MEEG346 Thermal Laboratory

Laboratory Problem X4 – Measurement of Temperature on a Heated Plate

Objective

1. To investigate and measure transient two-dimensional conduction in an aluminum plate.
2. To report the measured temperature field to a space station contractor
3. To develop a computer model of the plate temperature field
4. **Design Objective:**Recommend design changes that might protect an instrument package attached to the plate.

Problem Statement:
You are employed by a research group designing a module containing apparatus and instruments for a biology experiment to be placed on the International Space Station. The only available place on the crowded station is on an existing 12" x 12" aluminum panel, two of whose edges are exposed to hot temperatures from an adjacent equipment room, and two edges exposed to nominal cabin temperature.

The research group needs to know the surface temperature distribution of the support panel, including the hottest area on the plate, in order to orient temperature sensitive specimens and instruments away from it. They want a computer model of the plate in order investigate on their own possible future variations in the plate environment, and finally any design recommendations to plate or module that would protect the biology specimens *Cimex lectularius* **from extremes.**

Your team has built a simple model of the panel, instrumented with thermocouples and a sophisticated visual system for observing plate temperatures.

Divide up your team responsibilities: for example two people operate and photo, two people record thermocouple data, two people work on numerical solution.

Description of Apparatus

The panel is modeled by a 12" x 12" x 2" thick aluminum plate, subjected to the following temperature boundary conditions:

- Two edges are heated using thermally bonded electrical resistance strip heaters simulating the hot temperatures from the adjacent room. This may be considered a constant heat flux boundary condition.
- The other two edges are cooled using thermally bonded heat exchanger plates supplied with cooling water from a chiller (constant temperature boundary condition).
- The bottom face is insulated with glass wool.

- The top face has a thermochromic liquid crystal (TLC) sheet glued to it. The TLC sheet changes color with temperature, providing a visual of the total temperature field, and can be an alternative means of measuring temperature. The top face is also insulated from the surroundings (as it would be with the instrument package placed on it) by an air gap underneath the glass plate. The glass plate allows observation of the color pattern of the TLC sheet.
- Temperature will also be measured directly by using 16 thermocouples inserted into tiny holes drilled into the plate on a 3 in. x 3 in. grid.

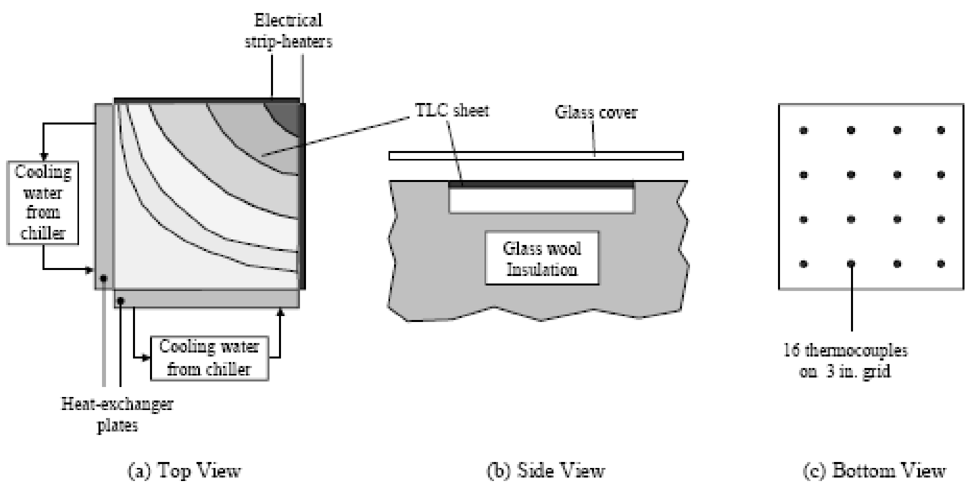

Figure 1: Schematic of heated plate

Theoretical Considerations

Thermochromic Liquid Crystals (TLC) are organic long-chain molecules that have the useful property of being temperature sensitive. They respond to temperature by changing molecular structure, and consequently the wavelength of reflected light changes with temperature. Contrary to conventional representation of colors for temperature, TLC are red when *cold* and blue when *hot.*

The equipment configuration for this investigation lends itself to two-dimensional conduction heat transfer analysis, i.e., $T = T(x,y,t)$. Under steady-state conditions the time dependence will disappear. The dependence of T on z is minimized provided that the top and bottom faces are well insulated; this experiment provides such an insulating boundary condition. Note that the heat transfer rate through the material from one edge to another will vary with different thicknesses. With reference to Figure 2, we can solve for the time dependent temperature $T(x,y,t)$ subject to the following initial condition:

$$T(x,y,0) = T_o$$

and boundary conditions:

$$T(L,y,t) = T_1$$

$$
\begin{aligned}
q(0, y, t) &= -k\frac{\partial T(0, y, t)}{\partial x} = q_1 \\
q(x, 0, t) &= -k\frac{\partial T(x, 0, t)}{\partial y} = q_2
\end{aligned}
$$

where k is the thermal conductivity of the aluminum plate. Temperatures T_1 and T_2 are assumed to be equal to the chiller setting, while q_1 and q_2 may be estimated by noting the electrical power supplied by solid state rheostats to each electrical heater. T_o is known from the thermocouples. Therefore all four boundary conditions and the initial condition are completely determined and can be used to solve for the temperature distribution within the plate.

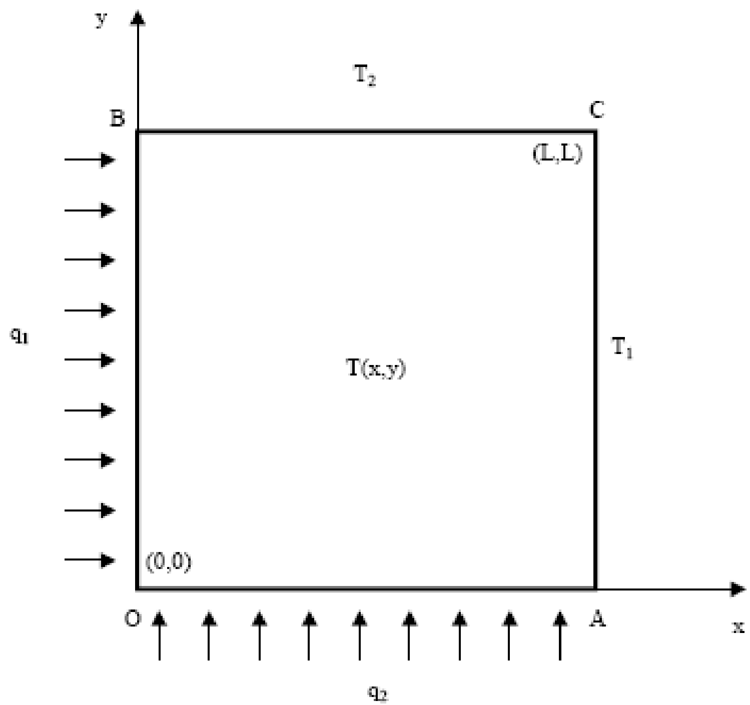

Figure 2: Geometry and boundary conditions for heated plate

The heat conduction law may be written as

$$
\nabla^2 T = \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} = \frac{1}{\alpha}\frac{\partial T}{\partial t}
$$

where α is the thermal diffusivity of the plate. You are required to solve the transient conduction equations using <u>a numerical</u> technique, such as the one taught in MEEG342 Heat Transfer, and compare your results with your measurements. You may also use other computer packages for heat transfer problems, such as ANSYS or FEHT. The most convenient ap to use in recent times has been the Heat Transfer Module in Solid Works.

Procedure

1. Record the initial plate temperature by cycling through all the thermocouples; also, snap an image of the color contours on the plate using your cell phone cam. This data will provide the initial condition for your numerical simulation.
2. Set the chiller temperature to 20 ^{o}C and start the flow through the heat exchangers. This will simulate cabin temperature and set the boundary conditions T_1 and T_2 (assuming that the water temperature does not increase very much during its travel across the plate).
3. Set the rheostats to provide a desired value of q_1 and q_2. The goal is to obtain maximum color play in the TLC sheet. It has been found find that a setting between 70 and 80 V is suitable. Record the voltage and amperage shown on the power box. Power provided to both heaters is $P = V* I$ The heat flux is obtained by using $q = P/A$ where A is the total area of the two edge heaters. This assumes that all of the power generated by the heater is directed into the plate (is this a good assumption?).
4. You will find that the plate takes a while to reach steady state. During this time, record (approx once every 5 minutes) the temperatures from all 16 thermocouples by using the computer display, or manually recording. Also, simultaneously snap an image of the color contours on the plate. Note down the time for each measurement. Photo and temperature recording should be as near simultaneous as possible. Teamwork!

You may terminate your measurements when steady state is reached. The best way to determine this is by observing that the thermocouple readings are no longer changing with time.

Analysis

You may present your results in various ways, but in general be mindful of what your client wants to know, as stated in the Objectives. The following is a suggestion, but may be modified according to what you believe tells the best story.

1. Plot all temperature contours obtained from the thermocouple readings to show the steady state. You may do this by hand on a sketch of the plate. There are software packages that can do this, but a sketch will do. Also plot temperature vs. time for a few representative thermocouples (e.g.,cold corner, center, hot corner).
2. Compare representative temperature contours with color images captured by camera at the same time.
3. Perform a numerical solution using the experimental boundary and initial conditions that you measured. Compare the solution with results you obtained from thermocouple measurements.
4. What NASA wants to know is the final steady state temperature field and where best to put the petri dish. Think of way to show this clearly and simply. Report grading will focus on this.

Discussion of experiment

1. In the current implementation, the TLC results are qualitative, and primarily present a picture of the temperature field. To make it quantitative, what procedure could you suggest? Essentially we would have to calibrate color with temperature. Is this a reasonable thing to do?
2. What are possible reasons for discrepancies between the three sets of results? Think about differences between the onsite (ISS) and model boundary conditions, for example.
3. The cabin-side temperature boundary condition assumed a constant temperature. Estimate the temperature rise of the cooling water as it flows along the plate edge. You will need to know the amount of heat being absorbed by the water, and the water flow rate (chiller specification sheet). (See sticker on top of the chiller box). An energy balance will give you the temperature rise.
4. Review the requests made by the client and be sure you have clearly addressed them in your report. Include suggestions you may have for creating a more uniform or cooler environment for their system. (Note from NASA: Finding another location on board the space station is <u>not</u> an option. There isn't one).

Uncertainty Analysis

1. Consider the temperatures measured by the thermocouples versus your computed calculation. For the <u>steady</u> state, make a table or diagram comparing measured and calculated temperature at each TC position. Choose and use a method for computing uncertainty.

2. A key part of the Design Objective is to advise NASA which data set to believe. There is not a right answer to this. You are the consultant. What is important to the report is your explaining why you made the choice. In addition to scientific value, the crew on the space station has a strong interest in keeping the specimens in the dish!