Lab 1f
Boiling Heat Transfer Paradox

OBJECTIVES

Warning: though the experiment has educational objectives (to learn about boiling heat transfer, etc.), these should not be included in your report.

- Obtain the boiling heat transfer curve of a copper sphere in saturated liquid nitrogen;
- To investigate effect of different layers of insulation on the sphere and resolve the apparent boiling heat transfer paradox;
- To analyze the heat transfer process from the experimental results by performing data processing and computing uncertainties

EQUIPMENT

Name	*Model*	*S/N*
Transparent Dewar		
Copper Sphere		
2 Thermocouples		
DAQ Omega OMB-DAQ 56		
Computer		
Hot Air Heat Gun		
3M Masking Tape		
Liquid Nitrogen		

The Boiling Heat Transfer Paradox workstation consists of a transparent Dewar, a copper sphere fitted with two thermocouples (one at the wall and the other at the center), data acquisition card, computer, hot air heat gun, masking tape and liquid nitrogen. The tape is 19 mm wide with an operational temperature of up to 339 K. The two thermocouples are attached to the DAQ to record temperature data. The data acquisition is controlled with software LabView 2010.

This lab was designed to be completed in 2 lab sessions. Data processing may take 1 or 2 more sessions. Data processing should be performed as data is taken, to guarantee good results.

REQUIRED READING

Read the papers by Guido Lavalle et al. [1] and Chase et al. [2] for details on background introduction and performing data reduction.

PRELAB QUESTIONS (10% of the total grade of the lab, 2% each)

a) What is the onset of nucleate boiling?
b) Describe the nucleate boiling heat transfer regime.

c) Describe the film boiling heat transfer regime.
d) What happens in transition boiling?
e) What is critical heat flux?

PROCEDURE

1. Write detailed explanation of how the different components of the experiment work. Be sure to include information about:
   - The different boiling heat transfer regimes that will be seen in the experiment.
   - What is the type of the thermocouples? Why use this type?
   - What the heat gun is used for, and why?
2. LabView program "lab1f.vi" (C:\Documents and Settings\Student\labview_program\lab1f.vi) is used to control the measurement of this experiment with the DAQ Omega OMB-DAQ 56. Note that the Measurement & Automation of LabView cannot recognize the DAQ in Devices and Interfaces, but it works fine with lab1f.vi without being recognized.

   Figure 1 in Appendix A shows the front panel of the program. By pressing "Ctrl + e" you can switch between the front panel and the block diagram. Note that the data saved in the specified file will be overwritten if the file name is not changed for each run of the program. Explore the program to understand its functionalities before conducting the experiment.

   i. Copy the program lab1f.vi to the place of your preference such that you can play around with it without modifying the original. Use the copy for the whole experiment.
   ii. Test whether the program is working properly by connecting the thermocouples to the appropriate channels of the DAQ Omega OMB-DAQ 56. Note that channels 1 to 5 can be used for thermocouple measurements, with the red line connecting to low port, purple line connecting to high port.
   iii. After connecting, select and enable the connected channel in the front panel of the program with the appropriate mode (Enable Analog = "On", Mode = "Differential");
   iv. Choose the appropriate path for saving your data.
   v. Run the program and check the results (time history of the temperature measurement in the graph and the saved file) to see whether the measurement is recorded correctly.

Basic measurements and calibrations

3. Measure the copper ball diameter and obtain an uncertainty to this measurement. Consult "Appendix A" of Mini-lab 2a, "Determining Accuracy and Precision of Measurements: Using Calibration to Estimate Bias and Precision Errors", for an outline on performing a calibration to determine the precision and bias errors for the sensors if necessary. Make sure you obtain data to evaluate precision errors due to deviation from sphericity and due to the finite number of measurements. Identify also the appropriate bias errors.

4. Open the LabView program lab1f.vi and set up the configurations in the front panel for the calibration. Note the important configurations of your DAQ and LabView program in your logbook, including the connection channel and port, measurement range of the channel, channel mode, sample rate, etc. Set the sample rate to 10 samples/s.

5. Calibration of the thermocouples. Use two fixed points to calibrate the thermocouples. These are the freezing point of water and the boiling point of liquid nitrogen at atmospheric pressure. The freezing point of water is approximated by the equation

$$P = -395.2\left(\left(\frac{T}{273.16}\right)^9 - 1\right) \tag{1}$$

where P is the local pressure in the lab in MPa and T the temperature in Kelvin. The boiling point of nitrogen at 101.3 KPa is 77.4 K (-195.75 C), with negligible change for normal variations of atmospheric pressures [3].

i. Collect tap water in a bowl and add ice to it until a mixture of approximately 90% ice, 10% water is formed.

ii. Start the data acquisition, insert the copper ball, and continue recording the time history of temperature of both thermocouples until steady-state is reached.

iii. Note these two final temperatures but save the time history (how can you detect the center and the surface thermocouples from this calibration experiment?).

iv. Place the Dewar (carefully) on the floor and fill it 60 % full with liquid nitrogen.

v. Insert the copper ball (remove the clamp above the Dewar to insert the copper ball, then replace it to hold the top of the thermocouple connectors), start taking data, and record the time history as for the ice water experiment.

vi. Save the time history and note the final temperatures.

vii. Using the reference temperature, a linear calibration of the form

$$T_{corr} = a * T_{TC} + b \tag{2}$$

is used for each thermocouple, where T_{TC} is the temperature measured by the thermocouple and T_{corr} is the corrected temperature. *a* and *b* will be computed by solving equation 2 at the two fixed points. For instance, if the center thermocouple measured 77.7 K and 273 K for the fixed points at 1 atm, these two temperatures are the T_{TC}, while the corresponding T_{corr} are the boiling point of nitrogen, which can be assumed to be constant (77.4 K, the value at atmospheric pressure), and the freezing point of water, which can be obtained by solving equation 1 with the recorded local pressure, e.g. P = 0.103 MPa, thus resulting in the water freezing temperature of 273.15 K. Then,

$$77.4 = a * 77.7 + b$$

$$273.15 = a * 273 + b$$

Solving the equations, a = 1.0023041 and b = - 0.4790286.

Thus the calibrated temperature at the center is $T_{corr} = 1.0023041 * T_{TC} - 0.479028$

viii. You will use this calibration to correct the measured temperature from the DAQ of the following boiling heat transfer experiment for the data analysis.

Boiling heat transfer of bare sphere

6. Draw a diagram of your experimental setup for the boiling heat transfer, showing important components and their connections.
7. Make sure the Dewar is about 60 % full of nitrogen.
8. Take the sphere out of the Dewar and heat it to about 373 K (100° C) with the heat gun. Be careful not to touch it! Run the heat gun on the cool setting for a few minutes before turning it off to avoid damage. Monitor the appropriate indicator in the front panel of the LabView program to determine when the temperature reaches 373 K.
9. Once the temperature reaches 373 K, start the data acquisition and immediately insert the sphere into the Dewar. Make sure the sphere is not touching any boundary of the Dewar (e.g. the wall and bottom). Record the temperature histories of both thermocouples and the temperature difference until the temperature (corrected) is within 1 K or less of the saturation temperature of nitrogen.
10. Repeat 5 times to perform uncertainty analysis including precision errors.

Effect of insulation and heat transfer paradox

11. Take the sphere out of the Dewar and heat it to about 313 K (40 C) with the heat gun (no more!). Cover it with one layer of masking tape. Follow steps 7 to 8 to record the temperatures.
12. Repeat step 11 with two, three, four and five layers of masking tape. Be careful not to burn the tape with the heat gun.

Analysis

13. Correct measured temperature with the correction equation from the calibration part of this experiment.
14. The time saved in the file follows Universal Time. One convenient way to convert this time information to a more useful form is to subtract the first time value t_0 to all other values in the column. Insert a new column in your excel file next to the original time and use the above method to get the time in seconds for data analysis.
15. Determine the boiling curve from the bare sphere and with different layers of insulation added. For all the cases, compute the heat transfer coefficient at different temperatures (see

Guido Lavalle et al. [1] for details on how to do this). Analyze what happens when the sphere is insulated with tape.

16. Discuss uncertainties on temperature, heat flux and heat transfer coefficient. Perform a detailed error analysis only for the bare sphere case. Report the error in critical heat flux and corresponding temperature, minimum heat flux and corresponding temperature, and on one point in film boiling. More details in reference [2].

POST-LAB QUESTIONS (10% of the total grade of the lab, 2% each)

a) Why does the sphere cool faster when nucleate boiling is reached?
b) Discuss briefly why an insulated sphere cools faster than a bare sphere.
c) Why in film boiling does the vapor film become thinner as the sphere temperature decreases?
d) This is for extra points. Discuss what kind of T vs. q" curve you would obtain if you had a heater in the sphere, and started the experiment with a cold sphere and heated it up all the way to film boiling.
e) Please state briefly if you learned anything about boiling heat transfer with this experiment. Compare your knowledge of boiling before and after performing the experiment and writing the report/logbook.

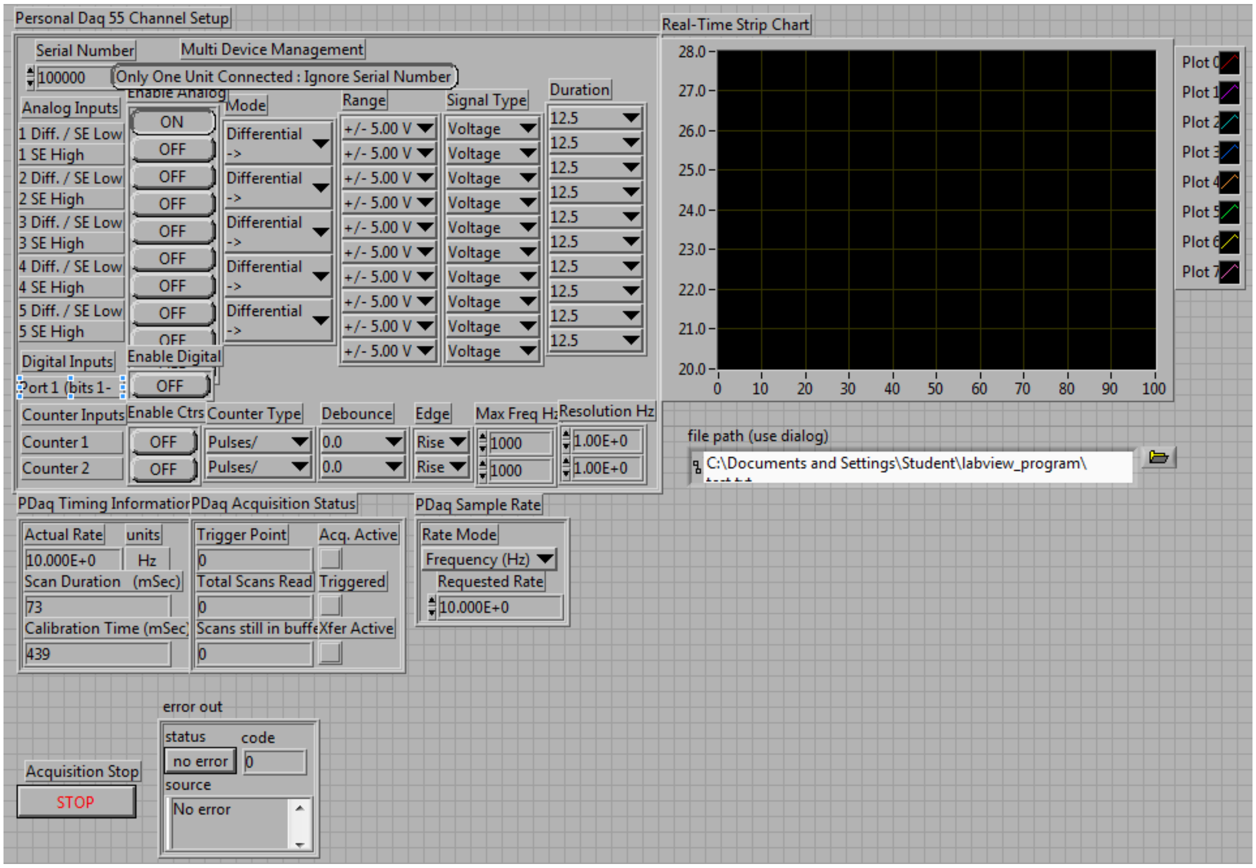
REFERENCES

[1] G. Guido Lavalle, P. M. Carrica, V. Garea, and M. Jaime, "A boiling heat transfer paradox," *Am. J. Phys.* **60**, 593–597 (1992).

[2] N. Chase, B. Choi and P. M. Carrica, "A Boiling Heat Transfer Experiment for Senior Level Engineering Laboratory," *International Journal of Mechanical Engineering Education* (In press) (2014).

[3] A. Beloshitskii, "The Use of the Boiling Point of Nitrogen to Calibrate Thermometers," *Meas. Techniques* **45**, 943-947 (2002).

APPENDIX A. FIGURES



Personal Daq 55 Channel Setup

Serial Number: 100000

Multi Device Management: Only One Unit Connected : Ignore Serial Number

Analog Inputs	Enable Analog	Mode	Range	Signal Type	Duration
1 Diff. / SE Low	ON	Differential	+/- 5.00 V	Voltage	12.5
1 SE High	OFF	->	+/- 5.00 V	Voltage	12.5
2 Diff. / SE Low	OFF	Differential	+/- 5.00 V	Voltage	12.5
2 SE High	OFF	->	+/- 5.00 V	Voltage	12.5
3 Diff. / SE Low	OFF	Differential	+/- 5.00 V	Voltage	12.5
3 SE High	OFF	->	+/- 5.00 V	Voltage	12.5
4 Diff. / SE Low	OFF	Differential	+/- 5.00 V	Voltage	12.5
4 SE High	OFF	->	+/- 5.00 V	Voltage	12.5
5 Diff. / SE Low	OFF	Differential	+/- 5.00 V	Voltage	12.5
5 SE High	OFF	->	+/- 5.00 V	Voltage	12.5

Digital Inputs	Enable Digital
Port 1 (bits 1-	OFF

Counter Inputs	Enable Ctrs	Counter Type	Debounce	Edge	Max Freq Hz	Resolution Hz
Counter 1	OFF	Pulses/	0.0	Rise	1000	1.00E+0
Counter 2	OFF	Pulses/	0.0	Rise	1000	1.00E+0

file path (use dialog): C:\Documents and Settings\Student\labview_program\

PDaq Timing Informatior
Actual Rate: 10.000E+0 units: Hz
Scan Duration (mSec): 73
Calibration Time (mSec): 439

PDaq Acquisition Status
Trigger Point: 0 Acq. Active ☐
Total Scans Read: 0 Triggered ☐
Scans still in buffe: 0 Xfer Active ☐

PDaq Sample Rate
Rate Mode: Frequency (Hz)
Requested Rate: 10.000E+0

error out
status: no error code: 0
source: No error

Figure 1. Screenshot of front panel of lab1f.vi