Thermal performance of perforated pin finned heat sinks: A simulation based study

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Introduction: Need for efficient heat sinks has been ever increasing, particularly in two contexts: (1) increasing performance of electronic circuits increases high power density demanding higher efficiency of heat removal for sustainability, (2) faster heat transfer rate that can improve coefficient of performance (COP) of thermoelectric systems. Several researches have proposed designs of heat sinks that can improve convective heat transfer [1]. This study compares the thermal characteristics of solid and perforated pin fin heat sinks of copper and aluminum. The thermal behavior of different configurations of heat sink is analyzed using CFD module in COMSOL environment to mark significant inferences.

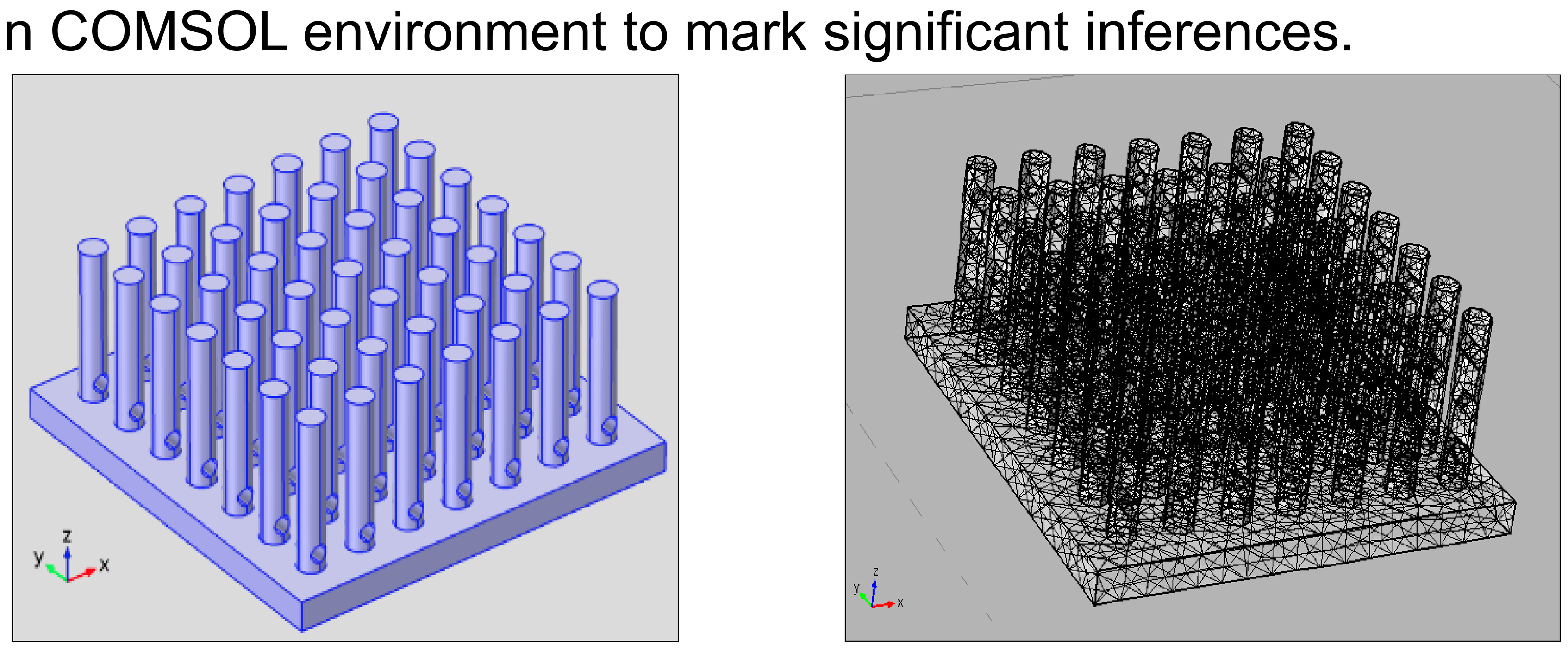

Figure 1. COMSOL® model geometry and Physics based Mesh of Single perforated Cylindrical fin Heat Sink

Computational Methods: Thermal characteristics of pin-fin heat sink of different geometries were analyzed in the COMSOL® 4.4 simulation environment. Aiming the use of heat sink in context of thermoelectric refrigeration system, we conceived an enclosed thermally insulated hollow cube where a heat sink was attached to one of its walls such that fins face inward and the base faces outward to a constant heat source. The interior of the box has an initial ambient temperature of 300K while the base of the heat sink was subjected to a constant temperature of 600K, and conduction from base to pins inside the box was recorded. Copper and Aluminum heat sink with solid pins and solid pins with 1, 3, and 4 perforations were considered. The pins are cylindrical with radius of 0.25cm, height 2.5 cm, the gap between pins is 0.3 cm, and the base dimensions are 7.5 cm*7.5 cm*.5 cm. A 3D geometry of this fluid-flow problem was built in COMSOL with user-controlled tetrahedral meshing to compute the solution for time-dependent analysis [2].

Governing equations

Continuity equation: $\frac{\partial \rho}{\partial t} + \nabla.(\rho u) = 0$

Conduction: $q = -k.A\frac{dT}{dx}$

Convection: $q_c = h_c\, A\, (T_s - T_a)$

Radiation: $q_r = \varepsilon\sigma(T_s{}^4 - T_a{}^4).A$

Heat equation: $\rho\, Cp\, \frac{\partial T}{\partial t} = \nabla.(k\nabla T) + Q$

Rayleigh number: $Ra = \frac{\rho^2 g\alpha\, C_p}{\mu k}\Delta T\, L^3$

where ρ is density, u is velocity vector, k = thermal conductivity [W/ (m•K)], A=surface area perpendicular to direction of heat transfer (m^2), T_s = surface temperature of hot body (K), T_a = air temperature air (K), ε is emissivity of the surface of hot body (W/m^2), σ is Stefan Boltzmann constant (5.67 x 10^{-8} Watt), C_p is heat capacity (J/Kg/K), Q is heat source (W/m^3), g is gravity (m/s^2), α is thermal expansion coefficient (1/K)

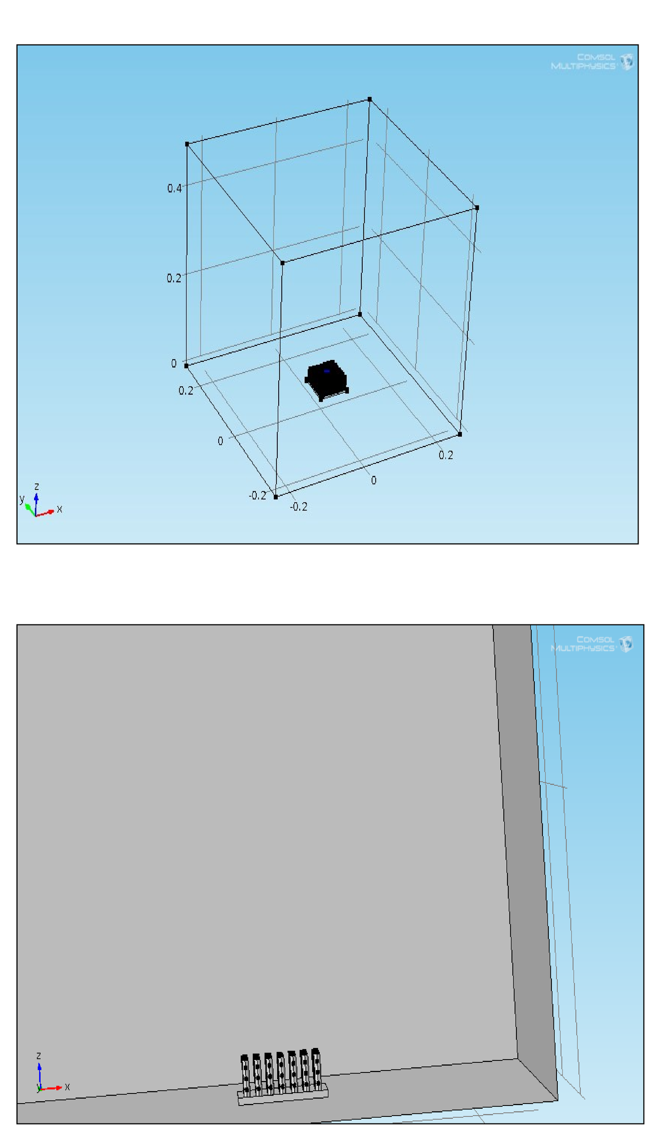

Figure 2. COMSOL model

Simulation Results:

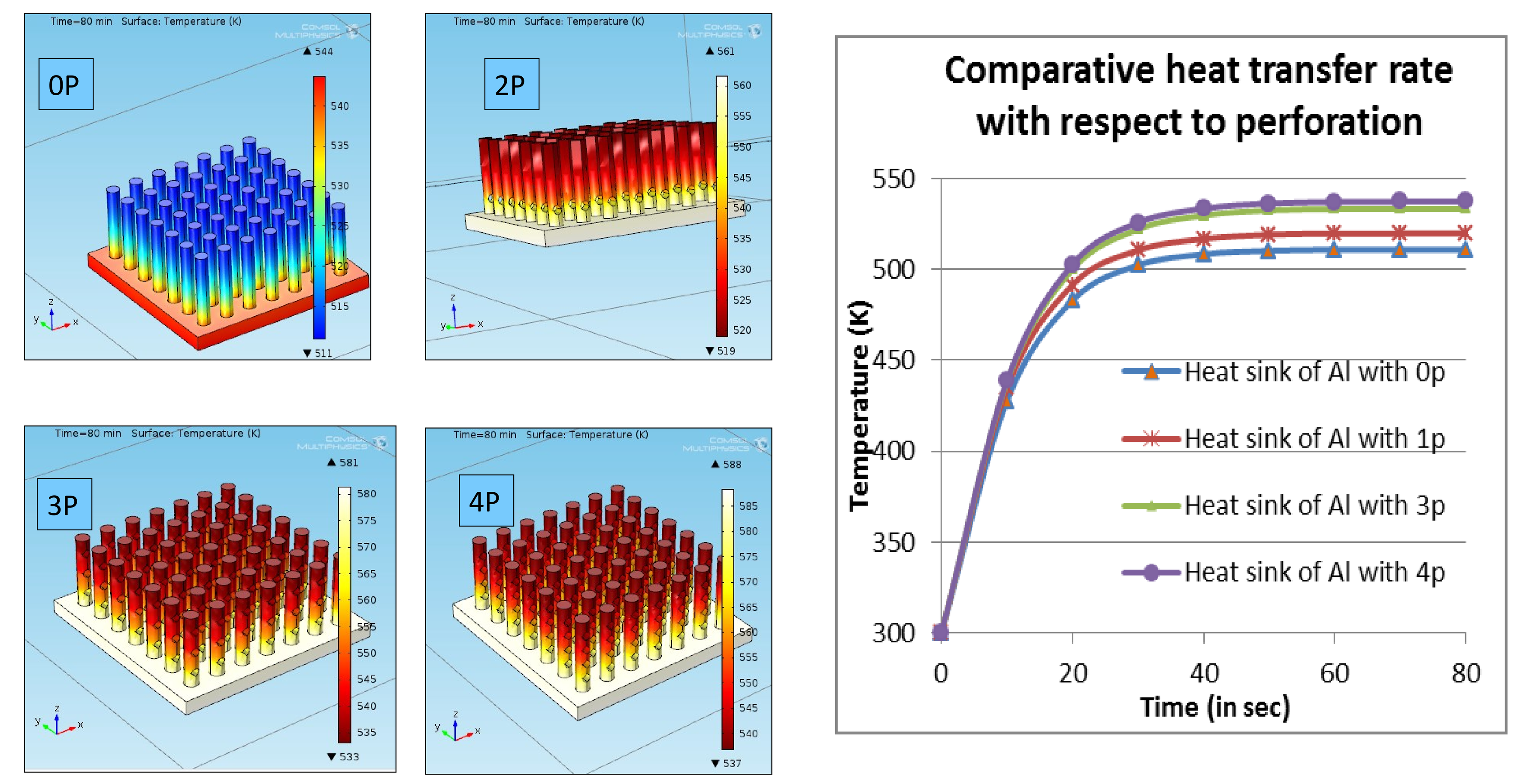

Figure 3. Results and comparative analysis of heat transfer for Aluminum heat sink

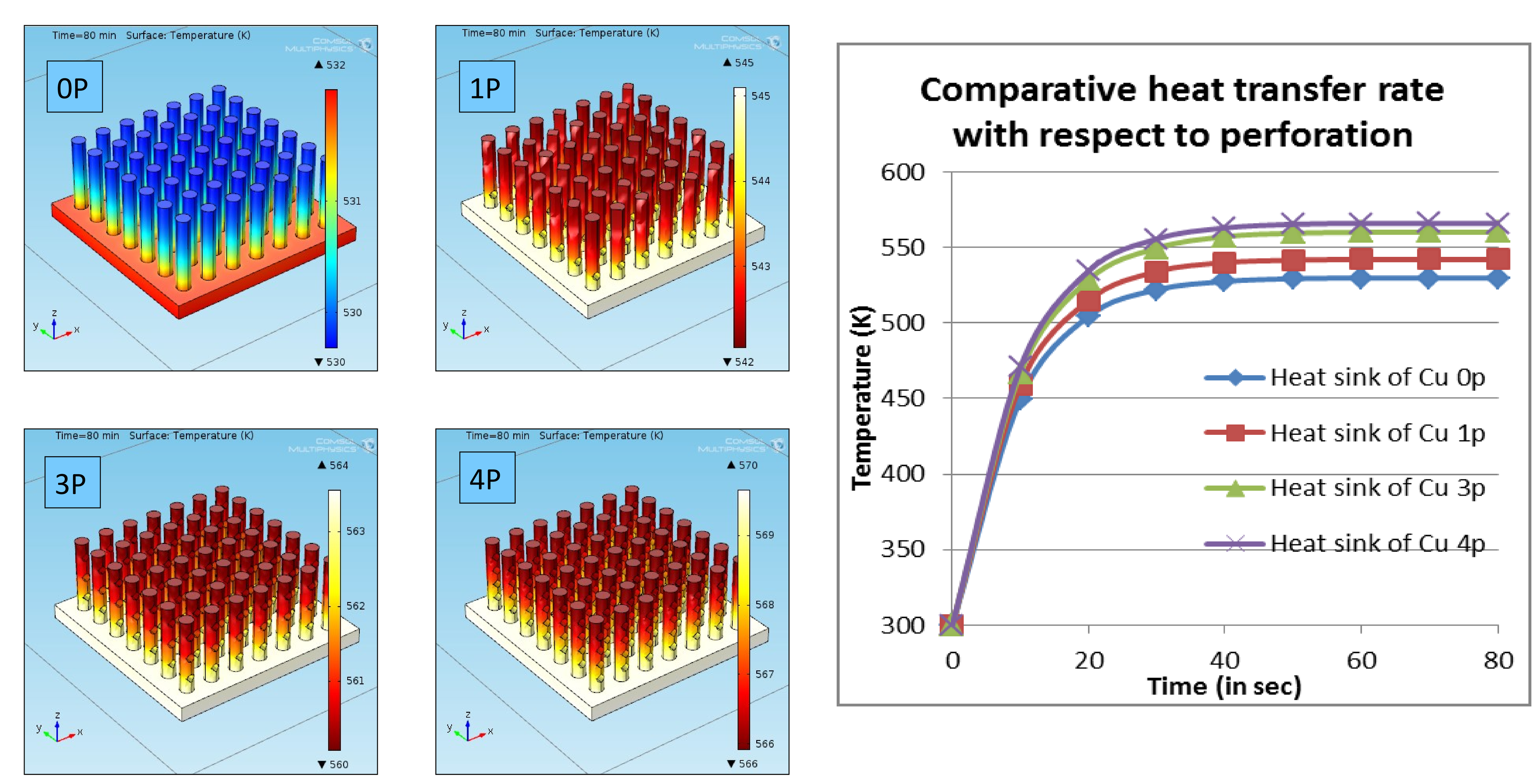

Figure 4. Results and comparative analysis of heat transfer for Copper heat sink

Conclusions: The simulation results demonstrate that pin fin heat sink with four circular perforations have better heat transfer characteristics than solid pin fin (zero perforation) or pin fins with less number of perforations for both Copper and Aluminum material. This higher performance may be attributed to larger surface area for convection and higher Nusselt number arguably due to the change in airflow directions. Besides improving cooling performance of electronic circuits, the perforated pin fin heat sink can improve COP of thermoelectric systems. As observed from [3], reduction of temperature by 5 degrees between the hot and cold side of thermoelectric module may lead to improvement of COP by more than 10%.

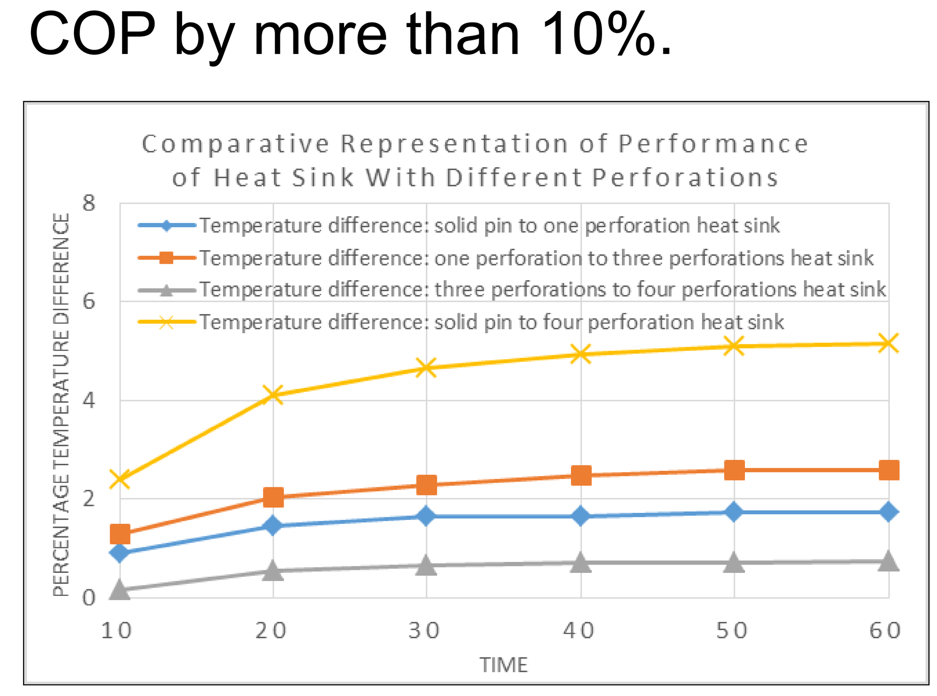

Figure 5. Comparative performance of perforated heat sinks

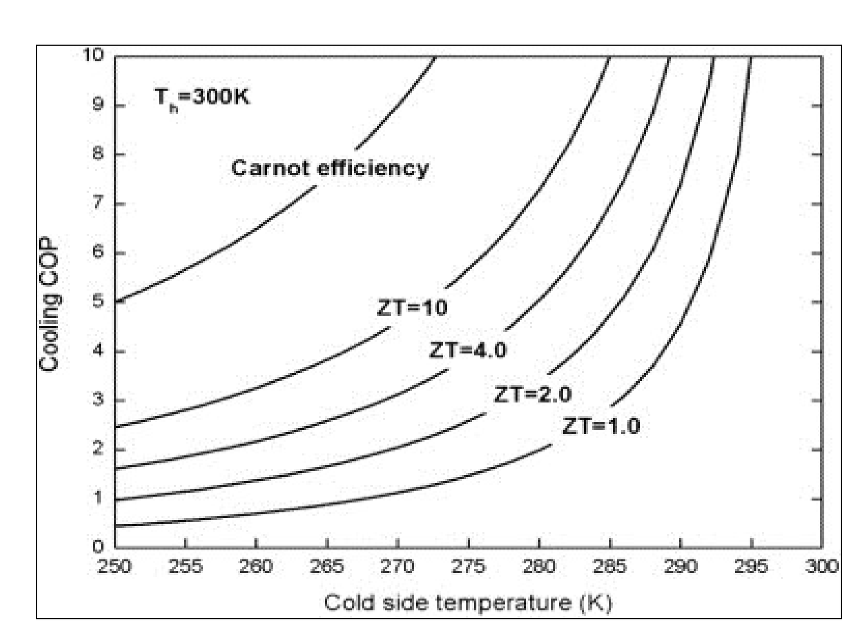

Figure 6. Cooling COP of a thermoelectric module under optimum electrical current with fixed hot side temperature of 300 K.

References:

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2. COMSOL Multiphysics User's Guidel, version 4.3, COMSOL, Inc, www.comsol.com
3. Zhao, D., & Tan, G. (2014). A review of thermoelectric cooling: materials, modeling and applications. Applied Thermal Engineering, 66(1-2), 15-24.