

Temperature and Flowrate Measurements

Process Engineering Measurements Module

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Revised 10/5/98

Before Laboratory Period:

Read the laboratory handout. Prepare your laboratory notebook for data entry for each experiment. For the flowrate experiment steps 1,2 and 6 on page 4 must be prepared in advance. For the temperature experiment steps 2.1, 2.2, 2.3 and 2.8 on page 6 must be done in advance. **Bring a computer diskette for data storage to the laboratory.**

Laboratory Write-ups are due one week from the date of the laboratory. The information required is detailed at the end of each experiment.

Laboratory Notebook

A laboratory notebook must be used to record data for each experiment. All information should be written directly into the laboratory notebook in ink. Attach one copy of the data from the group laboratory recorder's notebook pages. The minimum amount of information required for the laboratory notebook will be given in each experiment. Submit one set of yellow pages from each group at the end of the laboratory period.

MS Office 97 Excel Procedures and Hints:

Formulas

In this laboratory you will use MS Excel to analyze your data. You will need to experience using a spreadsheet package.

Formulas, in spreadsheet packages, are equations that you type in a specific cell. To start this process click on the cell you would like to enter the formula; press the = key or = button; type in the formula by typing a combination of numbers, cell addresses and built-in formulas. For example in the spreadsheet given above, the flowrate at 20 mm is calculated to be 56.5 mL/min. Data is entered into cells A3, B3 and D3. Time is converted into minutes in cell C3 with the formula: =B3/60. The flowrate is calculated using the formula shown in the formula bar as: =D3/C3.

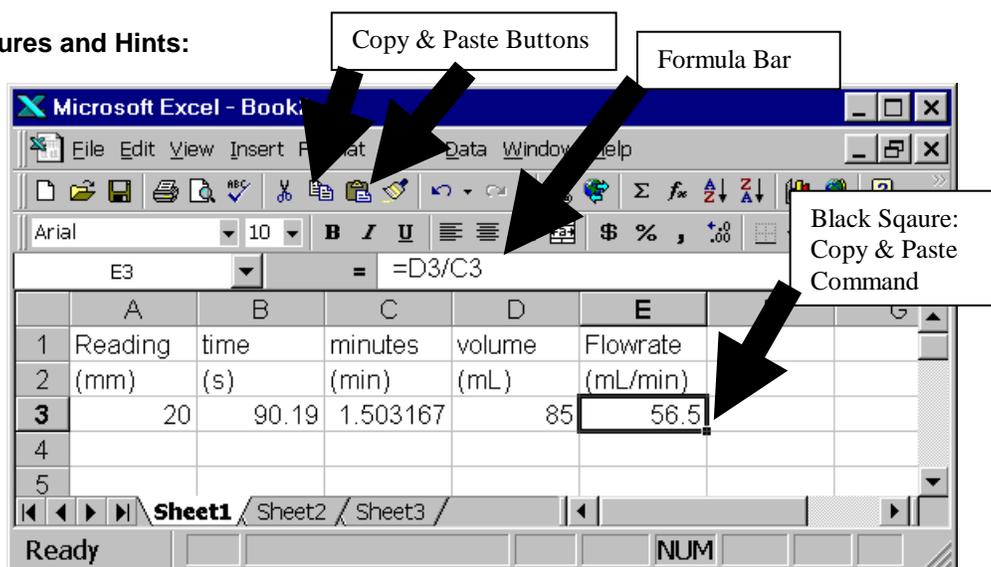
Copying Formulas Formulas can be copied (to save repeated typing) by using the Edit, Copy and Paste commands; using the copy and paste buttons or by dragging on the "black square" located in the lower right corner of the highlighted cell. For more help you can type in a question into the help wizard (an image of a paper clip with eyes!)



Making the chart

Since you may not have had experience making plots with excel we have written a brief description below. The suggested way to proceed is to use the chart wizard.

1. First highlight your x and y columns (including labels): highlight the first column by dragging the mouse; select another column by holding down the Ctrl key while dragging the mouse over the data in the column. Now you should have two columns highlighted.



2. Choose the chart wizard and click on a cell in the spreadsheet to place the graph. All plots are of the Chart-type: **XY (Scatter)**.
3. Choose the data points only subtype (Scatter. Compares pairs of values.)
4. Check to see if the data are correctly plotted by choosing the series tab. If the cell ranges that you desire are not correct, click on the red arrow next to either x or y values and select the data by dragging the mouse. Finish by pressing enter or clicking on the button with the red arrow. Once the data range is correct, press Next >, and then press finish.
5. Add Titles for the graph and each axis.. All data points should be represented by symbols and should not have lines connecting them! Do not title your graph a title such as x vs. y. This title is redundant since the x and y axis are already labeled
6. *It is required that all graphs have Chart titles and Axis Titles. Units must be specified in the axis title with parenthesis around the units, for example an axis title for pressure with units Pascal should be: Pressure (Pa).*

Now that you have completed your graph you may want to change or add something. To begin formatting you must select the item on the graph to make the menus active. **Formatting** is conducted by first selecting the item and then using the menus or right mouse button. Select the data either by clicking on the data or scrolling with the up and down arrow keys ($\uparrow\downarrow$). You will find that the arrow keys are very useful in selecting a data set that is very close to another.

If you need to add an additional column of data, select the chart and go to Chart, Add data... and follow the instructions. If you have more than one row of legend you will need to make corrections to the Name box of the Chart, Source data... menu. For Help on an option, click the question mark (?) and then click the option.

Regressions

In Excel there are two common ways to regress a set of data points and an equation (fit an equation to a set of data points): **Trendlines** and Tools, Data Analysis, Regression. Trendlines is simple and very easy to use. The amount of statistical information is limited to reporting the R-squared coefficient. The data analysis package (Tools, Data Analysis) is extensive and you will be required to use it in later classes. (Please note: If the data analysis package is not active in the tools menu, then it must be made active by running the Add-Ins command under the Tools menu.) In these experiments you will fit (correlate) your data with an equation. The Trendline feature can correlate many types of equations to data (e.g. polynomial, power law, logarithmic, exponential). The example given below is for the correlation of your data with a straight line of the form $y = ax + b$. The trendline tool will report both the slope, a, and the intercept of the line b. In addition it will draw a line given by this equation on the graph for you.

1. Select the data series that you would like to regress (click on data points or use arrow keys).
2. Choose Chart, Add Trendline.
3. You will be fitting a straight line to the data, so choose Linear. Then Click on the Options tab and check mark the boxes: Display Equation on Chart, and Display R-squared Value on Chart. Click OK and move the equation and R-squared value to an appropriate location on the chart.

You have completed the regression of the data in 3 easy steps! Save and/or printout information.

Formatting Graphs and Trendlines

- 1) To format the trendline to give a smaller line thickness, select the trendline using the mouse or arrow keys. Select Format, Selectd Trendline, Patterns tab. Change the Weight (line thickness) and color of the line. Examine the fit of the data using both the R-squared value and the trendline.
- 2) To format any other object in a graph, select it with the mouse or arrow keys and choose Format.
- 3) Edit any text by clicking on the old text and typing on text.
- 4) If you need to change any of the data ranges, then select the chart, choose Chart, Source Data. Select the series tab. Edit the Y-value data series.

Flowrate Measurement: Rotameter Operation and Calibration

Objectives

1. To obtain a calibration curve for the rotameter.
2. Understand how a rotameter works
3. Plot data and regress the data with the governing equation for a rotameter
4. Use dimensional homogeneity to develop an equation in different units

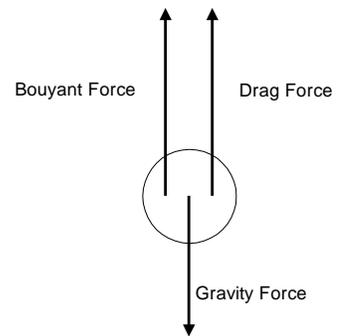
Introduction

Fluid flow measurement is used in almost every process from small-scale medical applications to large petroleum refineries. You have just seen orifice flowmeters at the Rowan University Cogeneration facility. Industries use flow metering devices to regulate the amount of chemicals to be reacted or separated in a continuous process and accurately determine the production rate. Flow meters are also indispensable in the supply of utilities such as water and gas to your home. There are many types of flowmeters used in industry, but all flowmeters need to be calibrated. In this experiment you will calibrate a variable area, float-type, rotameter.

Theory

A rotameter or variable area flowmeter consists of a graduated tapered glass tube mounted vertically in a frame with the larger end up. The fluid flows upward through the tapered tube and suspends a float (a.k.a. *bob*) in the flowing stream. The float indicates the relative flow rate of the fluid using the graduations on the glass scale. Measurements using the float are made at its largest cross-section that is at the center of a spherical float.

At a given flow rate the float maintains an equilibrium position and therefore does not move. The three forces acting on the float are: (1) the weight of the float \downarrow , (2) the buoyant force of the fluid on the float \uparrow , and (3) the drag force on the float \uparrow .



A simplified rotameter equation

$$q = C_{rot}h + A$$

q flowrate of liquid (mL/min)

h rotameter reading (mm)

C_{rot} rotameter constant (mL/[min mm])

A rotameter constant (mL/min)

is used to describe the rotameter operation. This expression relates a volumetric flow rate q to the scale reading, h , using the rotameter constants C_{rot} and A . These constants are a function of the fluid properties and the physical dimensions of the rotameter and float. In this experiment these properties will be constant. If a new fluid is used or there is a change in pressure (especially if the fluid is a gas) then a new constants would need to be determined.

The rotameter that you will use has millimeter markings on the glass tube. By calibrating the meter you will obtain a graph and equation of the liquid flowrate as a function of the rotameter reading in mm. If you used the standard industrial calibration curve that is mailed with the rotameter, the listed accuracy is $\pm 2\%$ of full scale reading. For example, Gilmont gives the flowrate at 150 mm (full scale reading) as 482.08 mL/min! Since this value is only accurate to $\pm 2\%$ of full scale reading, then the actual flowrate is ± 9.64 mL/min or between 472.4 and 491.7 mL/min. Please remember that the value of 9.64 mL/min is a constant. So that for a flowrate of 100 mL/min the accuracy of the calibration chart readings is only ± 9.64 mL/min. In this experiment you will obtain a calibration curve that is accurate to less than 1% of the actual reading. Why is there such a difference in accuracy? The relatively poor accuracy of the industrial flowmeter calibration is because the calibration curve is conducted on a typical flowmeter and not on the flowmeter that you are using today. Each flowmeter manufactured has variances in tube diameter, ball diameter and density. These variances are within the company specifications given resulting in an accuracy of $\pm 2\%$ of full scale reading.

Experimental Materials and Methods

The rotameter experiment utilizes a Gilmont calibrated rotameter (#GF-5541-1700) with either a GE700 or GE701 glass tube and stainless steel float. The glass tube is 150 mm in length with markings every millimeter. Water is used as the process fluid. The cost of this rotameter is \$205. There are no hazardous materials utilized in this experiment and no extreme operating conditions. Standard PPE for eye protection must be worn for the experiment.

Laboratory Notebook (Steps 1,2, and 6 must be prepared before class):

1. Enter your name and your group names and date at the top of the page
2. title this experiment
3. write a brief description of this experiment
4. Record the type of float inside the rotameter tube.
5. Record the brand name and the model number of the rotameter and the tube.
6. Construct a table with 5 columns. The headings on these columns will be: Rotameter Reading, Volume of Liquid, Time, Graduated Cylinder, and Flowrate. In the second row give the units for each of the 3 measurements and 1 calculation. You will need at least 7 rows to record your data from this experiment. See step number 8 for an analysis of cylinder selection.

Experimental Procedure

1. Review the procedure and safety analysis with your instructor.
2. Inspect the rotameter to make sure that the rotameter float is resting at the bottom of the scale.
3. The rotameter valve (needle valve), the knob on the base of the rotameter, should be turned off (clockwise). This is a DELICATE valve, NEVER apply undo force. The water supply valve (green valve) on the counter top should be in the off position.
4. Slowly open the water supply valve (Green valve on bench top) by turning the valve counter clock wise until it is in the fully open position and then turn it back a partial turn. (This will help to remind you that the valve is open.)
5. Check to see that the discharge tube will drain into a container.
6. VERY SLOWLY open the rotameter control valve (knob) and set it so that the stainless steel float sits at the 20 mm mark. Remember to read the float at its widest cross-section. You should see the water discharging at the exit tube.
7. Obtain a steady-flowrate. Since the water pressure may vary through out the experiment, one person will have to adjust the flow to keep the float at the specified level.
8. Choose an appropriate sized graduated cylinder. You have three cylinders to choose from 100, 250 and 1000 mL. The maximum water flowrate given above should be close to 482 mL/min. To obtain an accuracy better than 1% of the actual reading, the time of the experiment must be greater than 30 s. Remember that there are three major error sources in this experiment: reading the mm marking at the center of the ball, and measuring the flowrate (volume and time measurements). Note that the error in timing can be estimated by starting and stopping a stop watch. The error in reading the graduated cylinders of 100, 250 and 1000 mL, which have graduations of 1, 2 and 10 mm, is $\pm 1/3$ of the graduation.
9. Simultaneously time and place the empty graduated cylinder under the discharge tube that exits the top of the rotameter.
10. Repeat for subsequent rotameter scale graduations. Suggested scale graduations are 20, 40, 60, 80, 100, 120, 140.
11. At the conclusion of the experiment first turn off the water supply valve (at the counter) and then SLOWLY close the rotameter valve.

Data Analysis – Individual (Submit in one week)

1. Prepare a spreadsheet that has an entry for each laboratory measurement: : Rotameter Reading, Volume of Liquid, Time, and Flowrate. Remember to include your units in the spreadsheet. Printout this spreadsheet page.
2. Plot rotameter scale reading in mm vs. flow rate in ml/min
3. Perform a regression on the data using the equation given above using the trendline feature in MS Excel (see first two pages of handout). Show the calibration equation on your plot.
4. On engineering paper submit the following:
 - 4.1. Present the rotameter calibration equation with the appropriate units of the the constants.
 - 4.2. Determine the flowrate at a rotameter reading of 80 mm. Show calculation on engineering paper.
 - 4.3. Determine the rotameter reading at a flowrate of 100 mL/min.
 - 4.4. Transform your rotameter equation determined above to give the flowrate in units of gal/hr from the rotameter scale reading in mm.
5. Submit as a printout from the computer:
 - 5.1. graph (with titles, axis labels with units, trendline (regression of data) and equation.)
 - 5.2. spreadsheet page from step one. (show a sample calculation on engineering paper.)

Temperature Measurement: Immersion Heaters

Objectives

1. Set-up and run an experiment in which temperature is measured and recorded as a function of time using a data acquisition system employing DaqView software. Plot the data using Excel.
2. Understand the accuracy limitations of a thermocouple compared to a glass thermometer.
3. Analyze data using a linear regression. Obtain the rate of heat input to the water from the slope of a line.
4. Perform unit conversions of temperature.

Heat exchangers are ubiquitous in industry and in every day life. Last week you visited the university heating plant containing conventional boilers and a cogeneration unit. In a petroleum refinery, heat exchangers are at the bottom and top of distillation columns used to separate crude oil into gasoline and other fuels. You are sitting near equipment that contains several heat exchangers. Examine the top of the computer monitor. What is the purpose of the small holes? On the central processing unit of the computer (CPU) is a heat exchanger used to keep processors such as the Pentium chip cool. The large ears on elephants and desert foxes are used for maintaining body temperature.

In this experiment you will use an immersion heater to boil water. Examine the inside of your kettle (if possible). The metal coiled heating element contains a Nichrome wire. As electrons move through the wire, heat is created and transferred to the surrounding water. If your water is heated by electricity in your house, then you are using an immersion heater. In industry, this heater is similar to a kettle reboiler on a distillation column of a petroleum refinery. Instead of electricity flowing through an element, steam flows through tubes to heat the *pool* of liquid.

There are many methods of temperature measurement including the thermometer, thermocouple, resistance temperature detectors (RTD), thermistors, optical and radiation pyrometers. In this experiment you will employ a thermocouple to measure the temperature of water. A thermocouple consists of two dissimilar metals joined together at one end (a junction) that produces a small thermoelectric voltage when the junction is heated. These metals are normally wires with diameters ranging from 0.0005 in. to 0.162 in. (American Wire Gauge: AWG from 56 to 6). In many instances, such as in today's experiment, these small thermocouple wires are enclosed by insulation and a metal sheath. For temperature measurement thermocouples require a reference junction. In our experiment we use hardware compensation known as Cold Junction Compensation (CJC) for temperature measurement. This device is an integrated circuit located on the DBK19 thermocouple card. If you are using only a digital display, the reference junction is on the circuit board of the display.

Data acquisition requires a substantial capital investment! For the experiment you are performing today, the computer costs about \$2600, the DBK 19 thermocouple card costs \$395, the Daqbook A/D converter costs \$1395, and the thermocouple costs \$30! Given in the table below is a summary of the most common thermocouple types and their properties. Detailed information on temperature measurement can be found in most handbooks.^{1,2}

Limits of Error for Thermocouples

Thermocouple Type	Alloy & Composition	Temperature Range	Error Use whichever is greater
J	Iron - Constantan	0 to 750°C	±2.2°C or ± 0.75% of reading
K	Chromel - Alumel	-200 to 1250°C	±2.2°C or ± 0.75% of reading
T	Copper - Constantan	-200 to 350°C	±1.0°C or ± 0.75% of reading
E	Chromel - Constantan	-200 to 900°C	±1.7°C or ± 0.5% of reading

Constantan: 55% Cu - 45% Ni

Chromel: (CHROMEGA[®]) 90%Ni-10%Cr

Alumel: (ALOMEGA[®]) 95%Ni 2%Mn 2%Al

Table is based on ANSI MC 96.1 (1975)

You are already familiar with glass thermometers, but are probably unaware that you have nearly always used a total immersion thermometer. The other type of thermometer is a partial immersion thermometer in which the liquid level must be less than or equal to a line marked on the thermometer. The typical accuracy of a glass thermometers is approximately ±1 scale division.

¹ *The Omega Temperature Handbook*, Omega Engineering, Volume 29, 1995. (Located in the computer room)

² Holman, J.P., *Experimental Methods for Engineers*, 6th ed. New York: McGraw-Hill. 1993.

For example if the scale division is 1°C then the accuracy is ±1°C. Remember that both the thermocouple and the glass thermometer have a difference between accuracy and precision: Accuracy is the difference between the measured value and the true value of a tested material. Precision is the repeatability of successive measurements under the same conditions.

In this experiment you will be using a data acquisition system from IOtech Inc. The hardware you are using is shown in the Figure below. This consists of the computer, DaqBook100, thermocouple card and the thermocouple. As stated above the thermocouple generates a small voltage or an electric signal from the two wires. This voltage is very small and needs to be

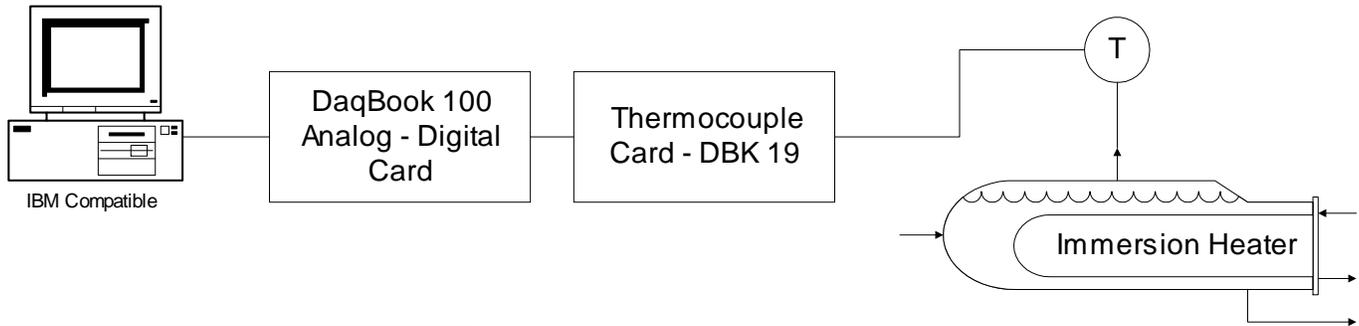


Figure 1: Data Acquisition System

increased (amplified) before it is sent onward. For example, the thermoelectric voltage of 4.096 millivolts is produced with the thermocouple junction at 100°C and the reference junction at 0°C. This signal is amplified from millivolts to the range of -5 to +5 V direct current (DC). In addition this thermocouple card contains a resistance-capacitance low pass filter (RC-LPF) which removes high frequency *noise* from the signal. The amplified voltage is sent from the thermocouple card to the analog to digital (A/D) conversion card. Since a software program needs a *digital signal*, then the magnitude of the amperage or voltage of the electric signal must be converted to a digital signal. The digital signal (a combination of 0's and 1's) is then used by the DaqView and Excel software packages.

The results of this experiment will be two columns of data for time and temperature. You will make a plot of temperature as a function of time and use an engineering equation (energy balance) to obtain the energy used to heat the water from room temperature to boiling. You will compare this value to the measured value from the wattmeter.

Equipment:

Digital Wattmeter WD-768 from Vector-VID Instrument Division

Immersion Heater (See bottom of unit of specifications)

Type K Thermocouple probe

DaqView Data Acquisition System and Software: DaqBoard (inside computer), DBK19 Thermocouple Card, DaqView 7.0, and DaqViewXL.

Procedure

WARNING - Make sure the surge suppressers connected to the immersion heaters are turned off

1. Safety
 - 1.1. Review the procedure and safety analysis with your instructor.
 - 1.2. Hot fluids will be used in this experiment
 - 1.3. An electrical hazard is present.

2. Laboratory Notebook (Steps 2.1 –2.3 and 2.8 should be done before class)
 - 2.1. Enter your name and your group names and date at the top of a new page
 - 2.2. title this experiment
 - 2.3. write a brief description of this experiment
 - 2.4. Record the brand name of the immersion heater and rated wattage (on bottom)

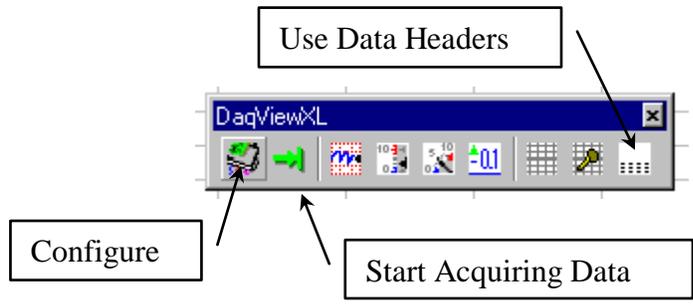


Figure 2: DaqView Toolbar

- 2.5. Record thermocouple type, data acquisition board and software
- 2.6. Record Watt meter brand name
- 2.7. Your data will be stored in a Microsoft Excel file. Record the name of your file and a brief summary of the data stored in the file.
- 2.8. In your laboratory notebook make a table with 2 columns for time and wattage.

3. Sample Preparation

- 3.1. Pour 900 mL of cold water into the kettle
- 3.2. Place the thermocouple into each kettle. Make sure that the thermocouple is not touching the heating element and is approximately in the center of the fluid.
- 3.3. Plug the wattmeter into a surge protector that is turned on. Do not plug in the immersion heater yet.

4. Set-up DaqView Temperature Measurement

- 4.1. Start Excel
- 4.2. Start DaqView by answering yes to the menu box.
- 4.3. Configure DaqView by depressing the configure button on the DaqViewXL toolbar shown in the Figure 2.
- 4.4. The screen shown in Figure 3 will appear and is the configure menu. In this menu you will tell the computer what card and device you are using to collect data, how many samples should be taken, the frequency of data sampling and the amount of data averaging. Check to see that the device is not a simulation, by choosing Device, Select Device, and DaqBook.
- 4.5. Select Configure Hardware Settings and the Configure System Hardware menu will appear. Under External Connection select the DBK19 Thermocouple Card next to channel zero. To save results select the OK button.
- 4.6. Referring to Figure 3, turn all the channels off by pressing the "triple off button." Then turn the cold junction compensation channel (CJC) on and turn the thermocouple channel 02 on. To turn these channels on you can double click on top of the No or select an option from the drop down menu.
- 4.7. Now select the thermocouple type. The default is Type J. Examine the yellow top of the thermocouple probe and you will see that it is a type K. Also examine the channel connection to the

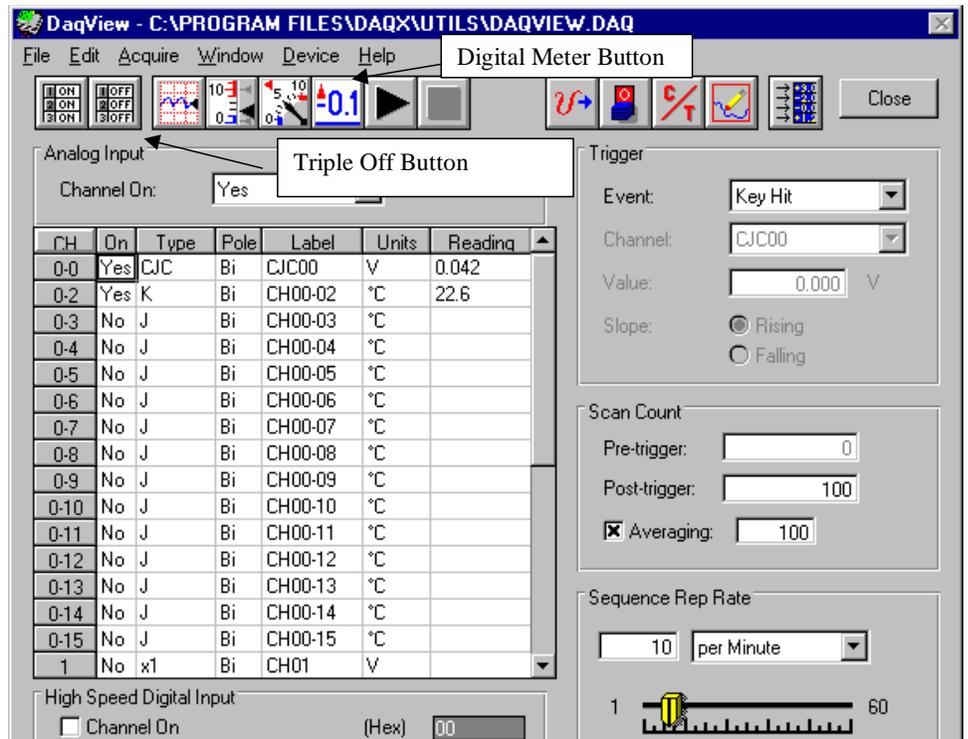


Figure 3: Configuration Menu

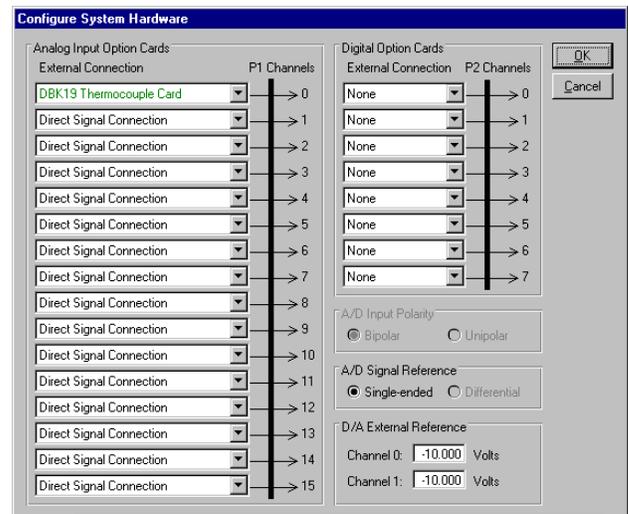


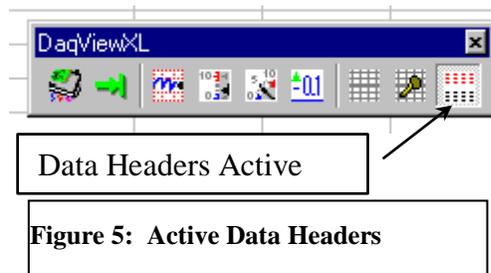
Figure 4: Configure System Hardware

DBK19 thermocouple card. The thermocouple extension wires should be connected to channel 02. The red wire is negative or Low (L) and the yellow coated wire is connected to positive or Hi (H). Notice that channel 0-0 is the cold junction compensation device and there is no channel 0-1.

- 4.8. Now test to see that your thermocouple is working properly. Turn the temperature monitor on by pressing the black triangle (VCR play button ▶). You should see a temperature of around 20°C. In some cases this is misleading and a faulty thermocouple will also give a room temperature reading. Test the thermocouple by heating the tip of the thermocouple. One way of doing this is to place your fingers over the tip. You should see the temperature increase. Please note that you are not acquiring data in this mode. The temperature is displayed on the screen, but is not recorded in any file for future analysis.

5. Setup Data Collection System

- 5.1. **Sampling Rate:** Set the Sequence Repetition Rate (**Sequence Rep Rate**) to collect 10 samples per minute. Every 1/10th of a minute a new temperature will be recorded and written into the spreadsheet after data collection is completed.
- 5.2. **Sample Conditioning:** Set the data averaging to 100 per sample. This feature is a form of data smoothing. Within a period of 6 seconds (1/10th of a minute) 100 samples will be collected. These samples will be averaged and the average value will be reported to the spreadsheet.
- 5.3. **Scan Count:** Set the data acquisition system to collect data for 10 minutes. Since you are collecting 10 samples per minute, then set the Scan Count Post-trigger to 100 samples. The length of time required to heat water to 100°C will vary depending on the rated wattage of your immersion heater, but it should be under 10 minutes.
- 5.4. Activate the Data Headers on the DaqViewXL toolbar. When this is activated a red set of horizontal lines will appear above the black lines on the button as shown in Figure 5.
- 5.5. Open a digital meter by selecting the digital meter button (See Figure 3). Select 1 channel of data and double click on the data channel to select channel 02.
- 5.6. Run a test run for several minutes to make sure that your data acquisition setup is correct and that all of the thermocouples are working. Select a cell to start the data collection. Note that using the data header feature will give you 13 of your summary lines of your data sampling conditions. Start DaqView by clicking on the green arrow (→) button of the data acquisition toolbox. Check to see that the percent data collection corresponds to your timing setup.
- 5.7. During the data acquisition process the data has been stored in a temporary file in the C:\Windows\Temp directory. This file is a binary file called _\$d1.bin. After the data collection has been stopped, either through the program or pressing the cancel button, the binary file is converted to a text file, _\$d1.txt, which is read by Excel into the spreadsheet. After several samples, press the cancel button. Notice that in the bottom left corner the program tells you what is happening!. Now check that you have collected 2 columns of data: CJC and 02. Notice that there are three columns of data for time, CJC channel in Volts and the temperature channel in °C. If you would like to give new names for your channels then you can type these names in the DaqView configuration panel shown in Figure 3.



6. Experimental Run

- 6.1. Prepare to start DaqView by clicking on the green arrow (→)
- 6.2. When you are ready to begin, you will simultaneously turn the power on to the immersion heater and click on the manual trigger button of DaqView. Note that the Betty Crocker and Proctor Silex immersion heaters have an on-off switch, while the West Bend and Rival immersion heaters will be turned on as soon as they are plugged into the wattmeter. Press on the W button on the watt meter and make sure that you have a value greater than zero! If you have a zero value you must start the experiment again.
- 6.3. Record the wattage of the immersion heater in the laboratory notebook every 30 seconds. The data acquisition system will record the temperature for you.

7. Data Analysis – Individual (Submit in one week)

- 7.1. Distribute the data to each group member. Remember to bring a computer diskette.

- 7.2. Calculate the average value of power (W) from the wattmeter during the heating process. Note: some of the kettles have an automatic shut-off and will result in a wattage of zero after it turns itself off. Do not average the value of zero into your data.
- 7.3. Make a plot of Temperature vs. time in minutes.
- 7.4. Calculate power input to the water, Q_{in}

7.4.1. The following equation results from an energy balance on the water during the heating stage:

$$(T - T_{initial}) = \frac{Q_{in}}{mC_p^{liq}} t.$$

Test this theory by making a second plot with [Temperature - Initial Temperature] on the y-axis and time on the x-axis. You will need to make a new column on your spreadsheet. Fit a trendline with zero intercept to the *linear portion* of the data. For additional information see the theory given below. To fit only the linear portion you will need to remove data points from the plot. One way of doing this is to select the chart; click on the Chart menu, choose Source Data. . .; select the Series tab, and edit the Y-values. If you reduce the cell number in the Y value window and then click on another entry point the preview of the graph will be updated.

7.4.2. From the slope of the above trendline determine Q_{in} . $Q_{in} = (\text{slope of the line})mC_p^{liq}$. The density of water is 10^3 kg/m^3 and the heat capacity of water is $C_p^{liq} = 4,181 \text{ J/(kg }^\circ\text{C)}$.

Remember that the slope of a line has units!

- 7.5. Submit on engineering paper: summary of experiment and findings; sample calculations and answers to questions
- 7.6. Submit as a printout from the computer: the two graphs (with titles, axis labels with units, only the second graph with a trendline (regression of data) and equation.)

Your plot of temperature vs. time should have resulted in a straight line during the heating phase. Some kettles have an automatic shut-off and the temperature drops after the maximum. Other kettles hold the temperature at boiling which results in an oscillation in the data. The slope of the straight line portion of the plot is defined as the change in temperature over the change in time.

$$\text{Slope} = \frac{\text{Change in Temperature}}{\text{Change in Time}} = \frac{\Delta T}{\Delta t}.$$

From your calculus course if you take the limit of Δt to zero then the slope of any curve is a derivative:

$$\lim_{\Delta t \rightarrow 0} \frac{\Delta T}{\Delta t} \equiv \frac{dT}{dt}.$$

An energy balance on the liquid water can be formulated using the above concept resulting in the following differential equation (for information only!):

$$mC_p^{liq} \frac{dT}{dt} = Q_{in} - Q_{lost}$$

If we assume that the heat lost to the surroundings is small compared to the heat added from the immersion heater then the following equation results:

$$mC_p^{liq} \frac{dT}{dt} = Q_{in} - 0$$

This equation can be integrated assuming m , C_p^{liq} , and, Q_{in} are constant: $\int_{T_{initial}}^{T_{final}} dT = \int_{t=0}^{t_{final}} \frac{Q_{in}}{mC_p^{liq}} dt$

This results in the equation that you will use to determine the energy input into the water Q_{in} :

$$(T_{final} - T_{initial}) = \frac{Q_{in}}{mC_p^{liq}} t$$

m mass of liquid water (kg)

C_p^{liq} heat capacity of liquid water 4,181 (J/[kg °C])

Q_{in} power added from immersion heater (W)

Q_{lost} rate of energy lost from liquid water to surroundings

T temperature of liquid water

t time (s)