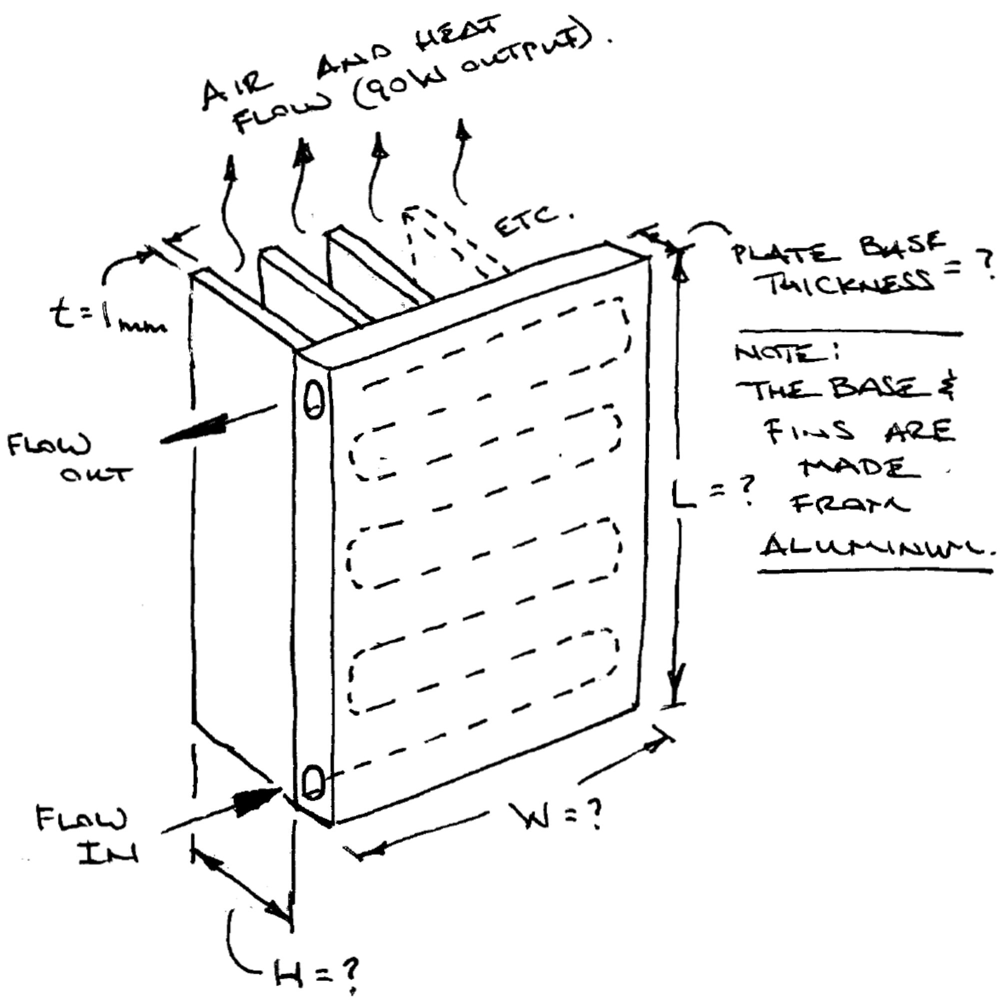
me263 – Fluids and Heat Transfer

Finned cooling/finding h/fluid flow design Tutorial & Assignment 7

In this assignment/tutorial you are asked to deal with a rather open-ended design question. That means that you will have to think and make decisions about the design that will likely be different than other class members. As this calculation is a bit lengthy, please hand in work that is very well organized and super easy to follow, step-by-step.

Here is the problem you are to deal with.

You have been asked to design the 'heat output side' of an electronic cooling system. The rest of the system has been designed to circulate water through a heat absorber attached to some electronics that gives off 90 Watts. The warm water will then flow into your heat output device so it can be rejected to the surrounding air. A generalized sketch of your design is shown below.



The **average water temperature** should be no warmer than 90°C, the **temperature difference** between inlet and outlet of your heat sink should be 12°C and the **ambient air temperature** will be no hotter than 30°C.

Notice that many of the dimensions have been left off the drawing. Importantly though, the heat sink fin thickness has been specified as 1 mm. Also, the flowrate of warm water that will circulate through the back of your heat sink has not been specified.

Your task is to:

Water Side

a. Based on the water temperature difference between the inlet and outlet of your heat sink, stated above, determine the required mass flowrate in kg/s. (recall that: $\dot{q} = \dot{m}C_P\Delta T$)
b. Convert this mass flowrate to volume flowrate (m^3/s) noting that the average temperature of the flowing water as it passes through your heat sink is stated above.
c. Based on this volume flowrate determine a water tube size for the water to flow in. Recall that this is done by first select a reasonable velocity of flow based on the recommended velocities provided in class (class web page, week 1). Assume that the hole drilled in the aluminum back plate of the heat exchanger can be produced in even, 1 mm increments (that's the actual inside diameter to use). Choose an even mm increment of ID and calculate the actual velocity of the fluid in the pipe.
d. Based on the actual flow path ID you have selected, decide on the Plate Thickness the base of your heat sink should have.

Fin Side

a. Read over the information on natural convection heat sinks shown in the pages below. Take careful note of the calculation of the 'optimum fin spacing' for natural convection. You will be expected to use this in your work.
b. Choose an assembly length, L. This is the *characteristic length* of the fin design and is thus important. You need to decide on this first. How do you choose this number? Just think about what you want your design to look like and choose a number that feels right. Yup, that's right. You just pull a number from thin air.
c. Now decide on a fin height, H. Again, you simply decide on this based on what you want the design to look like in the end.
d. Follow the notes and example below and determine the optimum fin spacing and corresponding convective heat transfer coefficient, h.
e. For a single fin, determine its heat transfer output in the usual way (fin efficiency, etc.). Assume the base temperature is at the average water temperature, stated above.
f. Determine the total number of fins required based on your desired total system output of 90 watts and your, now known, single fin heat output.
g. Work out the width of the complete heat sink, W.
h. Finally determine the actual total heat output of the fin assembly by adding in the heat given off by the exposed portion of the base.

Natural Convection from Finned Surfaces

Finned surfaces of various shapes (heat sinks) are used in microelectronics cooling.

One of most crucial parameters in designing heat sinks is the *fin spacing*, *S*. Closely packed fins will have greater surface area for heat transfer, but a smaller heat transfer coefficient (due to extra resistance of additional fins). A heat sink with widely spaced fins will have a higher heat transfer coefficient but smaller surface area. Thus, an *optimum spacing* exists that maximizes the natural convection from the heat sink.

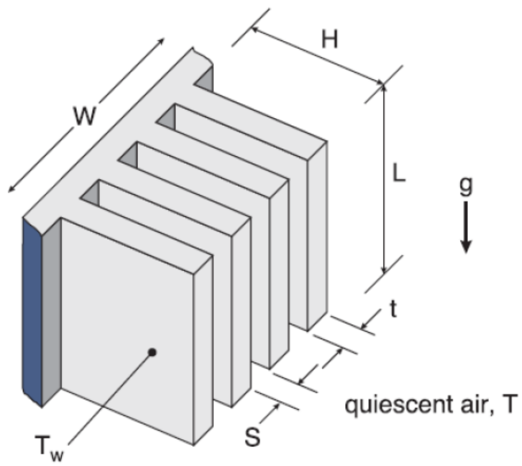


Fig. 4: A vertical heat sink.

Consider a heat sink with base dimension *W* (width) and *L* (length) in which the fins are assumed to be isothermal and the fin thickness *t* is small relative to fin spacing *S*. The optimum fin spacing for a vertical heat sink is given by Rohsenow and Bar-Cohen as

$$S_{opt} = 2.714 \frac{L}{Ra^{1/4}} \qquad Ra = Gr\,\Pr = \frac{g\beta(T_s - T_\infty)\delta^3}{\nu^2}\Pr$$

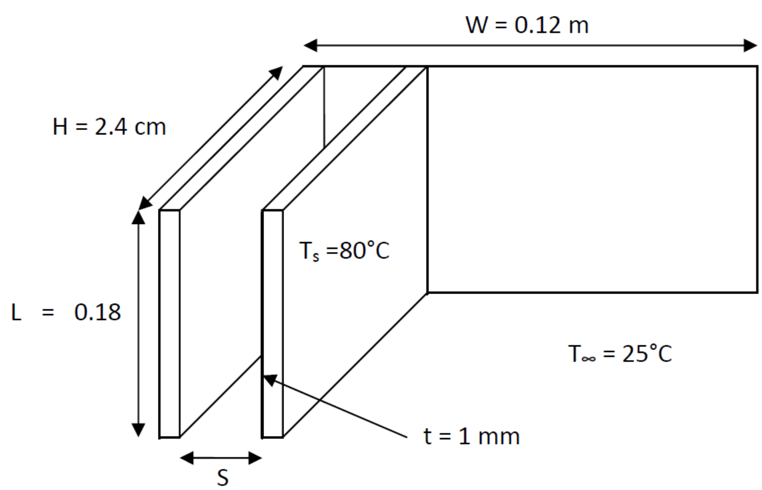
where *L* is the characteristic length in *Ra* number. All the fluid property are determined at the film temperature. The heat transfer coefficient for the optimum spacing can be found from

$$h = 1.31 \frac{k}{S_{opt}}$$

Note: as a result of above-mentioned "two opposing forces" (buoyancy and friction), heat sinks with *closely spaced* fins *are not suitable* for natural convection.

EXAMPLE

A 12-cm wide and 18-cm-high vertical hot surface in 25°C air is to be cooled by a heat sink with equally spaced fins of rectangular profile. The fins are 0.1 cm thick, 18 cm long in the vertical direction, and have a height of 2.4 cm from the base. Determine the optimum fin spacing and the rate of heat transfer by natural convection from the heat sink if the base temperature is 80°C.



Assumptions:

The fin thickness t is much smaller than the fin spacing *S*.

Solution:

The properties of air are evaluated at the film temperature:

$$T_f = (T_\infty + T_s) / 2 = 52.5°C = 325.5\ K$$

At this temperature, $k = 0.0279\ W/mK$, $\nu = 1.82 \times 10^{-5}\ m^2/s$, Pr = 0.709, and assuming ideal gas $\beta = 1 / T_f = 1 / 325.5\ K = 0.003072$ 1/K.

The characteristic length is $L = 0.18$ m.

$$Ra = \frac{g\beta(T_s - T_\infty)L^3}{\nu^2}\Pr = 2.067 \times 10^7$$

The optimum fin spacing is determined

$$S_{opt} = 2.714\frac{L}{Ra^{1/4}} = 0.0072\,m = 7.2\,mm$$

The number of fins and the heat transfer coefficient for the optimum fin spacing case are

$$n = \frac{W}{S+t} \approx 15 \text{ fins}$$

$$h = 1.31\frac{k}{S_{opt}} = 5.08\frac{W}{mK}$$

Now that h has been determined and the number of fins established one can calculate the total heat transfer from the fin/base arrangement in the usual way … that is using fin efficiency to determine the heat transfer from the fin part and adding to that the heat transfer from the exposed parts of the base.