Lab 2: Natural and forced convection

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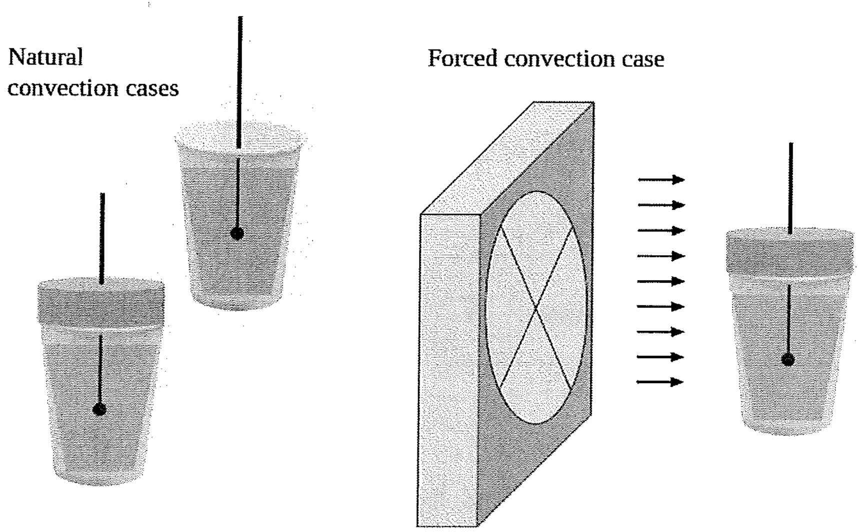
Introduction

This lab will explore the modes of heat transfer involved in the cooling of hot water. You will use several standard paper cafe cups with and without insulated lids to quantify the heat transfered by natural and forced convection. For your forced convection case, a box fan will generate airflow over the cooling cup. You will record the cooling of water in three particular cases: natural convection only (no fan) with an insulated lid, natural convection only with no lid and forced convection with an insulated lid.



Theory

As we learned in Lab 1, the temperature evolution of a lumped system can be described by

$$\theta = \frac{T(x) - T_\infty}{T_{initial} - T_\infty} = e^{-\frac{t}{\tau}} \tag{1}$$

where

$$\tau = R_{eff}C = \frac{\rho c_p V}{hA_{surf}} \tag{2}$$

Here we investigate the cooling of a lumped object via natural convection and forced convection. It is important to note that our lumped system here may contain multiple sources of resistances that contribute to R_{eff}.

Natural and forced convection are other modes by which heat can be moved into or out of a system. Natural convection depends on geometry and orientation, as well as the physical properties of the fluid involved (in our case, air). Since there are not many analytical solutions for natural convection cases, correlations that are based on experimental studies are used. The handouts from class will be essential for the natural and forced convection portions of the analysis and will provide the necessary correlations. The appendices in the back of the book also have useful material properties tabulated. In general you need to compute the Rayleigh number:

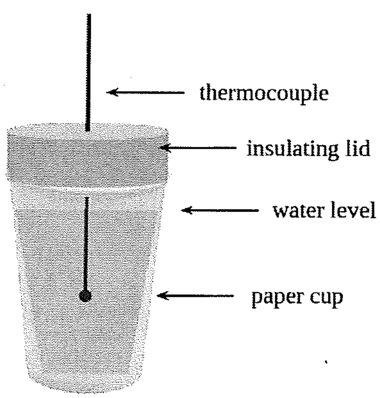
$$Ra_L = \frac{g\beta(T_s - T_\infty)L_c^3}{\nu\alpha} \tag{3}$$

(which represents the ratio of buoyancy forces to thermal and momentum diffusivities) on the way to computing the Nusselt number, which is related to h:

$$Nu = \frac{hL_c}{k} \tag{4}$$

Experimental procedure

Since it takes some time for boiling water to cool by natural convection you will do only one trial in this lab. Make sure before you begin, LabView is up and running and you are ready to begin recording.



<u>Cup parameters</u>

Height	11 cm
Water height	8.5 cm
Note: This is L_c for your correlations	
Top diameter	8.9 cm
Bottom diameter	6 cm
Wall thickness	0.3 mm
k	0.05 W/mK

1) Use the water heater to bring water to a boil. While the water is boiling, set up the box fan facing one cup. Place the other two cups where they will not be affected by the air flow.

2) Fill the three cups to the specified level (marked inside each cup).

3) Place a purple insulation lid on the cup in front of the fan and on one of the other cups.

4) Insert a thermocouple through the hole in the center of each lid. For the cup with no lid, hold the thermocouple in the middle of the liquid.

5) Click RECORD in Labview. Make sure to record which thermocouple is being used where (they are numbered).

Analysis

For your analysis, assume:

1) The cup of water can be approximated as a lumped system.

2) The cup of water is cylindrical with height 8.5 cm and radius 3.7 cm.

3) The top and bottom of the cup are perfectly insulated except for the case in which there is no lid.

Analysis steps:

1) Draw a resistance network and write down symbolically the effective resistance for the system.

2) Use the lumped approximation to find equations of best fit and h values for your data. Do this by guessing and checking and fitting exponentials to your raw data, OR by finding a linear fit to the linear portion of $\ln(\theta)$ vs time and determining the best fit time constant that way. This is the same approach as lab 1, just be careful when you extract h to consider the total effective resistance of the system. How successful were your fitting efforts? Discuss. If you were unable to fit an exponential curve to your data, why do you think that might be? What are the sources of heat loss for each setup?

3) For the curves that were well approximated by the lumped approximation, use the appropriate natural convection correlation to compute h theoretically. Pick a temperature you feel is representative of the average temperature of the system over the course of the experiment and make sure to use appropriate values for the properties of air. Note you may need to use more than one correlation.

4) For the cup that was fanned, use the h value you computed in 1) and the appropriate forced convection correlation to determine what the flow speed of the fan must have been. You may assume the Reynolds number is between 4,000-40,000. Confirm that your assumption about the Reynolds number was correct.

5) For the two natural convection cases (no fan), use an average h value to compute the rate of heat transfer by natural convection to the air using Newton's law of cooling. Discuss any discrepancies you find. What other mechanisms could be contributing to the heat transfer?

Deliverables

Results and Analysis

1) Plot of raw data.

2) Resistance network diagram with all parts labelled.

3) Best fits for all θ vs time curves. You can do this by guessing and checking, or you can find a linear fit to the $\ln(\theta)$ plot as you did in Lab 1.

4) Compute h for each of the cases from your best fits curves. Show all your work!

5) Theoretical natural convection h values. Show all your work!

6) Compute the fan speed. Show all your work!

7) Compute the rage of heat transfer for the natural convection cases. Show all your work!

Discussion

This is where you discuss your results and what you found during your analysis. Elaborate upon the questions mentioned in the lab. Discuss anything else you think is relevant. This is also where you can discuss potential sources of error and how they may have affected your results.

Conclusion

Summarize your findings. Discuss what these findings indicate in the context of heat transfer. Thoughtfully consider the implications for future use or alternative application! This may seem annoying to you, but if you ever find yourself writing grants, you will be grateful you practiced. Being able to frame what you are working on (or worked on) is important in communicating the value of your work.

References

This is where you cite your textbook, lab manual and any other source that you used. This is not where you put tables of reference data. If you have reference data you want to include, that is what appendices are for!