

Further simulations have been carried out by removing three fins (enlarging the hydraulic diameter while the still one pin is added to the flow channel) but the thermal resistance becomes more than the original case. Since it can be said that removing two fins and adding one pin in each channel provides the same thermal performance. Hence, the calculations of material saving have been carried out. It can be concluded that the better thermal-hydraulic performance can be obtained by using pinned fin MCHS with ξ = 0. 8 and ψ = 1 and Dh = 1. 1679×10-3 m and Wc = 1. 214×10 3 m instead of plate-fin MCHS having ten fins under same conditions. With best Nusselt number ratio (1. 42 times) and JF = 1. 24 compared to plate-fin MCHS with a reduction in the substrate material around (5. 41%).

Now, to show the hydraulic performance of using a single pin in each channel with ξ = 0. 8 and ψ = 1 and Dh = 1. 1679×10 3 m, on the pressure drop and pumping power reduction has been estimated. For the case of the plate-fin channel, the Nusselt number is (3. 55) at Re = 1200. By using a pin, the Nusselt number ratio is greatly enhanced. To get the same value of Nu number of the smooth channel (i. e., Nu*/ Nuo = 1), the flow rate must be reduced when the pin is used. By this way, Reynolds number is reduced to 834 for the pinned fin MCHS to provide the same thermal performance of smooth one. It could be deduced that the pumping power required for pushing the fluid in plate-fin MCHS decreases in the case of pinned fin MCHS for the corresponding amount of the heat transfer rate. In that case, a reduction in the pumping power is obtained around (24%)

The pressure drop and pumping power reduction for four types of the heat sinks when temperatures on bottom surfaces bases (Tb) remain 70 °C. It shows that the pressure drop and pumping power decreases as the fin number reduction ξ decreases, and the JF factor of the pinned fin MCHS is about (24%) higher than that of the plate-fin MCHS with the same pumping power. This indicates that the pinned fin MCHS needs less pumping power than the plate-fin MCHS requires when the heat dissipation power is the same for the two types of heat sinks. Therefore, adopting the pinned fin MCHS can make the volume of air-cooling system smaller. It is worth to be mentioned here that the results of Shaalan and his group showed that the thermal performance of HS increased with increasing the fin numbers under turbulent flow regime. But besides, additional pressure drops were registered with the thermal enhancement. In this study, it is proved that the thermal performance of the HS can be improved by reducing the fin numbers and adding pins in the channels simultaneously.

In contrast, the present results agree well with the results of Zhuo et al. in terms of thermal-hydraulic performance of plate-fin HS, which was increased with using turbulators. In addition, the present results show that the enhancement of thermal-hydraulic performance in large values of ξ is greater than that of small ones, and they agree well with the results of Ebrahimi et al. due to the short width of the channel which prevents the formation of vortices. Furthermore, the results obtained by Ahmed and Ahmed illustrated that increasing the number of grooves does not mean enhancing the thermal performance, but just additional machining processes and further costs. Their results support the present findings.