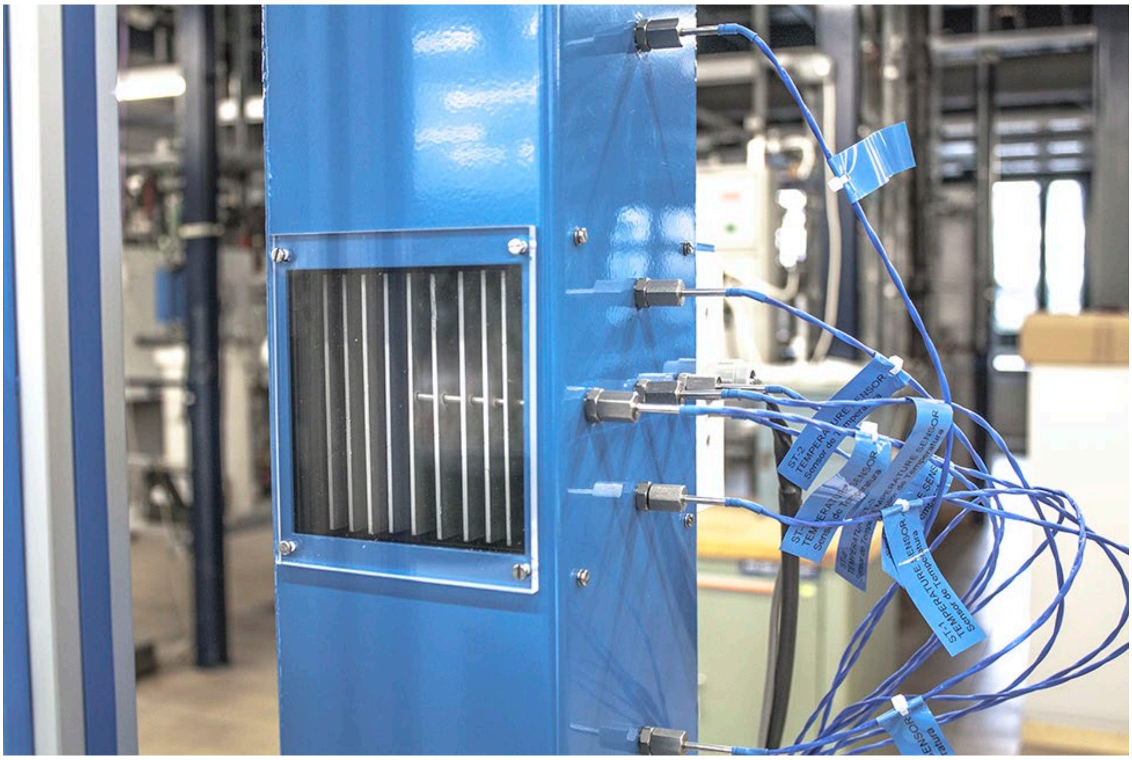
ChE-309 TP-8
Forced convection on a heat sink

instructions for use, spring 2024



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1. Statement of the problem

Advanced Micro Devices wants you to design a simple heatsink for their new Microprocessor for 1024-core servers. The face of the processor is 10 cm by 10 cm and it will produce 500 W of heat when operating at full power. The solder used to connect the processor to the motherboard may not exceed 150°C. The company has developed a new aluminium alloy and a new surface treatment to provide exceptional heat transfer characteristics. In these experiments you will study new heatsink models made with this alloy and surface treatment and then use what you have acquired to design a simple finned heatsink for this company.

2. Theoretical part

A heat sink is a device designed to promote the evacuation of excess thermal energy created by power semiconductor elements. These devices are usually equipped with fins to facilitate convective cooling. The fins increase the surface area available for heat transfer between the metal walls and poorly conductive fluids such as gases.

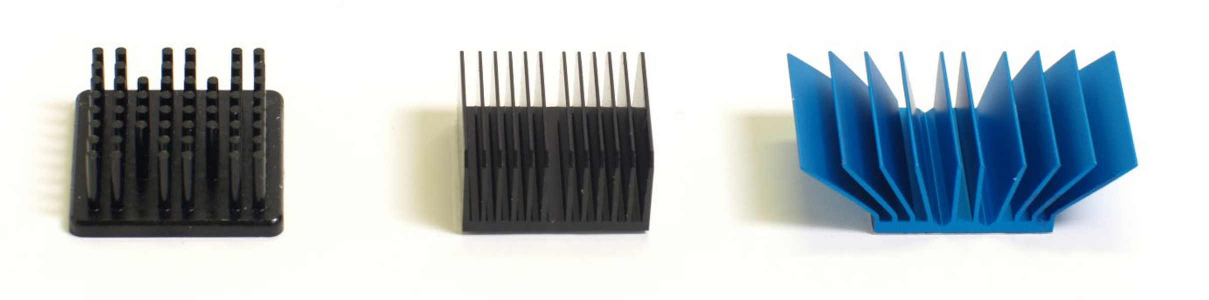

Figure 1. Heat sinks (Wikipedia)

The efficiency of a single fin of a heat skink is defined by:

$$\eta = \frac{\text{actual rate of heat transfer from the fin}}{\text{rate of heat transfer from the fin is it was isothermal at } T_w}$$

Where T_w is the temperature of the wall (or base) of the heat sink.

A simple rectangular fin is shown in Figure 2.

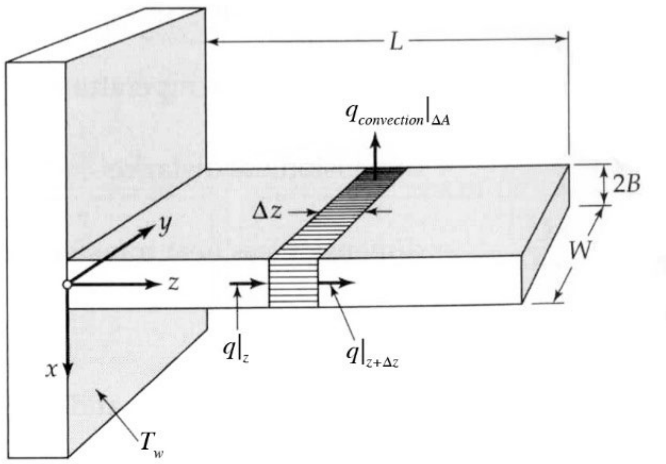

Figure 2. Model of a fin.

In the case of B << L and B << W, the system can be described relatively well by making the following assumptions:

- The Temperature of the fin, *T*, is a function of *z* only
- No heat is lost through the end (tip) of the fin (W × 2B) or from the edges (L × 2B)
- The heat loss from the surfaces of the fin 2 × (W × L) is given by $q_z = h(T - T_\infty)$ where *h* does not depend on *z*, but $T = f(z)$.

A steady-state energy balance can easily be done on a Δz section of the fin.

$$2BWq_z|_z - 2BWq_z|_{z+\Delta z} - h(2W\Delta z)(T - T_\infty) = 0$$

By dividing by $2BW\Delta z$ and taking the limit as $\Delta z \to 0$ we have

$$-\frac{dq_z}{dz} = \frac{h}{B}(T - T_\infty)$$

By applying Fourier's Law ($q_z = -k\, dT/dz$), where *k* is the thermal conductivity of the metal (assumed constant with respect to temperature), we get:

$$\frac{d^2T}{dz^2} = \frac{h}{kB}(T - T_\infty)$$

This equation is solved with the following boundary conditions:

BC.1: @ $z = 0,\ T = T_w$

BC.2: @ $z = L,\ \frac{dT}{dz} = 0$

This system of equations is easily solved by introducing the following dimensionless quantities:

$\Theta = \frac{T - T_\infty}{T_w - T_\infty}$ = dimensionless temperature, $\zeta = \frac{z}{L}$ = dimensionless distance,

$\mathrm{N}^2 = \mathrm{Bi}\left(\frac{L}{B}\right) = \frac{hL^2}{kB}$ = dimensionless heat transfer coefficient (Bi is the Biot number, $\frac{hL}{k}$).

Then the differential equation takes the form:

$$\frac{d^2\Theta}{d\zeta^2} = \mathrm{N}^2\Theta$$

With the BCs as $\Theta|_{\zeta=0} = 1$ and $\left.\frac{d\Theta}{d\zeta}\right|_{\zeta=1} = 0$.

This equation can be integrated to give hyperbolic functions of the form:

$$\Theta = C_1 \cosh \mathrm{N}\zeta + C_2 \sinh \mathrm{N}\zeta$$

After resolving the integration constants using the boundary conditions, we have:

$$\Theta = \frac{\cosh \mathrm{N}(1-\zeta)}{\cosh \mathrm{N}} \quad \to \quad \frac{T - T_\infty}{T_w - T_\infty} = \frac{\cosh \sqrt{\frac{hL^2}{kB}}\left(1 - \frac{z}{L}\right)}{\cosh \sqrt{\frac{hL^2}{kB}}}$$

with this result we are able to find an expression for η in a stationary state.

However, in a transient case, the situation is more complicated. In the case of transient heating of a fin, initially at constant temperature, T_∞, and at t = 0, a constant $q = q_0$ is introduced into the fin at z = 0, the differential equation and boundary conditions can also be derived:

$$2BWq_z|_z - 2BWq_z|_{z+\Delta z} - h(2W\Delta z)(T - T_\infty) = \rho c_p \Delta z 2BW \frac{dT}{dt}$$

$$\frac{d^2T}{dz^2} = \frac{h}{kB}(T - T_\infty) + \rho c_p \frac{dT}{dt}$$

BC.1: @ $z = 0$, $\frac{dT}{dz} = -\frac{q_0}{k}$

BC.2: @ $z = L$, $\frac{dT}{dz} = 0$

IC.1.@ t = 0, $T = T_\infty$

The form of the solution to this transient problem (e.g. logarithmic, hyperbolic, polynomic…) will be important for this work (but not the actual solution).

3. Laboratory Practical Work

3.1 Objectives

The objectives of this experiment are as follows:

- Use the experimental set-up with the finned heatsink to estimate the heat transfer coefficient, h, between the surface of the heat sink and the air at different air velocities.
- Estimate the efficiency of the finned heatsink.
- Determine if the assumptions made in section 2 are valid for our finned heatsink.

3.2 Experimental set-up

The assembly (Figure 3) consists of a vertical duct with a fan placed in the upper part (AVE-1) capable of driving the air upwards through a duct. The air volume flow is measured by a sensor at the bottom of the duct (SC-1). The heat sink coupled with its heat generator (thermal resistance, AR-1) is placed in a vertical position in the middle of the duct. Temperature measuring thermocouples (ST-1-8) are strategically placed throughout the installation.

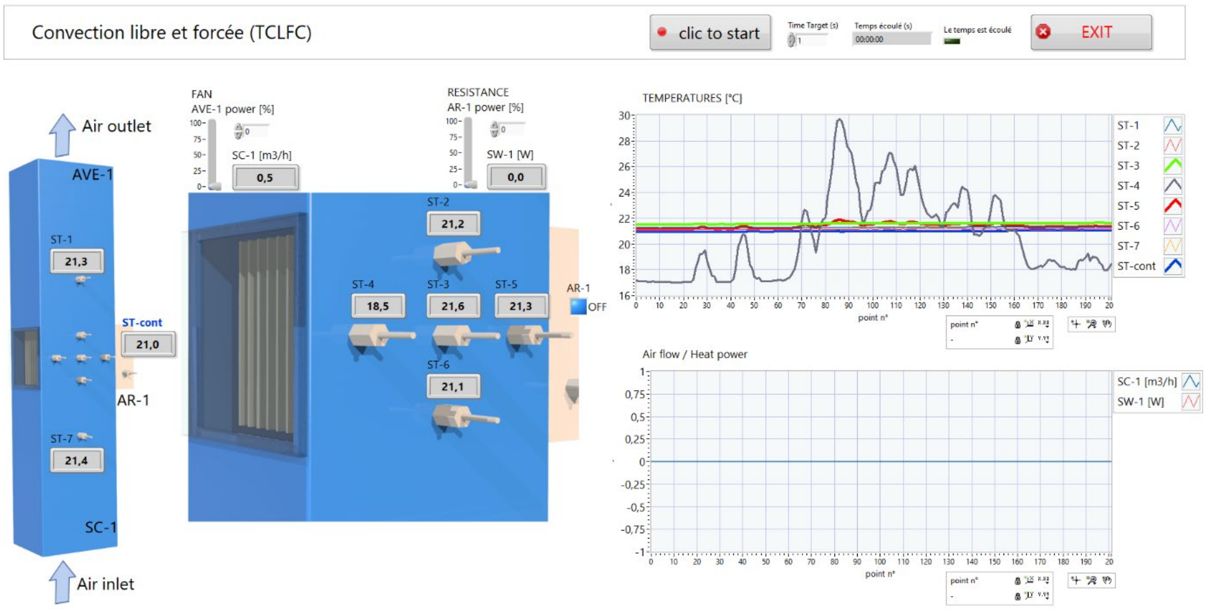

Figure 3. Experimental set-up

3.3 Manipulation

1. When you arrive, the finned heat exchanger should be placed next to the control unit (not installed in the system).
2. Analyze the different properties of the exchanger (material, geometry, etc.).
3. With the control unit first switched off, make sure that the finned heat exchanger is connected to the rear of the control unit (there are two connections, AR-1 and ST-CON). If not, connect it and turn on the unit. Place the finned heat exchanger in position and carefully install all thermocouples in the heatsink. Try to ensure that the tip of the thermocouples (ST-2 - 6) are inside the fin and not in the airflow. Ensure that all thermocouples are in the correct position. Start the “TCLFC-new” program.
4. Press "clic to start" (choose the file name of the group) and start recording data (set the “Time Target (s)” as every 10 seconds is sufficient).
5. Examine the range of the AVE-1 and the effect it has on SC-1.
6. Before activating the AR-1, establish a data collection methodology to estimate *h* for three different air velocities covering the entire equipment. Obtain approval of this methodology with the assistant. (hint: Each condition takes about 1 hour to come to a steady state).
7. Set AR-1 to approx. 50% (beyond this, the temperature safety switch can switch the heater on and off) and collect the data for the "blades forced eff".
8. At the end of the "blades forced eff" experiments, press "clic to stop". Then press "EXIT". Switch off the unit and remove the heat sink (be careful, it will be hot!).

3.4 Report

1. Describe the methodology for estimating *h* for different values of v_∞ for the finned heat sink. Explain how you proceeded and what assumptions you made.

2. For the finned heat sink, estimate the heat transfer coefficient with your measurements. What are the sources of error and assumptions made in your calculation?

3. For the finned heatsink, calculate the "measured" efficiency based on the effective heat loss of the heatsink, the geometry of the finned heatsink, and the value of the h of the finned heat exchanger for the different v_∞. Explain the calculation. Describe AND explain the effect of different air velocities v_∞ on efficiency.

5. For the problem posed in Section 1, using what could be learned, how could a finned heat sink be designed for a heat dissipation rate of 500 W in the stationary state, with a maximum wall temperature of 150°C and with the highest of the v_∞ tested in these experiments? (Give number and size of fins) How efficient would this heat exchanger be?

Include graphs of raw data from the experimental data obtained in the Appendix.