58:080 Experimental Engineering

Lab 2f
Pool Natural Convection and Boiling on a Platinum Wire

OBJECTIVE

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

-   To measure the heat transfer curve on a platinum wire immersed in the organic fluid FC72.
-   Observation of three different regimes of boiling heat transfer: Natural Convection, Nucleate Boiling and Film Boiling.

EQUIPMENT

Name	Model	S/N
Chamber		
Power Supply	XHR 33-33	
Preheater		
T-Type Thermocouples	NI USB-TC01	
Fluid FC72		
BK Precision power supply		
DAQ Card	NI USB-6008	

INTRODUCTION

A heated wire immersed in stagnant fluid at saturation temperature will experience different heat transfer modes as the temperature of the wire is increased. These modes are common for most heated geometries. In Fig. 1 a typical boiling curve is shown for liquid FC72 subcooled about 5 °C (meaning 5 °C below its boiling temperature), measured with the experiment you are about to perform. The heat flux leaving the wire is plotted against the wall super heating (wire wall, or surface, temperature minus fluid temperature far from the wire). Black dots indicate increasing voltage states, while red are decreasing power states.

As shown in Fig. 1, at the beginning of the increasing power ramp the wire heat transfer mode is natural convection. This is a fairly inefficient heat transfer mode, as can be seen in Fig. 2. Remember that the heat transfer coefficient is defined as $h = q''/\Delta T$.

During natural convection, as the wire temperature increases the heat flux increases but the heat transfer coefficient decreases. When the superheating reaches about 40 degrees, nucleate boiling starts on the wire and the wire temperature decreases dramatically, while the heat transfer coefficient increases from about 1400 $W/m^2 C$ to 5000 $W/m^2 C$. As the power continues to increase, the wire remains in nucleate boiling showing highly efficient heat transfer rates. At about 20 W/cm^2 the critical heat flux is reached and the wire transitions to film boiling. The wire temperature increases some 200 $^\circ$C, with a considerable deterioration on the heat transfer

efficiency from about 11000 W/m^2C to less than 1000 W/m^2C. At a superheating of 300 °C the power ramp is reversed and the power reduction ramp starts. The wire remains in film boiling as the wire temperature decreases until a superheating of about 100 °C is reached, where parts of the wire transition to nucleate boiling and others remain in film boiling. Eventually all the wire sets in nucleate boiling and high heat transfer rates with low superheating are recovered. Notice from Figs. 3 and 4 that the high superheating regions of natural convection are not repeated on decreasing power. The same hysteresis phenomenon occurs in the transition from nucleate to film boiling and vice versa. Once the wire is in one heat transfer mode, it remains in that mode until a significant change in superheating makes the heat transfer mode unstable.
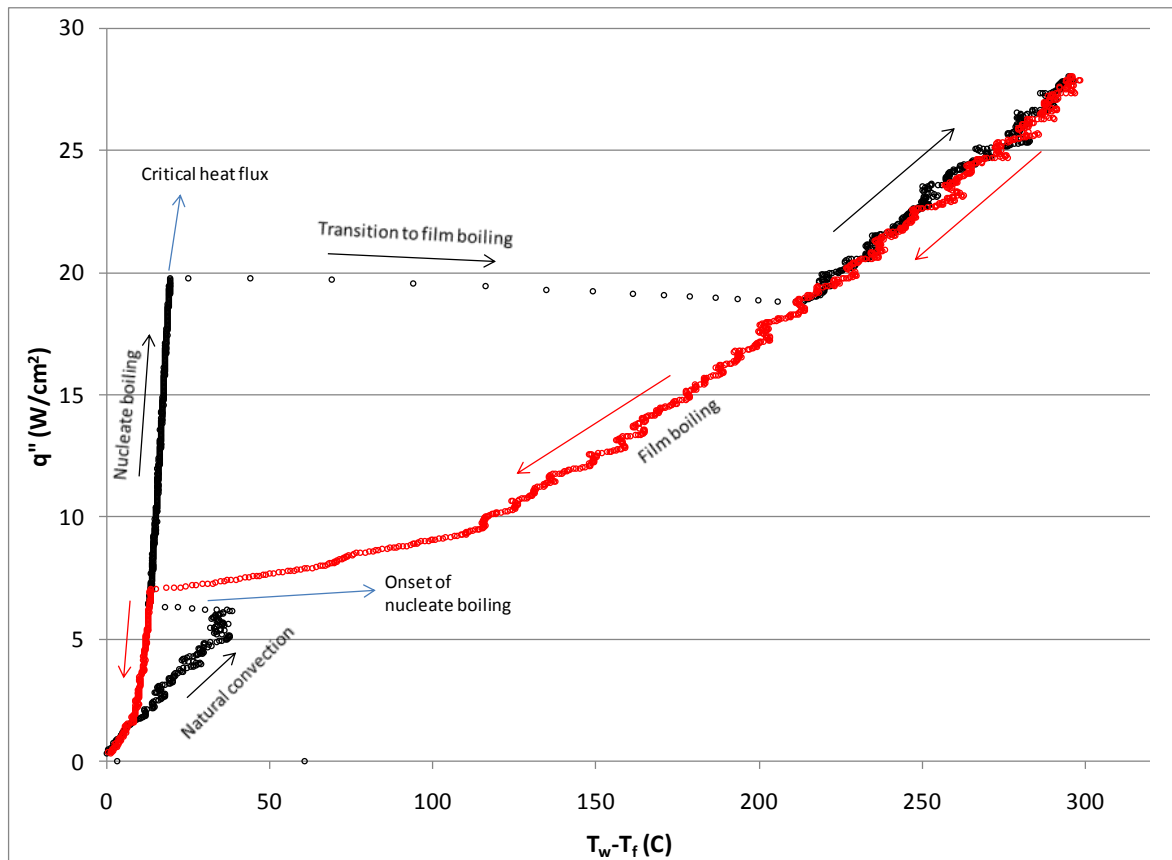

Figure 1: boiling curve for FC72

REQUIRED READING

See references [1] and [2] for discussions of the boiling process and details on performing data reduction.

PRELAB QUESTIONS

1- Describe the three different regimes of boiling heat transfer. What is the sequence of regimes the wire will see as it is heated and cooled?
2- Describe how you can determine the resistance of the platinum wire at the temperature of the fluid (R_{Tf}).
3- What is Critical Heat Flux?
4- Does critical heat flux depend strongly on pressure? Why or why not?
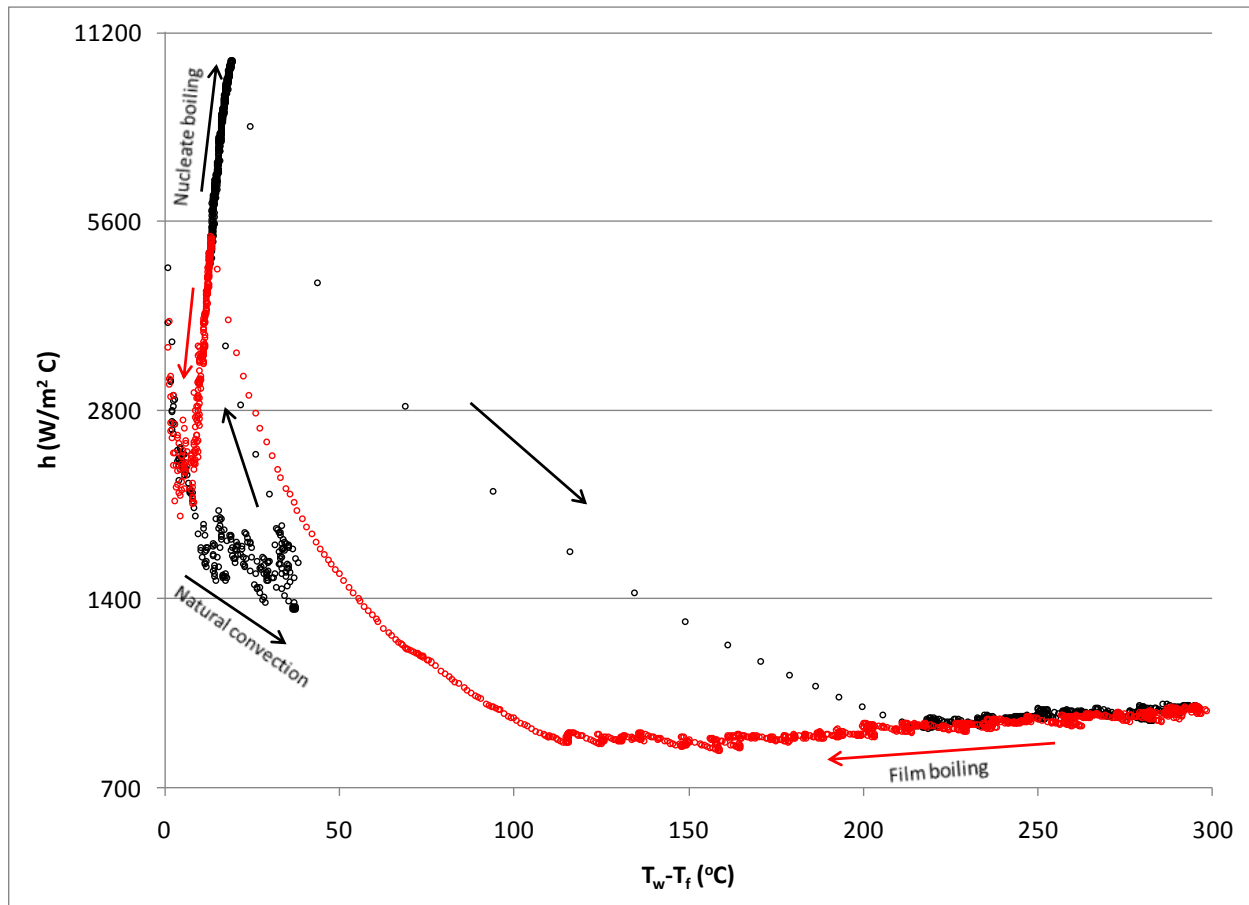5- What is each power supply responsible for?

Figure 2: heat transfer versus wall super heating.

EXPERIMENTAL SETUP

The experimental setup is depicted in Figs. 3 and 4. The chamber or vessel containing the test section has four windows that allow illumination and observation of the different heat transfer phenomena present during the experiment. The chamber is filled with FC72 to slightly below the upper level of the windows. A preheater made of nichrome wire is fitted at the bottom of the chamber and fed with a Xantrex XHR 33-33 power supply. This preheater is used to control the fluid temperature during the experiment. The temperature inside the chamber is

measured with T-type thermocouple. A copper condenser is used to condense back the FC72 that vaporizes. To maintain the chamber at atmospheric pressure and avoid losses of refrigerant, a glass "cold trap" condenser is fitted at the top of the chamber. This condenser and the copper condenser inside the chamber are both fed with cold tap water. Maximum effort must be made to avoid losses of FC72, which is a very expensive fluid (about $600/gallon).
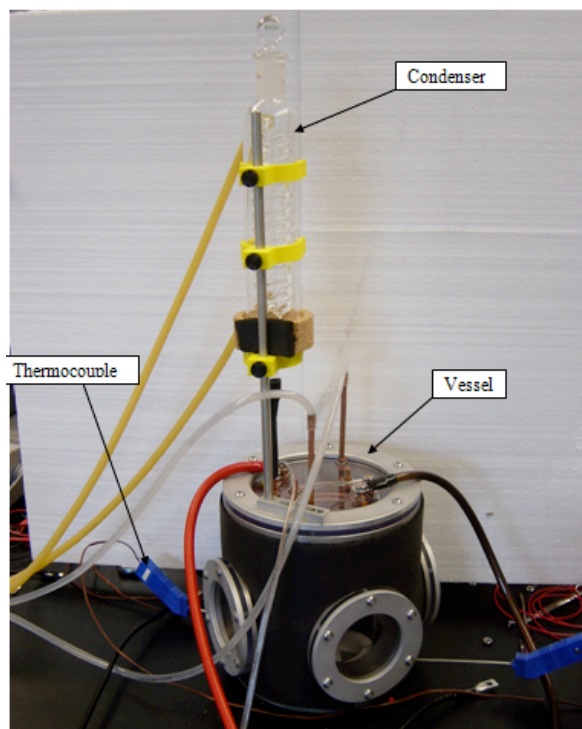

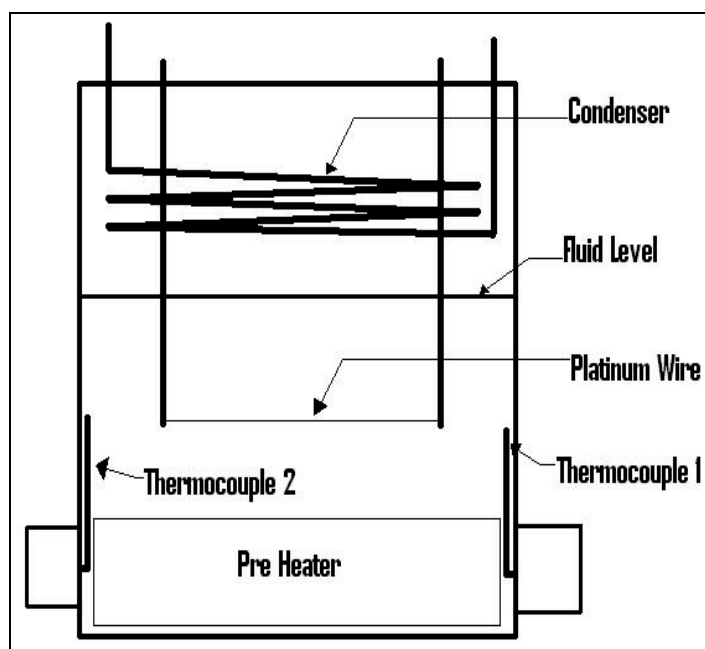**Figure 3:** Picture of experimental setup

Figure 4: Experimental Setup

The electrical schematic is depicted in Fig. 5. Power is fed to the platinum wire through the support copper bars with an Agilent 6673A controllable power supply. Voltage sensing wires are soldered to the ends of the platinum to measure the voltage drop across the boiling wire section. The transparent lid of the chamber holds all the connections for powering the preheater, the platinum wire and sensing the voltage drop across the wire. The platinum wire measurements are given in Table 1.

Table 1. Platinum Wire Measurements

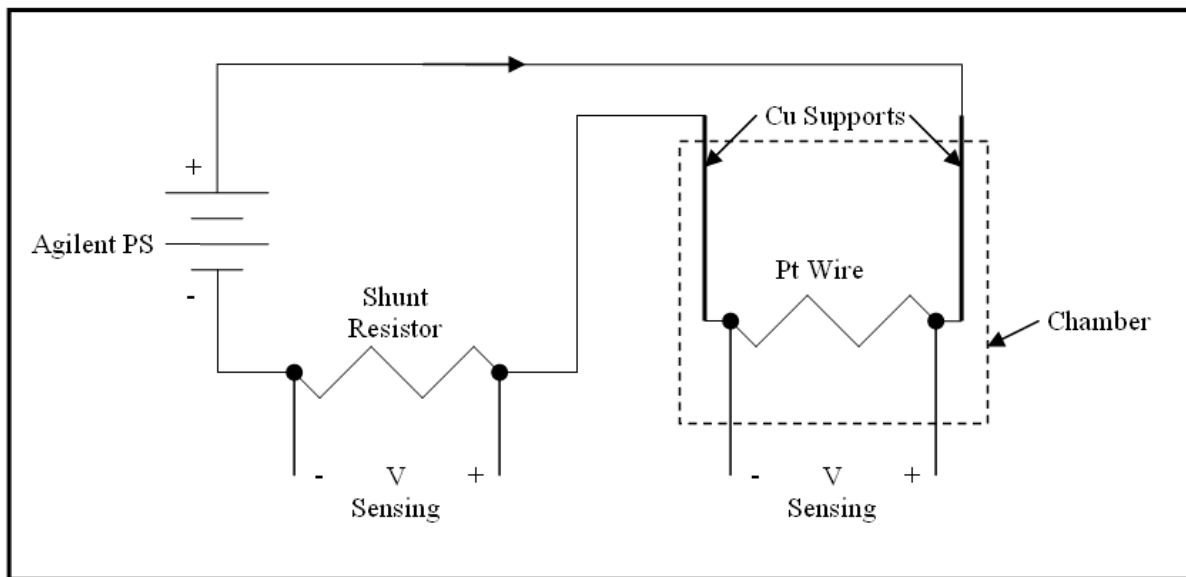| Length [mm]	Diameter [cm]	Area [cm^2]	Resolution [mm]
44.196	0.0259	0.3597	0.0005

Figure 5: Electrical Schematic of Experiment

The experimental measurement is controlled by a LabView program, which uses three AD/DA data acquisition cards (DAQs) for measurement: NI USB-6008 to control the voltage output of the BK Precision power supply; NI 9219 to measure the voltage drop of the platinum wire and shunt resistor; NI USB-TC01 to measure the T-type thermocouple of fluid temperature. The DAQs are chosen in such a way that the data acquisition has both fast sample rate and high resolution, guaranteeing the heat transfer phenomena of the experiment can be recorded and analyzed and uncertainties computed. During the experiment, the LabView program will control the BK precision power supply to follow a linear increase in power through constant voltage mode. This is done by controlling the voltage output of NI USB-6008 in proportion to the square root of time. (The power supply is controlled trying to follow a linear increase in power, so the voltage increases with the square root of the time.) The reason for performing the experiment in voltage control mode is that, when the critical heat flux (CHF) and the subsequent transition to film boiling occur, there is a large jump in the wire temperature, which results in a large jump of the wire resistance. A voltage control mode leads to a decrease of the power to the wire after transition (see Fig. 1), because the power to the wire is $P = V^2/R$ and R increases. This can avoid the burn out of the wire due to large power surges. If current were controlled instead of voltage,

the power delivered to the wire would be $P = I^2R$, and thus the power would increase with increasing R after CHF, which could damage the wire.

PROCEDURE

1. Write a detailed explanation of how the different components of the experiment work. Be sure to include information about:
   - The different heat transfer regimes that will be seen in the experiment
        i. The sequence of regimes the wire will see as it is heated and cooled
        ii. The effectiveness (in terms of h) of each heat transfer regime
   - What each power supply is responsible for
   - The function and purpose of the two different condensers
   - How the voltage drop across the wire is measured
   - How the current through the wire is measured
   - How the temperature of the wire is determined (refer to step 10 below)

   This explanation should be very detailed. Work on it as a team if you are doing the group logbook option. This should take up a large percentage of your first day in the lab.

2. LabView program "lab2f.vi" (C:\Documents and Settings\Student\labview_program\lab2f.vi) is used to control the measurement of this experiment with the DAQ. You should be able to find the devices NI USB-6008, NI 9219 and NI USB-TC01 in the Measurement & Automation of LabView in the Devices and Interfaces.

3. Power up the Agilent power supply. Set the Over-Voltage protection to 2.5 V. **This is very important**. Press "OV", enter 2.5 V and then "enter". Pressing "OV" again should read 2.5 V, pressing "Enter" will validate the value on the display (that should always be set to 2.5 V. Remember: **Every time the power supply is powered the Over-Voltage protection must be set to 2.5 V**. This is to avoid burning the platinum wire.

4. Turn the power supply voltage as low as possible by pressing "Voltage," enter 0, and press "Enter." Then press "Current" and enter "60" and press "Enter". This will set the maximum current to 60 amperes, guaranteeing that the PS is in voltage controlled "CV" mode.

5. Make sure the output is on by pressing the "output on/off" button on the power supply as seen in Fig. 6.

Figure 6: Output on/off Button

6. Current and voltages are measured in differential form, using the following channels:

   Channel 0 = Wire Voltage
   Channel 1 = Shunt Voltage

   Note that you can select any other channels but make sure you choose a right channel for your set up. For this you can go to block diagram of your LabVIEW program.
   Note that the current is computed by measuring the voltage drop through a calibrated resistance (a Shunt resistor, see Fig. 5)

7. Review the calibration for these important quantities. The current is calibrated against the power supply ammeter and the voltage compared against a high quality multimeter. This will ensure that LabVIEW is properly reading the inputs. This can be done by setting the power supply voltage to zero and incrementally increasing the voltage up to 2 V, while reading the voltage across the wire with a high-quality multimeter and comparing against the voltage reported by LabVIEW. As the voltage changes the current will also change; compare the value reported in the power supply display versus the current measured by LabVIEW. Graph the relation for current and voltage and obtain the equations for the best fit line for each. If necessary, modify the calibration equations in the LabVIEW program. Consult with your TA at this point since this is a very delicate step.

8. Three fluid temperatures will be used in this experiment, approximately 52, 45, and 38 °C. This corresponds to approximately 3, 10 and 17 °C of subcooling. Remove the glass condenser cap and promptly turn on cold water from the sink. Be careful not to exaggerate the water flow rate since the latex hoses cannot take large pressures. Turn on the heating power supply (pre-heater) and set the voltage to 13.1 V. This can be seen in Figure 7.

Figure 7: Pre-heater Power Supply

The over-voltage protection for the pre-heater has been set to 13.9 volts and the pre-heater will automatically be disabled in the event that this voltage is attempted. If this occurs, the pre-heater must be turned off and then turned back on to be reset. The desired voltage setting of 13.1 volts will give a heating power of 150W. **DO NOT exceed 150W**. Monitor the fluid temperature until it reaches a temperature of 38°C. Adjust the heater power supply voltage so that the fluid remains approximately at 38°C. This is done by decreasing the heating power supply voltage.

9. Run your first experiment, checking that the fluid temperature is maintained at 38 °C.

10. Determine the resistance of the platinum wire at the temperature of the fluid (R_{Tf}).
    A second-order relationship between temperature and resistance of the platinum wire is used in the experiment based on the Callendar–Van Dusen equation,

    $$R_T = R_0[1 + AT + BT^2] \quad (0 \text{ °C} \le T < 850°C) \tag{1}$$

    Where R_T is resistance at temperature T, R_0 is resistance at 0 °C, and the constant

    $A = 3.9083 \times 10^{-3} \text{ °C}^{-1}$, $B = -5.775 \times 10^{-7} \text{ °C}^{-2}$. From Eq. (1), relationship between R_T

    and resistance R_{T0} at a specific temperature T_0 can be established as,

    $$R_T = R_{T_0} \frac{[1 + AT + BT^2]}{[1 + AT_0 + BT_0^2]} \quad (0 \text{ °C} \le T < 850°C) \tag{2}$$

    In the experiment, T_0 is the wire temperature when the wire is not being heated up, i.e. the same as the fluid temperature. Wire temperature T during the experiment can then be obtained with the known R_T, R_{T0} and T_0.

11. Now you are ready to take data. Set the ramp up time to 120 s and the maximum voltage to 2.3 V. Make sure the power supply output is properly set checking points 3, 4 and 5. **Make sure that under no circumstance the temperature on the wire exceeds 400 °C.**

12. Check your results opening the output file in Excel. Rename the file conveniently. Repeat with ramps of 240 s and 60 s of duration. Check your results to see if everything makes sense.

13. Repeat steps 8-13 for fluid temperatures of 45°C and 52°C.

14. Produce plots of q'' vs. ΔT (like Fig. 1) and h vs. ΔT (like Fig. 2) for all temperatures and ramp up times. Analyze the effect of ramp time and subcooling on critical heat flux, onset of nucleate boiling and heat transfer coefficients. Perform a complete uncertainty analysis for the case of fluid temperature 52°C and ramp up time of 240 s.

POST-LAB QUESTIONS

Responses to these questions should be posted in your logbook.

1- What are the differences between nucleate, transition and film boiling?
2- Why can't transition boiling be achieved in this experimental setup?
3- What happens with the boiling wire when critical heat flux is reached as the voltage is increased?
4- What happens with the boiling wire when the transition from film to nucleate boiling occurs as the voltage is decreased?
5- What is the effect of subcooling on critical heat flux?

REFERENCES

[1] S. Nukiyama, "Maximum and Minimum Values of Heat Transmitted from Metal to Boiling Water under Atmospheric Pressure," *J. Soc. Mech. Eng. Jpn.* **37** (1934), 367-374.

[2] P. M. Carrica, P. D. Marco, W. Grassi, , "Nucleate Pool Boiling in the Presence of an Electric Field: Effect of Subcooling and Heat-up Rate," *Experimental Thermal and Fluid Science 1997;15:213-220.* < http://www.engineering.uiowa.edu/~expeng/laboratories/lab_references/lab2f_ref.pdf >