

MASSACHUSETTS
MARITIME
ACADEMY

EN-4112
THERMO-FLUIDS
LABORATORY
ACTIVITIES

Compiled by Dr. Matthew J. Frain

Laboratory #1

Density & Measurement Uncertainty Laboratory

Purpose

The purpose of this lab is to calculate the density of water as a function of temperature based on measurements of sample mass and volume and to calculate the uncertainty in those values.

Materials

- Balance scale
- 100 mL graduated cylinder
- Thermometer
- Water bottle

Experimental Procedure

For three (3) water temperatures (room temperature, cold tap water, and hot tap water) perform the following procedure:

1. Setup and zero balance.
2. Measure the dry mass of the graduated cylinder.
3. Fill graduated cylinder with water. Record actual volume.
4. Using a thermometer, measure and record the temperature.
5. Measure the mass of water-filled graduated cylinder.

Analytical Procedure

1. Subtract the mass of the dry cylinder from the mass of the water-filled cylinder to determine the mass of the water.
2. Divide the mass of the water by the volume to determine density.
3. Calculate uncertainty using procedure described by instructor in laboratory.

Laboratory Deliverables

- ✓ Enter measured data into the lab worksheet, perform the indicated calculations, make the requested plots in Excel, and answer the attached questions. Present your Excel results and answers to the instructor for review.
- ✓ Clean and dry all equipment at your station before checking out with your instructor.

Laboratory #1
Density & Measurement Uncertainty Laboratory

NAME _____

PARTNERS _____

Measure and record the following values:

Dry mass of graduated cylinder _____ g

Uncertainty in measured mass δm _____ g

Uncertainty in measured volume δV _____ mL

Uncertainty in measured temperature δT _____ °C

Density Measurement #1

Temperature of water _____ °C

Volume of water _____ mL

Mass of graduated cylinder and water _____ g

Density Measurement #2

Temperature of water _____ °C

Volume of water _____ mL

Mass of graduated cylinder and water _____ g

Density Measurement #3

Temperature of water _____ °C

Volume of water _____ mL

Mass of graduated cylinder and water _____ g

Laboratory #1
Density & Measurement Uncertainty Laboratory

The following steps and calculations are to be done in Excel in lab by each student:

1. Enter the *measured data* into Excel as a table and format the cells as shown:

Measurement	Temperature T (°C)	Volume of Water V (mL)	Mass of Grad. Cylinder & Water m_{cw} (g)
1			
2			
3			

Mass of Dry Grad. Cylinder (g)	Uncertainty in Measured Mass δm (g)	Uncertainty in Measured Volume δV (mL)	Uncertainty in Measured Temp δT (°C)

2. Create a separate table in your spreadsheet and enter equations from your notes to generate *calculated values* of water mass, density, and uncertainty in density.

Measurement	Mass of Water m_w (mL)	Calculated Density of Water ρ (g/mL)	Uncertainty in Density of Water $\delta\rho$ (g/mL)
1			
2			
3			

3. Create a separate table in your spreadsheet comparing your calculated values of density against the expected values for the density of water interpolated from your property tables at those temperatures.

Measurement	Temperature T (°C)	Calculated Density of Water (g/mL)	Expected Density of Water (g/mL)
1			
2			
3			

4. Plot in your spreadsheet both your calculated density values and expected density values for all three measurements against temperature. Include error bars on your calculated data points.

LABORATORY #2

Calorimetry Laboratory

Purpose

The objective of this lab is to apply the 1st law of thermodynamics to a real-world closed system and to measure the specific heat of water.

Materials

- Balance scale
- 100 mL graduated cylinder
- Water bottle
- Calorimeter
- DC power supply
- Computer with DataStudio software to record temperature of water vs. time.

Experimental Procedure

1. Using the balance, measure the mass m_{al} of the small inner aluminum cup (empty and dry). Record the value on the lab worksheet.
2. Fill the small cup with approximately 50 mL of water and measure the combined mass of the water m_{H_2O} and the aluminum cup m_{al} . Record the values on the lab worksheet.
3. Place the small aluminum cup filled with water into the larger cup, and then place the cap with the resistor and thermocouple onto the large cup. Ensure the resistor is submerged.
4. Plug in the thermocouple to the Spark Link on the bench.
5. Open the DataStudio Activity folder on the computer desktop and open the **Calorimetry.ds** activity file. DataStudio should start and will automatically detect the thermocouple sensor.
6. Ensure that the resistor leads are NOT plugged into the power supply.
7. Switch on the power supply, press the 'Output On' button so that is illuminated, and verify that the voltage is around 12.5 volts. Check that the range is set for 16V/5A limits and that the constant voltage (C.V.) setting is selected. If any of these settings are incorrect, notify the instructor. Indicated current should be near zero.
8. Press the 'Output On' button so that is NOT illuminated. Voltage and current displays should both read zero.

LABORATORY #2

Calorimetry Laboratory

9. Plug the resistor leads into the power supply.
10. In Data Studio, click on the START button to begin recording of baseline temperature data.
11. Apply power by pressing the 'Output On' button on the power supply so that is illuminated. Record the starting time t_i (in seconds, based on DataStudio timer) and the current I and voltage V on the lab worksheet.
12. Monitor the thermocouple temperature. When the temperature approaches 50 °C, switch off the power supply and record the time the power is switched off t_f on the lab worksheet.
13. Wait for temperature to equalize. Gently swirl the calorimeter with the lid on for a few minutes to help equalize temperature. The temperature should peak, then slowly start to drop.
14. In Data Studio, press STOP to end data recording.
15. Use the data probe tool in Data Studio, select a temperature data point at the start of the experiment before the power supply, record the initial temperature T_i on the lab worksheet. Do the same with a point near the peak temperature observed on the plot, record it as T_f on the lab worksheet.
16. Click on File/Export Data, highlight Run #1, and name and save it as a text file.
17. Shut off power supply and disconnect the red and black leads from the power supply.
18. Carefully remove the lid of the calorimeter to permit the water to cool off.
19. Complete the required Excel plots and calculations described in this packet. Have these calculations checked and reviewed by your instructor.
20. When safely cooled at the end of the lab, dump the water in the sink and dry all of the equipment and work area. Leave the calorimeter disassembled to dry completely. Check out with your instructor before leaving the lab.

LABORATORY #2

Calorimetry Laboratory

NAME _____

PARTNERS _____

Measure and record the following values:

Measured dry mass of aluminum cup m_{al} _____ g

Measured mass of cup and water $m_{\text{al}} + m_{\text{H}_2\text{O}}$ _____ g

Current I _____ A

Voltage V _____ V

Starting time t_i _____ s

Ending time t_f _____ s

Starting temperature T_i _____ °C

Ending temperature T_f _____ °C

LABORATORY #2

Calorimetry Laboratory

The following steps and calculations are to be done in Excel in lab by each student. All calculations are to be entered as formulas in Excel; do not use calculators.

1. Open Excel, go to File/Open/Browse. In bottom right corner of dialog you will see Excel defaults to looking for only Excel files. Change this to 'All Files', and select the DataStudio text data file. A Text Import Wizard dialog will open to verify the format of the data. Simply hit 'Finish' to import the data into Excel. Save the file as an Excel Workbook. Plot the temperature vs. time using an X-Y Scatter plot, points only.
2. Enter the *measured data* into Excel as a table and format the cells as shown:

Mass of Aluminum Cup m_{al} (g)	Mass of Aluminum Cup & Water m_{al+H_2O} (g)	Current I (amps)	Voltage V (volts)	Elapsed Heating Time (s)	Change of Temperature ($^{\circ}C$)

3. Create a separate table in your spreadsheet and enter equations from your notes to generate *calculated values* of the energy supplied by the resistor, the change of energy of the water assuming an accepted value of the specific heat of water of $4.184 \text{ J/g } ^{\circ}C$, and the change of energy of the aluminum assuming an accepted value of the specific heat of aluminum of $0.9 \text{ J/g } ^{\circ}C$. Use cell references in Excel to set up these formulas.

Mass of Water m_{H_2O} (g)	Heat Supplied by Resistor (J)	Change of Energy of Water (J)	Change of Energy of Aluminum (J)

4. If we were to assume that the above energy balance was indeed correct, we could use this experiment to measure the specific heat for water (instead of assuming the value of $4.184 \text{ J/g } ^{\circ}C$). Rearrange the energy equation to solve for the unknown specific heat of water c_{H_2O} . Calculate the apparent value.

LABORATORY #3

Ideal Gas Law Laboratory

Purpose

The objective of this lab is to investigate the ideal gas law by measuring the pressure of a fixed mass of air while undergoing a constant temperature change in volume (Boyle's Law) and a constant volume temperature change (Gay-Lussac's Law).

Materials

- Absolute pressure transducer connected to computer data acquisition system
- Thermometer
- Variable volume syringe
- Erlenmeyer flask with #6 drilled stopper

Experimental Procedure

Constant Temperature Compression (Boyle's Law)

1. Connect the pressure transducer and thermocouple to the data acquisition system. Open DataStudio by clicking on **Ideal Gas Law.ds** in the DataStudio Activities folder.
2. With the syringe hose disconnected from the pressure transducer, set the plunger to the 20 mL level.
3. Reconnect the hose to the pressure transducer and click Start in DataStudio. The indicated pressure should be atmospheric (~101.5 kPa). Record both the syringe volume in mL and the absolute pressure in kPa.
4. Slowly decrease volume in increments of 2 mL and record associated pressures until 0 mL is reached. Note that there is a fixed gas volume in the hose.

Constant Volume Temperature Change (Gay-Lussac's Law)

1. Disconnect hose from syringe and attach it to the stopper in Erlenmeyer flask and ensure flask is sealed.
2. Allow flask to sit at room temperature for a few minutes, then record absolute pressure and temperature.
3. Put flask and the thermocouple into the hot water bath, wait a few minutes for the gas temperature in the flask to equalize, and record the temperature and pressure.
4. Repeat step 3 with an ice-water bath.

LABORATORY #3

Ideal Gas Law Laboratory

Analytical Procedure

Boyle's Law

1. Enter data into Excel and plot absolute pressure against volume using an X-Y scatter plot, only points. Label and provide units on each axis.

Gay-Lussac's Law

1. Enter the pressure and temperature data in Excel. Convert the measured temperatures to absolute degrees (Kelvin).
2. Plot absolute pressure (in kPa) against absolute temperature (in Kelvin) using an X-Y scatter plot, only points. Fit a linear trendline to the data setting the intercept to zero and display the equation on the plot. Label and provide units on each axis.
3. If the accepted value for the density of air at STP is 1.204 kg/m^3 , determine the gas constant R for air from the slope of this line. Compare this to the accepted measured value of $287 \text{ J/kg}\cdot\text{K}$.

Laboratory Deliverables

- ✓ Complete all spreadsheet calculations and present them to instructor for review.
- ✓ Complete all questions on following page and present them to instructor for review.
- ✓ Clean and dry all equipment at your station before checking out with your instructor.

Prepare for quiz at start of next lab meeting by studying your laboratory notes.

LABORATORY #3

Ideal Gas Law Laboratory

Questions (show calculations)

1. What should the intercept be of the linear trendline of the pressure vs. temperature data for a fixed volume (your data from part 1 of the lab)? Hint: Looking at the ideal gas law equation, what should the pressure be if the temperature was 0 °K?
2. A fixed mass of an ideal gas is compressed at constant temperature such that the final volume is $1/3^{\text{rd}}$ of the original volume. What is the final absolute pressure if the initial absolute pressure was 100 kPa?
3. A pressure gage on a rigid container containing an ideal gas indicates 150 psig when the temperature is 70° F. If the temperature is increased to 150° F, what is the new indicated pressure?
4. If ideal gas constant R for air is 53.3 ft·lbf/lbm·°R, and the pressure is 29 psig and the temperature is 70° F, what is the density of the air in lbm/ft³?

LABORATORY #4

Refrigeration Lab

Purpose

The objective of this laboratory is to measure temperatures and pressures in a refrigeration unit and to determine the rate of cooling, compressor power, and coefficient of performance based on refrigerant property tables and diagrams.

Materials

- P.A. Hilton A574/A661 Air Conditioning Laboratory Units

Experimental Procedure

- Instructor will start both refrigeration units and will allow system temperatures and pressures to stabilize.
- Record system temperatures, pressures, and R-134a refrigerant flow rates for your unit on the attached sheets.

Analytical Procedure

- From measured temperatures and pressures, determine refrigerant enthalpies from attached pressure-enthalpy diagrams for R-134a.
- Using measured refrigerant flow rate and enthalpies, calculate the cooling rate across the evaporator, the delivered compressor power, and the coefficient of performance of both units.

Laboratory Deliverables

Prior to leaving lab:

- Submit completed data sheets, labeled P-h diagrams, calculations, and refrigerant system drawings.

NAME: _____

LABORATORY #4

Refrigeration Lab

UNIT: _____ P.A. HILTON _____ (USE SI UNITS) _____

Drawing:

Draw the refrigeration loop indicating locations of significant components and temperature, pressure, and mass flow rate measurements.

NAME: _____

LABORATORY #4

Refrigeration Lab

UNIT: P.A. HILTON (USE SI UNITS) _____

Data:

	Value	Units
Evaporator Outlet Side Temperature		
Condenser Inlet Side Temperature		
Expansion Valve Inlet Side Temperature		
Expansion Valve Outlet Side Temperature		
Refrigerant Mass Flow Rate		
Condenser Side Pressure		
Evaporator Side Pressure		

Pressure-Enthalpy (P-h) Diagram:

Mark the system points corresponding to the evaporator inlet, compressor inlet, and condenser inlet on the appropriate P-h diagram and provide values below.

	Value	Units
Evaporator Outlet Side Enthalpy		
Condenser Inlet Side Enthalpy		
Expansion Valve Inlet Side Enthalpy		
Expansion Valve Outlet Side Enthalpy		

NAME: _____

LABORATORY #4

Refrigeration Lab

Calculations:

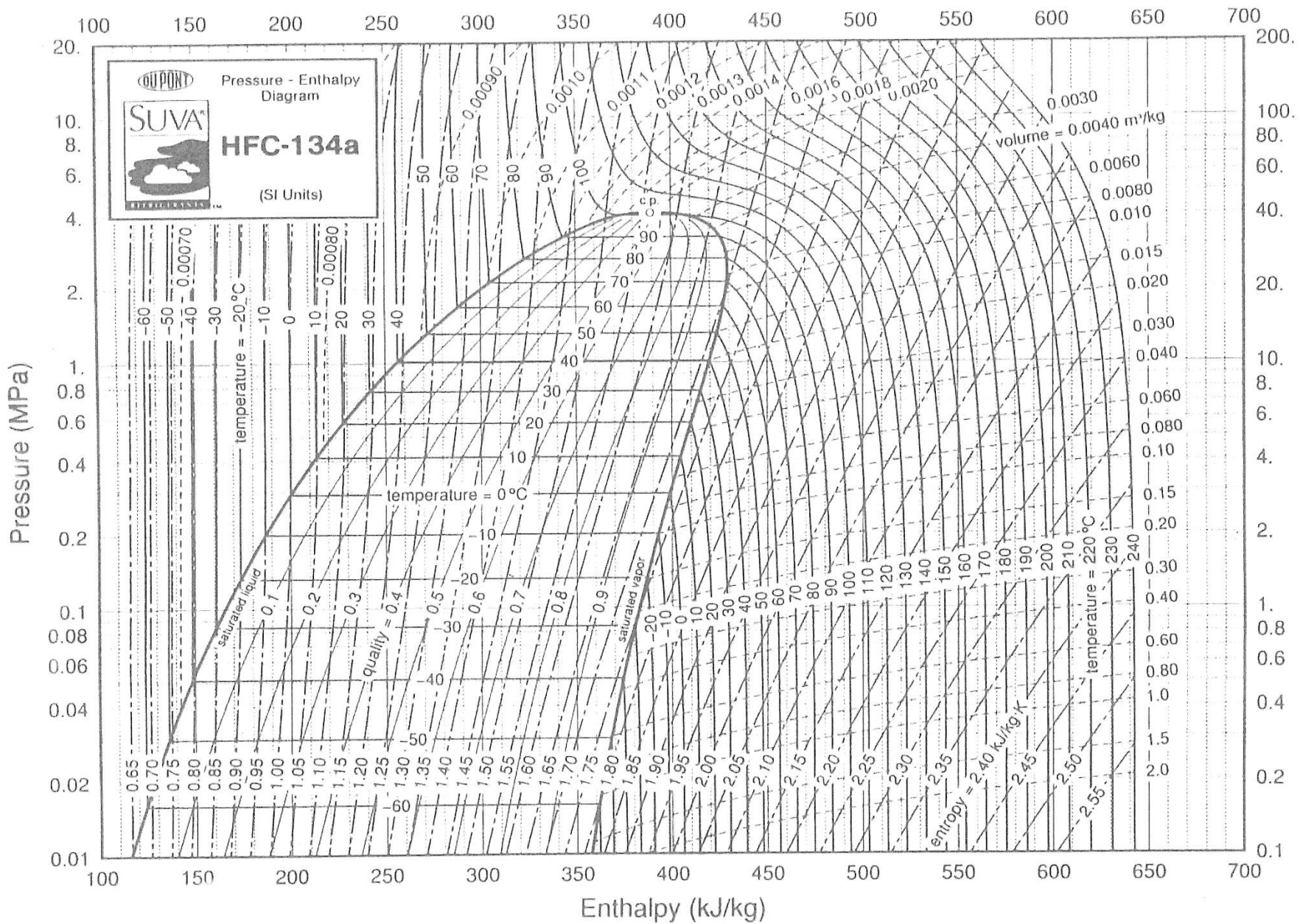
Calculate cooling rate across evaporator (in Watts):

Calculate delivered compressor power (in Watts):

Determine fan power (in Watts)

Calculate coefficient of performance (COP) of the unit:

NAME: _____



P-h DIAGRAM FOR REFRIGERANT HFC-134a

(metric units)
 (Reproduced by permission of the DuPont Company)

LABORATORY #5

Air Conditioning Laboratory

Objectives

The objectives of this lab are to measure the wet and dry bulb temperatures and air and condensate mass flows in an air conditioning duct subject to simple heating, cooling, steam injection, and dehumidification, draw the processes on a psychrometric chart and calculate rates of heat transfer and condensate removal.

Experimental Procedure

1. After unit is switched on and temperatures are stabilizing, draw duct indicating relative locations of temperature measurements (stations A,B,C,D), heaters, steam injection, and evaporator coils on attached page.
2. Record the wet and dry bulb temperatures of the air at stations A,B,C and D in air conditioning duct and the orifice manometer deflection z .

T1	Dry bulb temp ($^{\circ}\text{C}$) - A	
T2	Wet bulb temp ($^{\circ}\text{C}$) - A	
T3	Dry bulb temp ($^{\circ}\text{C}$) - B	
T4	Wet bulb temp ($^{\circ}\text{C}$) - B	
T5	Dry bulb temp ($^{\circ}\text{C}$) - C	
T6	Wet bulb temp ($^{\circ}\text{C}$) - C	
T7	Dry bulb temp ($^{\circ}\text{C}$) - D	
T8	Wet bulb temp ($^{\circ}\text{C}$) - D	

z	Manometer deflection (mm H_2O)	
-----	---	--

3. Using a watch, measure the amount of volume of condensate V_w produced for 20 minutes to determine the condensate flow rate.

V_w	Volume of condensate (mL)	
-------	---------------------------	--

4. Record system voltage V and resistances R_1 and R_2 of air heaters between stations C and D. Both stations: use voltage from the A661 unit.

V	Voltage (V)	
R_1	Air Heater Resistance (Ω)	
R_2	Air Heater Resistance (Ω)	

LABORATORY #5
Air Conditioning Laboratory

1. Draw duct indicating relative locations of temperature measurements (stations A,B,C,D), heaters, steam injection, and evaporator coils in the P.A. Hilton Unit.

- Mark the locations of A, B, C and D on the provided psychrometric chart. Draw the process path between each point.
- Determine the following quantities from the psychrometric chart at points A-D

Station	Enthalpy h (kJ/kg)	Relative Humidity ϕ (%)	Humidity Ratio ω (g/kg)	Specific Volume v (m ³ /kg)
A				
B				
C				
D				

- Calculate the air mass flow rate \dot{m}_a (in kg/s) from the duct orifice using the manometer deflection z (in mm H₂O) and specific volume v_D (in m³/kg) using Equation 1. C is 0.0504 (units of [(kg^{1/2} · m^{3/2})/((mm H₂O)^{1/2} · s)]) for the A574 unit and 0.0517 for the A661 unit.

$$\dot{m}_a = C \sqrt{\frac{z}{v_D}} \quad (1)$$

- Calculate the measured condensate mass flow rate \dot{m}_{wm} using the measured volume flow rate, elapsed collection time, and density of water (assume 0.998 g/mL at room temperature).

6. Calculate the estimated condensate mass flow rate \dot{m}_w using Equation 2 and compare to the result in item 4.

$$\dot{m}_w = \dot{m}_a(\omega_B - \omega_C) \quad (2)$$

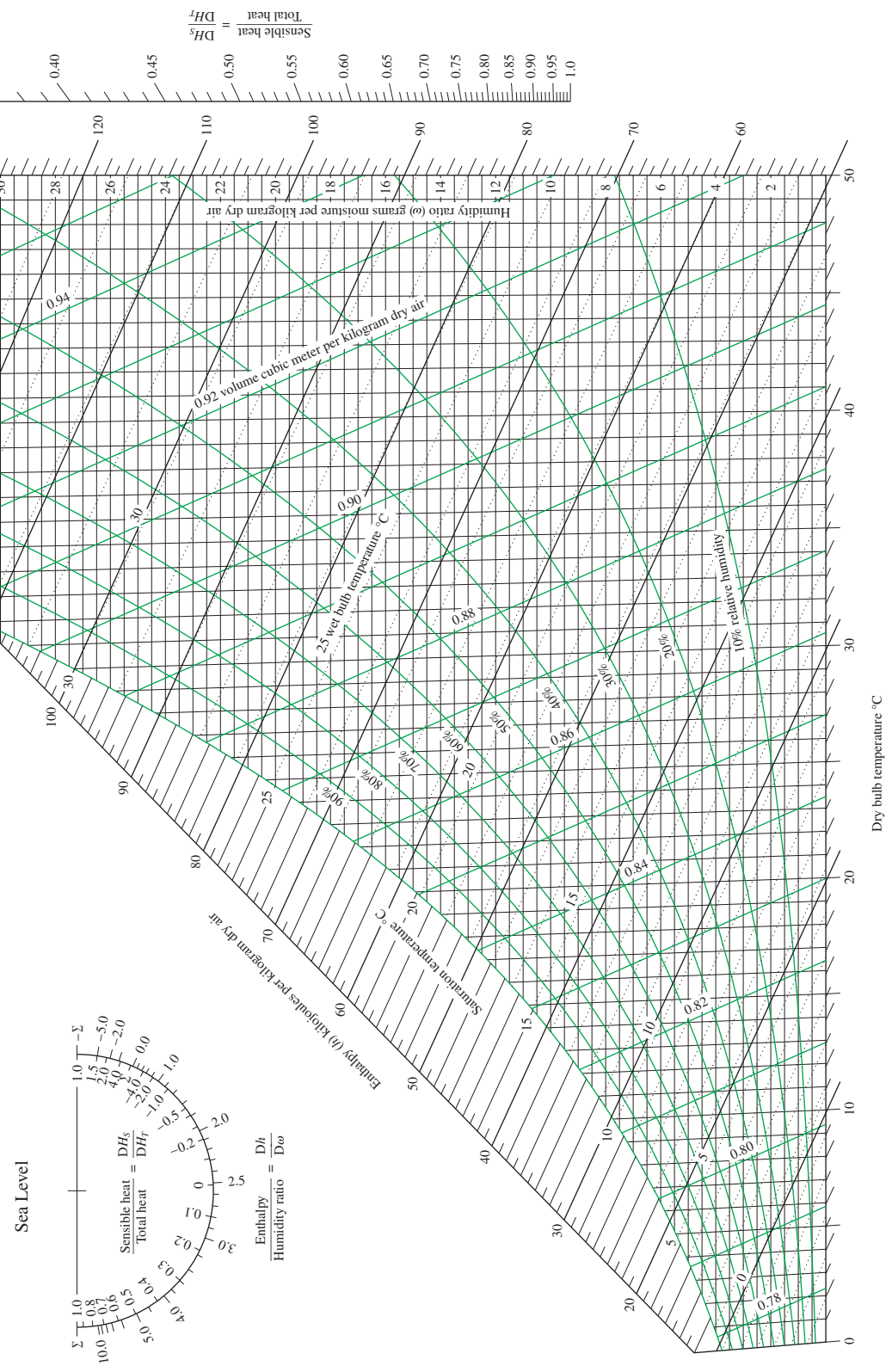
7. Calculate the power P delivered to the heater in W.

8. Calculate the rate heat is absorbed by the air passing the heater \dot{Q}_H in W. Compare this to the result in item 7.



ASHRAE Psychrometric Chart No. 1
Normal Temperature
Barometric Pressure: 101.325 kPa

©1992 American Society of Heating,
Refrigerating and Air-Conditioning Engineers, Inc.



Prepared by Center for Applied Thermodynamic Studies, University of Idaho.

FIGURE A-31
Psychrometric chart at 1 atm total pressure.

Reprinted by permission of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA; used with permission.

LABORATORY #6

Flow Rate Measurement Laboratory

Purpose

The objective of this lab is use conservation of mass to determine the mass flow rate and volume flow rate of a fluid.

Materials

- Force balance connected to computer data acquisition system
- Two (2) 5-gallon buckets
- Tubing
- One (1) tubing clamp

Experimental Procedure

1. Fill one 5-gallon bucket with water from the tap and place it on the table on top of the force balance.
2. Place rubber tube into filled bucket so that the end of the tube is close to the bottom. Hold tube in place with red clip on bucket.
3. With tubing clamp opened, start siphon through hose and allow it to drain into second bucket located under table. Once flow is established, squeeze clamp closed. Hold tube in place in second bucket with red clip.
4. Start DataStudio on computer by clicking on the file Mass Flow Rate Lab.ds found in the DataStudio Activity directory on the desktop. DataStudio should automatically detect force balance connected to computer.
5. When ready, open clamp on hose to start flow.
6. Once flow is started, click Start in DataStudio to collect data.
7. When the bucket on the table is nearly empty, click Stop in Data Studio.
8. In DataStudio, go to File/Export Data and save data from Run #1 to a text file.
9. Open text file to ensure weight and time data are recorded. Close DataStudio.

LABORATORY #6

Flow Rate Measurement Laboratory

Analytical Procedure

1. Open text data file in Excel.
2. Convert column of weight data (in Newtons) to mass (kilograms).
3. Plot mass M_{system} (kg) vs. time t (s) using a scatter chart. Label both axes and provide units.
4. Right click on data points in the plot and select 'Add Trendline'. Select a polynomial trendline, and check 'Display Equation on Chart'.
5. Right click equation on chart, select 'Format Trendline Label'. Under Number, select number format and increase decimal places to 6.
6. Equation will be of the form $M_{system}(t) = At^2 + Bt + C$. Mass flow rate \dot{m} is related to the derivative of this equation (the slope at any point in your plot). Evaluate the derivative and calculate the mass flow rate in kg/s in Excel vs. time.
7. Plot mass flow rate \dot{m} (kg/s) vs. time t (s) using a scatter chart. Label both axes and provide units.
8. Calculate volume flow rate Q in m^3/s from mass flow rate and density of water (998 kg/m^3).

Laboratory Deliverables

- ✓ Complete all spreadsheet calculations and present them to instructor for review. Save this Excel spreadsheet for use in future lab meetings.
- ✓ Complete and submit provided lab worksheet handout.
- ✓ Clean and dry all equipment at your station before checking out with your instructor.

Prepare for quiz at start of next lab meeting by studying your laboratory notes.

LABORATORY #7

Low Pipe Reynolds Number Lab

Purpose

The objective of this lab is to measure the pressure loss and friction factor in a pipe at flow rates spanning laminar, transitional, and turbulent Reynolds numbers and to determine the Reynolds numbers corresponding to the boundaries between laminar, transitional, and turbulent flow.

Materials

- Force platform connected to computer data acquisition system.
- Quad pressure sensor connected to computer data acquisition system.
- Two (2) 5-gallon buckets
- Rubber tubing
- One (1) tubing clamp
- One 5 ft length of $\frac{1}{4}$ " nominal I.D. PEX tubing with tee.

Experimental Procedure

1. Open the Data Studio activity file **Low Reynolds Number Lab.ds** found in the DataStudio Activity directory on the desktop. DataStudio should automatically detect the force platform and quad pressure sensor connected to your computer.
2. Fill one 5-gallon bucket with water from the tap and place it on the force platform.
3. Ensure that the clear vinyl tubing attached to the tee is connected to port 1 on the quad pressure sensor.
4. Establish a siphon through rubber tubing and PEX tubing and allow it to drain into second bucket located under table. Once flow is established, squeeze clamp closed.
5. Place rubber tubing into filled bucket so that the end of the tubing is close to the bottom. Hold tubing in place with red clip on bucket.
6. When ready, open clamp on rubber tubing to start flow.
7. Once flow is started, click Start in DataStudio to collect data.
8. Visually observe the jet of water issuing from the end of the pipe. As the flow rate decreases, the flow may change from turbulent to transitional to laminar. The transitional region is unstable and will be seen as "slugging" where the jet randomly fluctuates with time. The rate of change of pressure drop will be seen to change.
9. When the bucket on the top of the force platform is nearly empty, click Stop in Data Studio.

LABORATORY #7

Low Pipe Reynolds Number Lab

10. In DataStudio, go to File/Export Data and save data from Vertical Force Run #1 and 1-2 Differential Pressure Run #1 to separate text files.
11. Open text files to ensure weight and pressures vs. time data are recorded. Close DataStudio.
12. Distribute text data files to each member of your group for analysis.

Analytical Procedure

Items 1-7 below are identical to the procedure used in the Conservation of Mass Lab last week. **If you have that spreadsheet, delete the time and weight data from last week and replace it with the data from this week. Make sure all formulas are copied down to match the length of this week's data set, update the chart, and get the new A and B coefficients from the trendline. Once this is complete, continue the spreadsheet calculations on step 8.**

1. Open Vertical Force text data file in Excel.
2. Convert column of weight data (in Newtons) to mass (kilograms).
3. Plot mass M_{system} (kg) vs. time t (s) using a scatter chart. Label both axes and provide units.
4. Right click on data points in the plot and select 'Add Trendline'. Select a polynomial trendline, and check 'Display Equation on Chart'.
5. Right click equation on chart, select 'Format Trendline Label'. Under Number, select number format and increase decimal places to 12.
6. Equation will be of the form $M_{system}(t) = At^2 + Bt + C$. Mass flow rate \dot{m} is related to the derivative of this equation (the slope at any point in your plot). Evaluate the derivative and calculate the mass flow rate for all times in the data files.
7. Calculate the volume flow rate Q in m^3/s from mass flow rates and density of water (998 kg/m^3 at 20°C).
8. Calculate the average velocity of the water in the pipe V from the volume flow rate Q and the cross sectional area A of the I.D. of the pipe. Note that the actual I.D. of the pipe is 5.72 mm.
9. Calculate the Reynolds number $Re_D = VD/\nu$, where ν is the kinematic viscosity of water, which is $1.005 \times 10^{-6} \text{ m}^2/\text{s}$ at 20°C .

LABORATORY #7

Low Pipe Reynolds Number Lab

10. In another worksheet in your Excel workbook, open the 1-2 Differential Pressure data file.
11. Convert indicated pressures from kPa to pascals.
12. Calculate the pipe friction factor f at each pressure.
13. Create the following scatter plots with properly labeled axes with units.
 - a. Plot mass M_{system} (kg) vs. time t (s) (from step 3).
 - b. Pressure loss ΔP vs. velocity V .
 - c. Friction factor f vs. Reynolds Number Re_D .

Laboratory Deliverables

Prior to leaving lab:

- Perform indicated measurements and record data, distribute data file to group members.
- Perform individual calculations in Excel and produce the three plots requested in Analytical Procedure. Instructor will review results and plots prior to the end of the lab.
- Drain all water into lower bucket. Do not spill water on force platform!
- Clean and dry all equipment and work areas.

LABORATORY #8

Piping Friction Loss Laboratory

Purpose

The purpose of this lab is to measure the pressure drop and frictional head loss in a horizontal section of drawn Type L tubing and to compare the measured friction factor f to accepted values from the Moody Chart.

Experimental Procedure

All data is obtained using the pressure drop piping system. Measure the head loss for a long section of straight pipe over a wide range of flow rates. Repeat for 2 different pipe diameters specified by your instructor.

Analytical Procedure

- Record the flow rate Q , experimental head loss h_f , pipe length L between pressure taps, and nominal pipe diameter. Note the nominal pipe diameter is not the same as the actual pipe diameter d required for calculations.
- In Excel, calculate the corresponding flow velocity V , Reynolds Number Re_d , and friction factor f . The predicted friction factor from the Moody chart can be approximated using the Haaland formula (modified from Eq. 6.49 in White):

$$f \approx \left(-1.8 \log_{10} \left[\frac{6.9}{Re_d} + \left(\frac{\varepsilon/d}{3.7} \right)^{1.11} \right] \right)^{-2} \quad (1)$$

- In Excel, plot your measured friction factors vs. Reynolds number and compare them to the friction factors obtained from Equation 1.

Laboratory Deliverables

- ✓ Enter measured data into the lab worksheet, perform the indicated calculations, make the requested plots in Excel, and answer the attached questions. Present your Excel results and answers to the instructor for review.
- ✓ Clean and dry all equipment at your station before checking out with your instructor.

LABORATORY #8

Piping Friction Loss Laboratory

NAME _____

PARTNERS _____

Measure and record the following values:

Pipe #1

Nominal Pipe Diameter _____ in. Actual Pipe Diameter _____ in.

Pipe Length _____ in.

Q (gal/min)	h_f (in. H ₂ O)

Pipe #2

Nominal Pipe Diameter _____ in. Actual Pipe Diameter _____ in.

Pipe Length _____ in.

Q (gal/min)	h_f (in. H ₂ O)

LABORATORY #8

Piping Friction Loss Laboratory

The following steps and calculations are to be done in Excel in lab by each student:

1. For each pipe, enter the *measured data* into Excel as a table and format the cells as shown on the previous page.
2. Create a separate table in your spreadsheet for each pipe and enter equations from your notes to generate *calculated values*. Use $\nu = 1.082 \times 10^{-5}$ ft²/s for the kinematic viscosity of water and a roughness height ϵ of 7×10^{-6} ft. for drawn tubing.

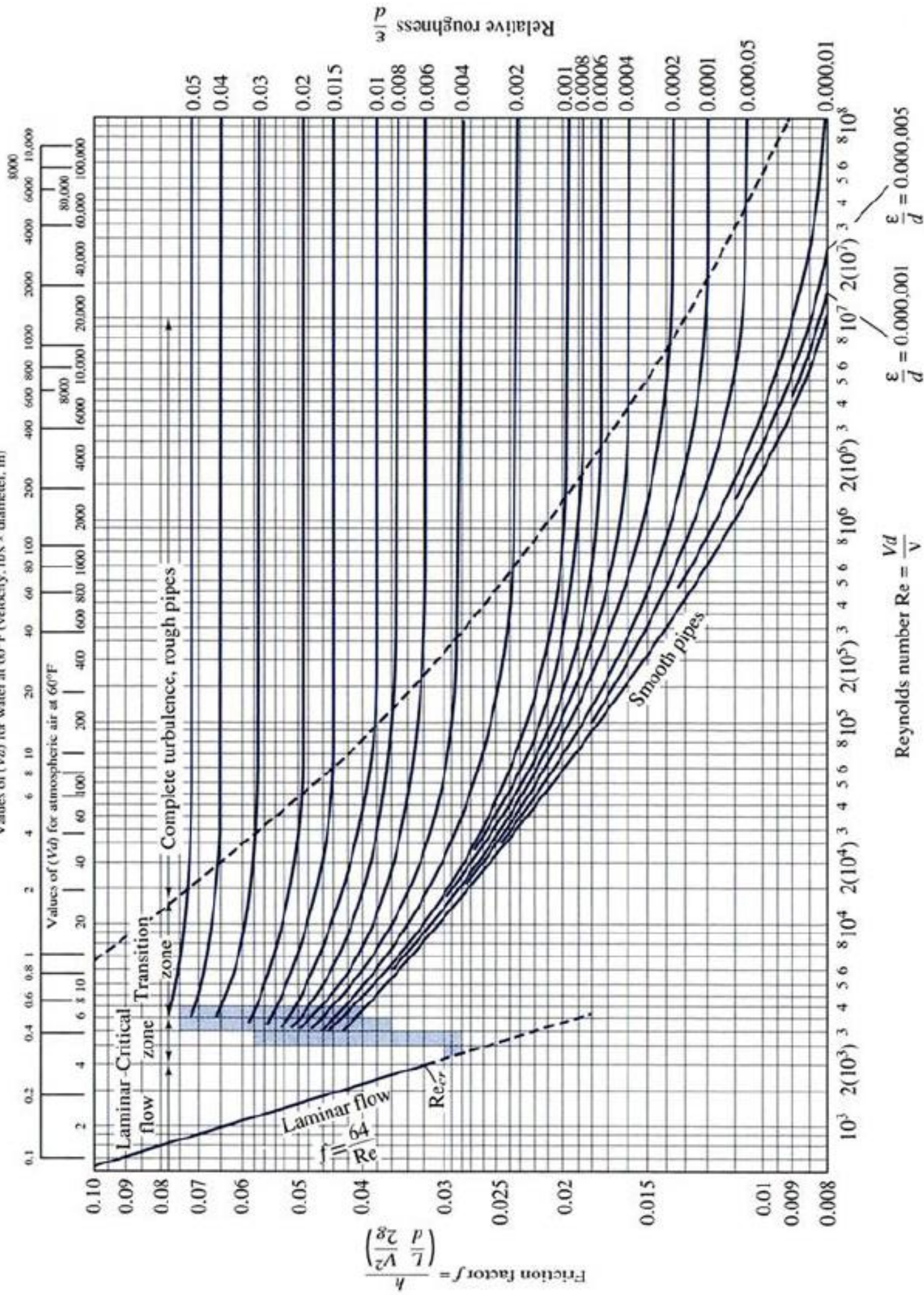
Q (ft ³ /s)*	h_f (ft H ₂ O)*	Velocity V (ft/s)	Re_d (-)	ϵ/d (-)	Measured f (-)	Haaland** f (-)

3. Plot the measured friction factor f vs Reynolds number Re_d for each pipe on the same scatter plot (2 series, plot only markers, no lines). On the same plot, plot Equation 1 for each roughness ratio (2 additional series, plot as solid smoothed lines, no markers).

*These values are simply the values from the measured data table converted to useable units.

** Calculated from Equation 1.

Values of (Vd) for water at 60°F (velocity, ft/s × diameter, in)



LABORATORY #9

Minor Loss Laboratory

Purpose

The purpose of this lab is to measure the minor loss coefficients (K) as a function of flow rate for a globe valve, gate valve, and an elbow and compare the results to available textbook data.

Experimental Procedure

All data is obtained using the pressure drop piping system. Measure the head loss across a fully open globe valve, a fully open gate valve, and an elbow over a wide range of flow rates.

Analytical Procedure

- Record the measured head losses h_m across each fitting over a range of flow rates Q .
- In Excel, calculate minor loss coefficients K from the measured head loss h_m and flow rates Q for all three fittings.
- In Excel, plot the head loss h_m against velocity V for all 3 fittings on the same plot.
- In Excel, plot the loss coefficients K against average flow velocity V for all 3 fittings on the same plot.

Laboratory Deliverables

- ✓ Enter measured data into the lab worksheet, perform the indicated calculations, make the requested plots in Excel, and answer the attached questions. Present your Excel results and answers to the instructor for review.
- ✓ Clean and dry all equipment at your station before checking out with your instructor.

LABORATORY #9

Minor Loss Laboratory

NAME _____

PARTNERS _____

Measure and record the following values:

Globe Valve

Nominal Pipe Diameter 1 in. Actual Pipe Diameter 1.025 in.

Q (gal/min)	h_m (in. H ₂ O)

Gate Valve

Nominal Pipe Diameter 1/2 in. Actual Pipe Diameter 0.545 in.

Q (gal/min)	h_m (in. H ₂ O)

Elbow

Nominal Pipe Diameter 3/8 in. Actual Pipe Diameter 0.430 in.

Q (gal/min)	h_m (in. H ₂ O)

The following steps and calculations are to be done in Excel in lab by each student:

1. Enter the *measured data* for each fitting into Excel as a separate table and format the cells as shown on the previous page.
2. Create a separate table in your spreadsheet and enter equations from your notes to generate *calculated values* for each fitting as shown.

Q (ft ³ /s)*	Velocity V (ft/s)	h_m (ft)*	Measured K (-)

3. Plot the measured head losses h_m for each fitting against velocity V in ft/s. Plot the data for all three fittings on the same plot.
4. Plot the measured minor loss coefficients K for each fitting against velocity V . Plot the data for all three fittings on the same plot.

	Nominal diameter, in								
	Screwed				Flanged				
	$\frac{1}{2}$	1	2	4	1	2	4	8	20
Valves (fully open):									
Globe	14	8.2	6.9	5.7	13	8.5	6.0	5.8	5.5
Gate	0.30	0.24	0.16	0.11	0.80	0.35	0.16	0.07	0.03
Swing check	5.1	2.9	2.1	2.0	2.0	2.0	2.0	2.0	2.0
Angle	9.0	4.7	2.0	1.0	4.5	2.4	2.0	2.0	2.0
Elbows:									
45° regular	0.39	0.32	0.30	0.29					
45° long radius					0.21	0.20	0.19	0.16	0.14
90° regular	2.0	1.5	0.95	0.64	0.50	0.39	0.30	0.26	0.21
90° long radius	1.0	0.72	0.41	0.23	0.40	0.30	0.19	0.15	0.10
180° regular	2.0	1.5	0.95	0.64	0.41	0.35	0.30	0.25	0.20
180° long radius					0.40	0.30	0.21	0.15	0.10
Tees:									
Line flow	0.90	0.90	0.90	0.90	0.24	0.19	0.14	0.10	0.07
Branch flow	2.4	1.8	1.4	1.1	1.0	0.80	0.64	0.58	0.41

Resistance Coefficients K for Open Valves, Elbows, and Tees. From Table 6.5, White, *Fluid Mechanics*, 7th Ed.

LABORATORY #10

Centrifugal Pump Laboratory

Purpose

The purpose of this lab is to measure the pump performance curves of centrifugal pumps and to evaluate the pump Specific Speed for comparison to book values.

Experimental Procedure

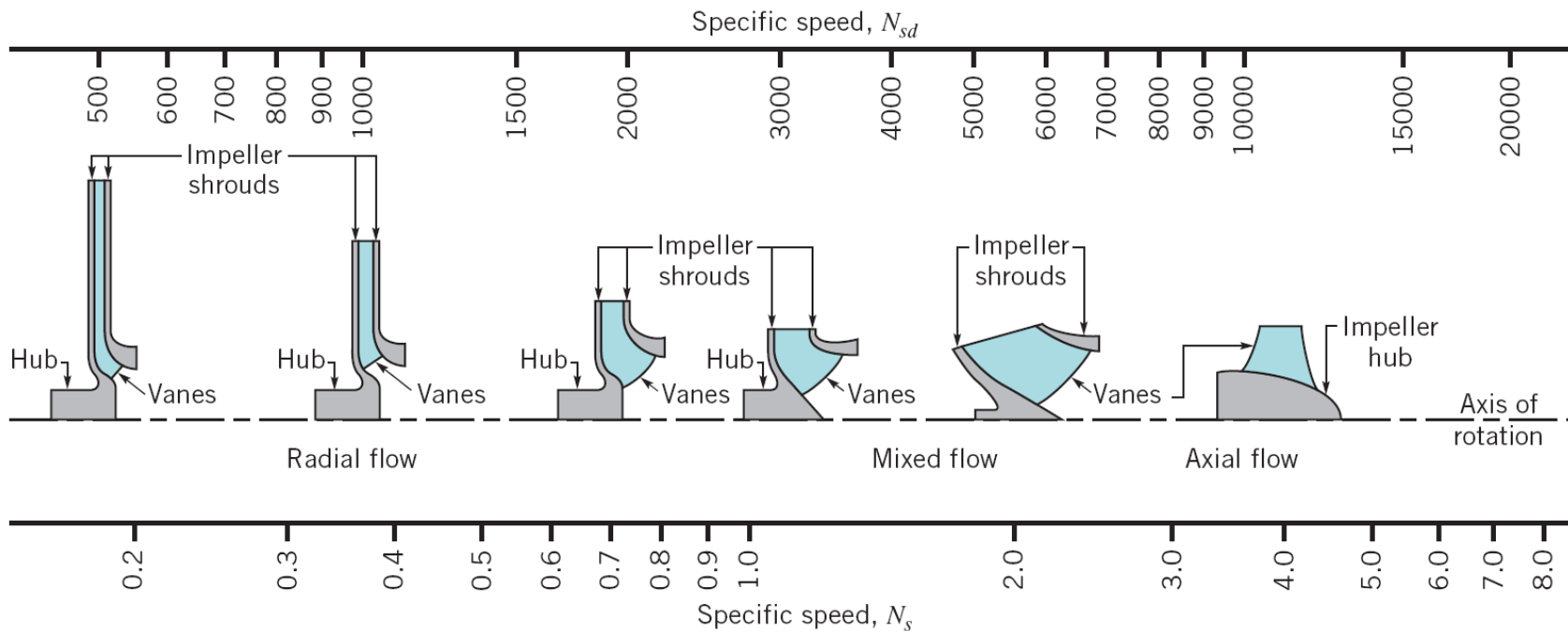
The experiment will be carried out on the Turbine Technologies pump stations. At constant shaft speed, measure and record the flow rate, suction pressure, discharge pressure, and shaft torque using the Pump Lab mapping function. Repeat for several flow rates by throttling the discharge valve. Include zero and maximum flow rates as data points. Export the data to a text file for analysis.

Analytical Procedure

1. Open the data file in Excel. The data text file will contain shaft speed n (rpm), motor torque T (ft-lbf), flow Q (gal/min), P_{in} (psig), P_{out} (psig), and shaft power (hp).
2. Create a separate table in your spreadsheet and convert flow Q from gal/min to ft^3/s , convert pressures from psi to lbf/ft^2 , and shaft speeds from rpm to radians/s.
3. Calculate the inlet and outlet velocities from the flow Q and pipe areas. The inlet pipe diameter is 1.85 inches and the outlet pipe diameter is 1.6 inches. The elevation difference $z_2 - z_1$ is 1 ft.
4. Calculate the head added H (in ft), the water power P (in ft-lbf/s), the shaft power (in ft-lbf/s), and the pump efficiency η (%) for all flow rates Q .
5. Plot both head added H and pump efficiency η against flow rate Q (in gallons per minute) on the same plot. Assign a secondary axis to the efficiency series. Add a second order polynomial trendline to both series data and show the equations on the chart.
6. Take the derivative of the efficiency η vs. flow rate Q trendline equation and set it equal to zero to determine Q^* in gpm at peak efficiency.
7. Determine pump head at peak efficiency H^* by entering Q^* into the pump head trendline equation.
8. Calculate the dimensional specific speed N_{sd} and non-dimensional specific speed N_s of the pump.

LABORATORY #10

Centrifugal Pump Laboratory



LABORATORY #11

Pump Cavitation Laboratory

Purpose

The purpose of this lab is to visualize the phenomenon of pump cavitation and to measure the minimum required Net Positive Suction Head ($NPSH_R$) needed for a pump to avoid cavitation at different flow rates.

Experimental Procedure

The experiment will be carried out on the Turbine Technologies Pump Lab stations. At constant shaft speed, the discharge valve on the pump will be adjusted to achieve a specified flow rate. The valve on the suction side of the pump will be closed in increments until a noticeable reduction in pump head is observed due to cavitation. At each increment, the flow rate, static suction pressure and static discharge pressure data will be collected using the Map function using the Turbine Technologies Pump Lab software and distributed to your partners for analysis.

Analytical Procedure

The onset of pump cavitation is defined by the Hydraulic Institute (www.pumps.org) to be where the total head difference across the pump is reduced by 3% due to cavitation. Cavitation occurs when the local absolute pressure in the system falls below the vapor pressure p_v of the fluid. The vapor pressure of water is approximately 0.35 psia at 70°F. The total head H across the pump is defined as:

$$H = \left(\frac{p_d}{\gamma} + \frac{V_d^2}{2g} + z_d \right) - \left(\frac{p_s}{\gamma} + \frac{V_s^2}{2g} + z_s \right) \quad (1)$$

In equation 1, p is the static pressure, V is the flow velocity, and z is the elevation of the suction (subscript s) and discharge (subscript d) sides of the pump. $z_d - z_s = 1$ ft on the Turbine Technologies pump station. V_d and V_s can be determined from the flow rate Q and the area of the suction (I.D. = 1.85 inches) and discharge pipe (I.D. = 1.6 inches).

You will plot your data in Excel and compare your total head data to the total head curve for the black impeller pump operating at 1800 rpm without cavitation (provided in attached table). On the same plot, you will add a third series, the available Net Positive Suction Head ($NPSH_A$), determined as the total absolute head above the vapor pressure head at the suction side of the pump (Equation 2):

$$NPSH_A = \left(\frac{p_s}{\gamma} + \frac{V_s^2}{2g} \right) - \frac{p_v}{\gamma} \quad (2)$$

LABORATORY #11

Pump Cavitation Laboratory

1. Plot the following total head H vs flow Q data for the black pump operating at 1800 rpm (see attached data table).
2. From your data file produced from the Pump Lab map function, convert volume flow rate Q from gpm to ft^3/s and calculate V_s and V_d in separate columns using the areas of the suction and discharge piping.
3. Calculate the total head rise H for each data point using Equation 1. Plot it as a second series on your existing plot.
4. Calculate the Net Positive Suction Head available $NPSH_A$ for each data point using Equation 2. Plot it as a third series on your existing chart. Your plot should resemble Figure 1.
5. Determine where total head departs from the established curve due to cavitation (3% of total head will be ~ 1 ft of head difference).
6. Determine the $NPSH_A$ at this point. This is the pump $NPSH_R$ at this flow rate.

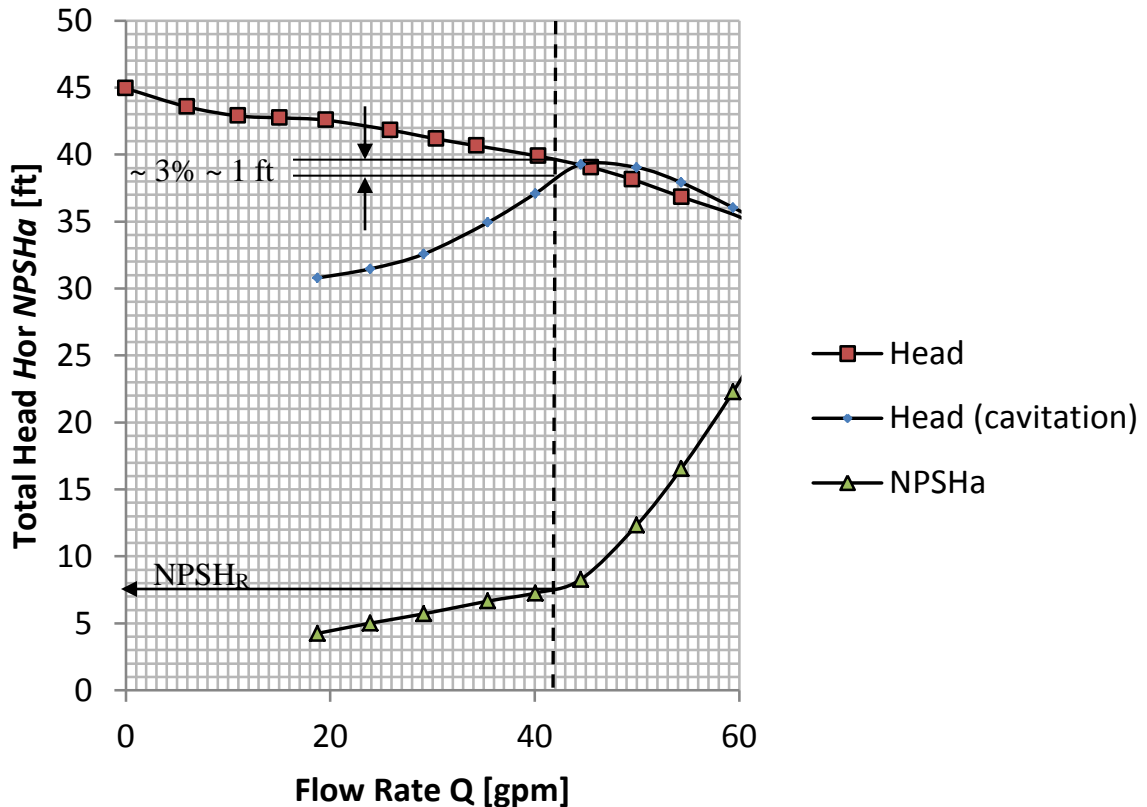


Figure 1: Example Head and NPSH Plot

LABORATORY #11

Pump Cavitation Laboratory

Data for black impeller at 1800 rpm without cavitation:

Flow Q [gal/min]	Head H [ft]
63.47	33.85
60.03	35.34
54.38	36.83
53.98	36.98
49.53	38.14
45.51	39.04
40.36	39.88
34.3	40.66
30.36	41.17
25.88	41.82
19.58	42.57
15.05	42.74
15.04	42.71
10.99	42.89
10.98	42.86
5.98	43.57
0	44.94

LABORATORY #12

PID Process Control

Purpose

The purpose of this lab is to understand the effect of proportional, integral, and derivative gains on the control response of a PID control system, and to tune a control system using the Ziegler-Nichols Method to achieve control of discharge pressure and flow in a pump system.

Experimental Procedure

The experiment will be carried out on the Turbine Technologies Pump Lab stations. With the system in Process Control Mode, instructor will set Feedback Source to flow and will start DAQ. Under PID Gains, the Integrator Clamp will be set to 0%. Set Process Setpoint to the value assigned by the instructor.

- **Trial and Error Tuning**

Attempt to modify the P,I, and D gains to achieve stable and accurate control. Under PID Gains, set P (the proportional gain K_p), I (the integral gain K_i), and D (the derivative gain K_d) to desired values and click RUN Motor after each change. Set all gains to zero and click RUN Motor when done.

- **Ziegler-Nichols Tuning**

1. Under PID Gains, verify that I and D are set to 0. Leave Integrator Clamp at 0%.
2. Click on Graph View
3. Set $P = 100$ and click Run Motor. Observe the response and steady state offset.
4. Click Stop Motor.
5. Increase P in increments of 100, repeating steps 2 and 3.
6. At a certain value of P, the system response will start to become unstable. Adjust P such that a stable oscillation is established. Record the value of P at which this occurs. This is called the ultimate proportional gain K_u . Enter this value on the table on the next page.
7. Click on the Logged Data View
8. Click Log Data
9. You want to record several oscillations in order to determine the oscillation period T_u . Record data for approximately 60 seconds.

LABORATORY #12

PID Process Control

10. Click LOG DATA (light goes off- data stopped being logged)
11. Click Write Data to File
12. Save Data to a text file. Transfer this file to your laptop for analysis in Excel.

Analytical Procedure

1. Plot flow vs. time in Excel. Determine the average oscillation period T_u by counting the elapsed time from the first peak to the last peak and dividing by the number of cycles during that period.
2. Calculate the Ziegler-Nicholas gains in Excel in a table as shown below:

Process Variable	K_u	T_u	K_p ($0.6 K_u$)	K_i ($T_u/2$)	K_d ($T_u/8$)
Flow					

3. Return to the pump station and enter your calculated PID gains, set the process variable and input your assigned setpoint value.
4. Click on the Logged Data View
5. Click Log Data
6. Click Run Motor to start the motor and observe the response.
7. Allow the system response to stabilize to the set point (approximately 60 seconds)
8. Click LOG DATA (light goes off- data stopped being logged)
9. Click Write Data to File
10. Save Data to a text file. Transfer this file to your laptop; plot the tuned response of your process variable vs. time in your spreadsheet.
11. Vary the discharge valve position and observe the control response.

Laboratory Deliverables

- ✓ Enter measured data into the lab worksheet, perform the indicated calculations, and make the requested plots in Excel. Present your Excel results and answers to the instructor for review.