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Updates to a Sequence of Thermodynamics Experiments for Mechanical Engineering Technology Students

This paper presents an outline of thermodynamics experiments and lab activities that accompany the introductory thermodynamics course for Mechanical Engineering Technology juniors at Central Washington University (CWU) in Ellensburg, Washington. It outlines and describes the current suite of thermodynamics lab activities, comparing the current suite of seven lab activities to a sequence outlined in an ASEE conference paper presented in 1995. Some lab activities in that paper have been replaced, while others have been updated. For example an experiment to measure the Joule-Thomson coefficient has been replaced with a First Law energy balance activity and the former First Law experiment has transitioned into a system efficiency activity. Both the previous and current experiments have been found to be useful in bridging the gap between theory and practice. The experiments expose the student to modern instrumentation and the collection and processing of data. Qualitative assessment of current student outcomes is addressed with a student survey. The purpose of this paper is to present these lab activities so that other thermodynamics instructors may learn from our experience.

Introduction

At CWU, the introductory thermodynamics class is a gateway class for the Mechanical Engineering Technology (MET) program. Most students are juniors entering the core sequence of classes in the major. Many of the students in this fall quarter thermodynamics class will be together on graduation day, and they come together for the first time in this class. Though students may have touched on many thermodynamics topics in Physics and Chemistry classes, this is their first engineering thermodynamics class. The current lab activities have evolved from those that were developed in the late 1980s and outlined in a paper by Kaminski (1) in 1995.

In order to keep students interested and engaged, efforts have been made to make the activities relevant to everyday life experiences. In some of these labs they must make and state engineering assumptions to complete the assignment. For example, the first lab (Energy Calculations) requires students to calculate the energy cost of taking a shower. To complete those calculations students must make an assumption about the duration of their typical shower along with a reasonable estimate of the variation in the time duration. They use a thermocouple to determine the comfortable shower water temperature, along with the variation in that value. Applying that information, along with water properties, an energy equation, and electricity cost data yields an energy cost estimate per shower.

Lab Activity Work Product

The original lab activities assigned one report per group. While the group report format helps foster team building and cooperation, it commonly results in one student burdened with the bulk of the work in preparing the report. Group reports also allow students who are weak in writing skills to avoid that task.

The work product assignment has been revised so that current lab activities require students to turn in individual reports. In assigning individual reports it is common in almost every class to identify students with weak writing skills. For students with a low grammar grade, an incentive is offered to change the grade if the student visits the campus writing center for help in revising the text.

The work product for the current lab activities is a report that falls into one of three categories: a full format lab report, a technical memo with supporting calculations in an appendix, or a trip report type memo. A majority of the labs utilize the full format lab report with cover sheet, introduction, procedure, data, results, discussion, conclusion, references, and supporting materials in the appendix. The technical memo is a one or two page report in memo format that answers a specific question, with supporting data and calculations in an attached appendix. This is similar to what might be required in a work setting where a coworker or manager needs a concise answer to a technical question. The third format utilized is a trip report memo, where a concise one-page memo addresses questions about what was observed on a tour.

Summary of Previous Lab Activities

The previous suite of lab experiments was originally developed for the CWU MET program by Kaminski (1). A list of the previous lab activities is outlined in the Table 1. These activities have been revised or replaced based on equipment improvements and perceived effectiveness in student learning. The work product for each of these was a single group lab report.

For example, the Joule-Thomson experiment has been replaced with an R134a expansion energy balance. The Joule-Thomson coefficient for an isenthalpic expansion is a minor topic in the course. By revising this activity into a demonstration of a first law energy balance, students gain a better understanding of the first law of thermodynamics (a major topic in the course) and the relevant thermodynamic energy balance calculations.

Previous Lab Activity Titles
1. Pressure & Temperature Measurements
2. First Law Lab - Air Motor / Gear Pump
3. Transient Temperature & Pressure Measurements
4. Joule - Thomson Experiment
5a. Vortex Tube Experiment
5b. Vortex Tube Refrigerator COP Analysis
6. Self-Designed Experiment

Table 1: Previous Thermodynamic Lab Activities

A transient temperature & pressure measurement experiment in the original suite of lab activities has also been replaced by other activities. This experiment was performed using a pressure tank vented to the atmosphere, with a data logger measuring the temp and pressure as it vents. Transient processes are not part of the curriculum for this introductory thermodynamics course, though transient processes are addressed later in MET316 Heat Transfer (along with the utilization of a data logger for transient data).

The Vortex tube activities have been replaced in favor of other activities. Students are still introduced to the vortex tube in lecture, and it is made available for them to experiment with on their own time in lab. The self-designed experiment activity has been discontinued, though there remains a self-designed experiment lab activity in the MET315 Fluid Dynamics course.

Outline of Current Lab Activities

The current suite of lab activities includes seven different activities, summarized in Table 2. The student work product for these labs varies from a simple trip report memo to a full format lab report. In this Paper, current lab activities are outlined following the table. For current lab activities that were revised from previous activities, a comparison is made.

Current Lab Activity Titles	Work Product
1. Energy Calculations	Technical Memo
2. Temperature Measurements	Individual Lab Report
3. Pressure Measurements	Individual Lab Report
4. R134a Expansion Energy Balance (Group Lab)	Individual Lab Report
5. Air Motor/Gear Pump System Efficiency	Individual Lab Report
6. Air/Fuel Ratio Lecture and Worksheet	Worksheet
7. Central Boiler / Chiller Plant Tour	Trip Report Memo

Table 2: Current Thermodynamic Lab Activities

What follows is a brief outline and discussion of each of the current lab activities, with comparison to the related previous lab where appropriate. The appendix includes more detailed information about the current labs, including the assignment sheets and typical data from the experiments.

Lab 1: Energy Calculations

This activity was added to introduce students to energy calculations, engineering assumptions, and error analysis of results.

Objective: The objective of this activity is to gain an awareness of electrical energy consumption of common objects and activities, and to gain experience in taking data and applying data to develop cost estimates.

Classroom	Bulbs	Pwr / bulb	Total Pwr	kW-hr /yr	Cost / yr	Savings
Before, Room 215	196	40 W	7840 W	13,720	$ 813.60	Baseline
After, Room 205	56	32 W	1792	3136	$ 185.96	77.1%
Shower Data	Time = 10 +- 1 min		$(T_2 - T_1)$ = 30 C +- 2C	Flow = 2.5 GPM +- 0.5 GPM		Energy = 3.26 kW-hr
Data Variability	+- 10%		+- 6.7%	+- 20%		Total + 41% - 33%
Shower Cost	3.26 kW-hr x $0.0593/kW-hr + $.04 water				Range	$0.17 - $0.31

Table 3: Typical Energy Calculation Lab Results

There are three parts to this energy calculation lab: 1) calculating energy consumption and annual energy cost of lights in the lab classroom, 2) estimating energy consumed and cost for a typical morning shower, and 3) estimating the range of error in the shower cost calculation due to data uncertainty. Typical results are summarized in Table 3. A method for unit conversions is presented, and error analysis is performed to show how data variability affects the final result uncertainty. For many students not yet conversant with energy units, the common industrial energy unit of kW-hr is unfamiliar and needs to be explained, especially as it applies to the shower energy cost. Water volume can also be calculated and the cost of that resource estimated using the utility rates. The total data variability is obtained by multiplying the individual data point uncertainties together (ie, based on the fourth row of Table 3, 1.10 x 1.067 x 1.20 = 1.41 or 41% variability for the upper error value estimate).

Lab 2 & 3: Pressure & Temperature Measurements

The first lab of the previous suite, addressing pressure and temperature, has been revised and split into two labs in order to focus in greater depth on these topics since they are both very relevant to subsequent labs. The original version of the lab discussed and used more types of sensors (ie, vacuum gauge, helium expansion and mercury bulb thermometers), but did not go into as much depth on the technology underlying the different sensor technologies. The original lab did give students experience with many types of pressure and temperature measurement equipment, however there were so many activities that students lost focus for the point of some activities. The current labs have a narrower and sharper focus and are outlined below.

Lab 2: Temperature Measurements (Zeroth Law Experiment)

Objective: To gain insight into temperature sensor characteristics, including output characteristics and settling times.

In this lab activity, students measure the temperature sensor outputs for three different sensors: Type K bead thermocouple using the NIST reference tables (using ice point and random temp junction), Type K bead thermocouple read by a digital thermometer, and Resistance Temperature Detector (RTD) output characteristic. The sensors are placed in ice water, room temperature water, and boiling water. Typical values for this experiment are shown in Table 4.

Sensor Type	Ice Water	Room Temperature	Boiling Water	95% Response Time
Type K TC bead & probe with Digital thermometer	0.0 C	21.0 C	99.0 C	Bead: < 1 sec Probe: 3 sec
Type K bead, room temp junction	- 0.838 mV	0.000 mV	3.258 mV	
Type K bead, ice point junction	0.000 mV	0.838 mV	4.096 mV	
Kitchen RTD Sensor	600 kOhm	260 kOhm	20 kOhm	Approx 23 sec

Table 4: Temperature Lab Typical Sensor Outputs

Of special note is the voltage difference between the room temperature junction and ice point junction for the K type thermocouple. From Table 4 it can be seen that the voltage spread for the two cases is essentially the same, but the absolute values show zero volts when the temperature of the thermocouple bead is the same as the junction of the thermocouple wires with voltmeter leads. The NIST tables give data for the ice point reference junction. Students compare their voltage spread based on the two reference junction temperatures, and use the NIST table with their ice point reference voltages to predict a temperature to compare with the TC meter reading. This point is discussed in the lab introduction, and usually requires additional explanation as students struggle to make sense of their voltage readings.

A settling time experiment is performed for Type K thermocouples, comparing the bare bead thermocouple with the shielded probe type thermocouple. This response test is also performed with the Kitchen RTD. Elapsed time for a 95% change (corresponding to 3 time constants) is timed with a stopwatch as the temperature sensor is removed from boiling water and plunged into ice water (or vice versa). This exercise helps students see how sensor construction and type can affect readings. Barometric pressure in the lab is recorded and used to predict the boiling temperature of water. This value is compared to the temperature indicated by the digital thermometer.

A lower budget simplification of this experiment could use only the kitchen RTD (usually sold as part of a kitchen timer/thermometer unit) and a handheld multimeter with adapter. The resistance measurement does not require the high precision voltage resolution needed for the thermocouple measurements (ie, resolution of .001 mV resolution to measure approx 39 to 42 microVolts per 1.0 C). Lower cost multimeters can work well for the RTD resistance measurements. This change still allows students to see the RTD sensor output and response to temperature changes.

Lab 3 - Pressure Measurements Lab

Objective: To compare mechanical and electronic methods used to measure and calibrate pressure. Using a pressure sensor, determine the internal pressure in a latex balloon.

This lab activity utilizes a dead weight pressure tester to generate a known pressure that is measured using a high precision electronic pressure sensor (FLUKE 700P07 and/or PV350 pressure sensor or equivalent) and a high precision bourdon tube mechanical pressure gauge. The bourdon tube gauge can be very accurate within a particular range, but may be off significantly at other values. The electronic sensor may need to have its zero value set to calibrate it. Some typical data for this experiment is shown in Table 5.

Device	Pressure 1	Pressure 2	Pressure 3	Pressure 4	Equipment Spec
Ashcroft 1305D Dead Weight Tester	5.00 psig	25.0 psig	65.0 psig	85.0 psig	+- 0.1% of reading
Bourdon Tube Pressure Gauge	4.7 psig	26.0 psig	66.5 psig	86.0 psig	+-0.5%
Fluke PV350 & DMM	5.0 psig	25.1 psig	65.0 psig	84.9 psig	+- 0.1% + 0.3 psig
Fluke 700X & Process Calibrator	5.02 psig	24.75 psig	64.66 psig	84.66 psig	+- .025%

Table 5: Typical Pressure Lab Data

In the balloon part of the lab, students blow up latex balloons and then measure the internal pressure. They are often surprised to find out that their best effort produces a relatively insignificant pressure reading (usually less than 1 psi).

Lab 4 - R134a Energy Balance (First Law Experiment)

Objective: The objective of this lab is to analyze the first law energy balance of an isenthalpic venting process for a control volume (a container of R134a refrigerant).

This experiment replaces the Joule-Thomson experiment from the previous suite of activities, and focuses on the more basic concept of a first law energy balance as compared to the previous emphasis on determining the Joule-Thomson coefficient. The Joule-Thomson coefficient is a minor topic mentioned in a few paragraphs in the textbook, while the first law of thermodynamics is a central topic of the course.

The format for this experiment is an instructor led whole-class group lab, going through the data sheet like an in-class worksheet. The reason for this format is to better guide the students through the complex process to highlight relevant points more effectively. It also serves to minimize the consumption of R134a refrigerant.

Students become familiar with calculating thermodynamic properties, using the data to perform a first law analysis of the energy on a control volume system (refrigerant and its container). This lab acquaints students with volume calculations using mass and specific volume data for water, determining quality of a saturated mixture of the refrigerant from mass and volume data, and predicting total enthalpy (energy) of refrigerant from mass, quality, and property tables. Students also calculate the energy given up by the mass of the can and valve in the process.

According to the First Law of Thermodynamics, the energy before should balance with the energy after with allowance for experimental error. In recent years the difference between initial and final energy values have been well within experimental variation, ranging between 0.6% and 2.6%. Due to the many data points used to determine the refrigerant mass, the refrigerant mass value may have a variability of +- 0.6 g, which can be 2% of the calculated mass value. Table 6 shows a result summary from a typical lab. More data detail can be found in the appendix.

State	Temperature	R134a in can Total Enthalpy	R134a released Total Enthalpy	Can + Valve Thermal Energy	Total Energy Content
Before	+25.6 C	20.54 kJ	0 kJ	5.78 kJ	26.32 kJ
After	- 23.5 C	3.09 kJ	23.4 kJ	0 kJ (ref state)	26.49 kJ
				Total Energy Balance Error:	0.65 % error

Table 6: Typical Energy Balance Lab Results

R134a has been commonly used as the "air" in air duster cans (sold in office supply stores for blowing dust out of computer keyboards etc). R134a is an ozone friendly replacement for R12, which is a controlled substance due to the Montreal Protocol. Though R134a has an ozone depletion potential (ODP) value of zero, it has been assigned a Global Warming Potential (GWP) number of 1300 (2). The typical lab releases 60 to 80 g of R134a. Over the past 5 years that has amounted to 3.8 g per student, with a total release of 352 g. Applying the GWP factor for R134a, this lab has had the climate impact over the last five years equivalent to burning 48 gallons of fossil fuel, or about ½ gallon per student.

Recently there has been a trend toward replacing R134a with R1234yf, which has an ODP value of 0 and a GWP value of 4 (3). Recent review of "air" dusters indicates that R134a is being replaced by materials with lower GWP values. In future this lab will switch to R1234yf if appropriately sized containers of the refrigerant can be obtained. With the new refrigerant this lab should be equally effective in demonstrating thermodynamic principles and properties.

Lab 5 - Air Motor/Gear Pump Lab (System Efficiency)

Objective: To calculate the power input, power output, and system efficiency of a water pump driven by an air motor.

This lab was part of the original lab suite of activities developed by Kaminski based on a paper by Otis (4). This lab is similar to the original lab, but the procedure has been refined to focus on calculating system efficiency at a single RPM with varying pump loads. The original lab was referred to as the first law lab but system efficiency was calculated, not an energy balance for the system. This lab has been moved to a point later in the course in order to coordinate related topics as they are presented in lecture.

The class is divided into lab groups of four students, with each group assigned one air motor RPM. With the motor driving the gear pump at the given RPM, students restrict the pump outlet to create a backpressure of 0, 20, 40, 60, and 80 psi (simulating a pumping load). Data for each operating point is taken after the air motor outlet temperature stabilizes. During grading, the instructor compiles data from each group into a whole class data set to graph and to show additional trends and make comparisons. Table 7 shows a summary of data taken by one group. Figure 1 shows a graph of Air Motor Power In vs Pump Power Out for a typical class data set.

Shaft RPM	Pump psid	Pump GPM	Air Motor T_{in}, C	Air Motor T_{out}, C	Air Mass, Ft^3/min	Air Mass, Temp, F	Air Mass psia
1110	3.5	2.6	19.3	8.7	4.7	62.1	14.08
1109	20.3	2.4	18.9	4.8	5.9	59.0	14.15
1115	40.3	2.2	18.7	0.6	7.7	54.7	14.28
1108	60.7	2.0	18.5	-3.1	9.4	51.6	14.28
1117	80.4	1.8	18.3	-5.8	11.2	46.6	14.28

Table 7: Air Motor / Gear Pump Lab Sample Data

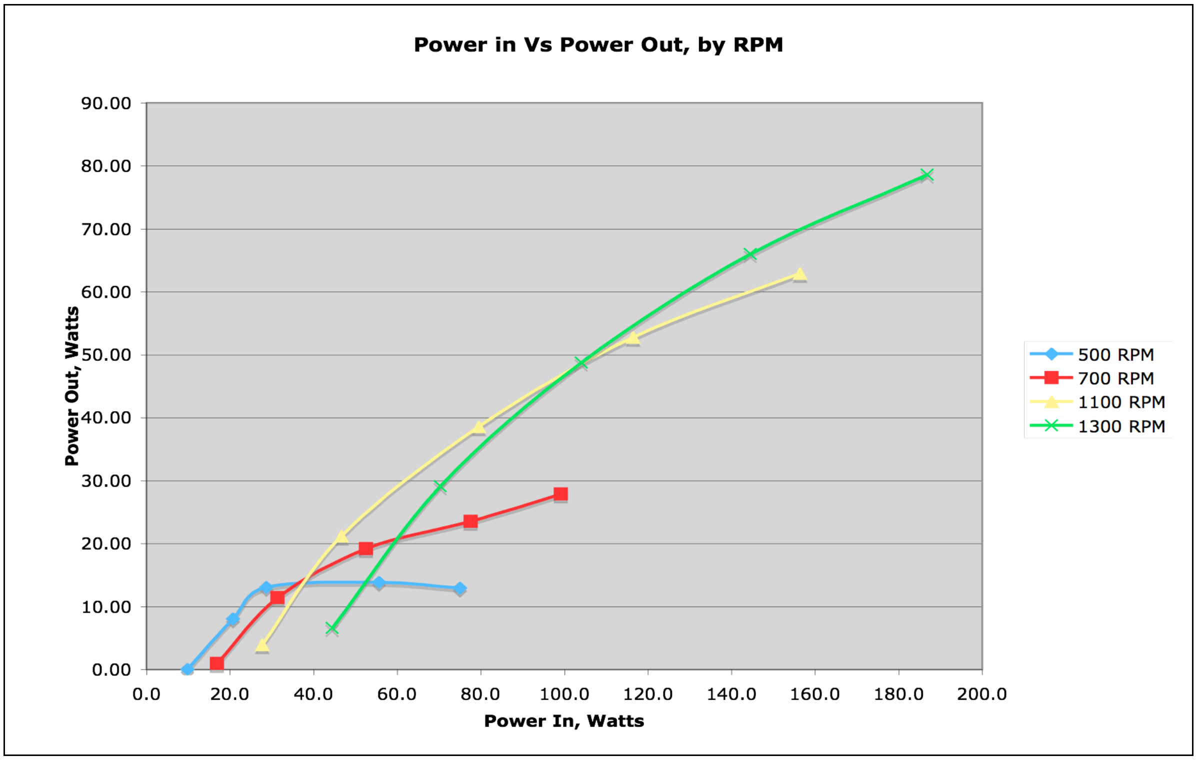

Figure 4: Air Motor / Gear Pump Lab Typical Results Graph

Students must calculate the pump power output from the power formula for incompressible fluids. They must also calculate the air motor thermodynamic power input from ideal gas formulas. The calculated thermodynamic system efficiency varies with power and speed, ranging from approximately 5% to 45%.

One of the aspects of this lab that is nonintuitive for most students is the exhaust temperature of the air motor. For most engines the exhaust gets hotter as power input increases; for the air motor the outlet temperature gets colder with increased power, as is shown in the data for T_{out} in Table G. With increasing power demand the air pressure at the air motor inlet must increase, so the air expands more to exit at room pressure. This expansion (and thus the inlet pressure increase) is reflected in the exhaust temperature drop.

It should be noted that the air motor is analyzed using ideal gas relationships. As such it is possible to determine the isentropic efficiency of the air motor by knowing the absolute pressure in/out and absolute temperature in/out. Isentropic efficiency is a difficult topic for some students to grasp. The air motor lab setup appears to be a good candidate for developing an entropy related lab activity.

Lab 6 - Air-Fuel Worksheet

Objective: To introduce combustion chemistry, balance stoichiometric combustion equations, and use that information to calculate stoichiometric air/fuel mass ratios.

This lab activity is a new topic that has been added recently. It is formatted as an in-class lecture and worksheet session on the combustion topic, which is not otherwise addressed in this introductory class. Usually it is scheduled in conjunction with lecture topics dealing with power cycles (ie, Otto, Diesel, Brayton, and Rankine cycles). Aside from dealing with an engine related topic, this activity also prepares students for their visit to the boiler plant, where it is easier to discuss the significance of some of the control parameters such as the oxygen sensors in the boiler exhaust stacks. The worksheet is presented in the appendix.

Lab 7 - Central Boiler Plant Tour

Objective: To introduce students to large scale industrial equipment used for steam production and refrigeration in HVAC applications.

This field trip lab has been added to give students a sense of the scale of a large industrial plant utilizing thermodynamic processes. The main campus of CWU is served by a central boiler / chiller plant. The plant contains four large boilers (total steam capacity of 210,000 lb/hr @ 115 psia at saturation), three large chiller units (3300 Tons total capacity), and a chilled water storage tank (one million gallon capacity). Students are given a 1+ hour tour of the plant by the staff mechanical engineer, with a list of questions to answer in a memo format trip report with supporting calculations and conversions.

This is the first exposure many students have to thermodynamics on an industrial scale. Some students have difficulty dealing with the conversion from a mass flow rate of saturated steam to energy flow in BTU/hr (ie, adapting textbook learning to the real world application). Because it is unfamiliar to most students, the typical commercial refrigeration unit of "Tons" needs to be explained. The scale of the plant seems to awe many students. This tour and the questions they must answer help link the textbook to actual industrial application of the topics presented in the course.

Qualitative Assessment of Student Objectives for Current Lab Activities

Students have been surveyed on their response to the thermodynamic lab activities. The survey used a 5 point Likert scale to qualitatively determine how well the labs helped them achieve the student learning objectives. A value of one indicates strong disagreement with the statement; a value of five indicates strong agreement. The survey instrument in included in the appendix. Table 8 summarizes the questions and the scores. A discussion of the results follows Table 8.

The survey results are based on a population of 19 responses, from MET juniors and seniors. With a sample this size the standard deviation value has limited relevance, but is included to give a sense of the response variation. In reviewing data separately for juniors and seniors, the two groups data values did not have significant differences. In general the student responses confirm that the experiments are valuable to their learning. A strong response for question A supported the value of starting the lab sequence by getting more familiar with energy unit conversions. The strongest response was for question E about the energy balance of R134a. Students agreed that the R134a experiment was a good exercise in analyzing the energy balance of a thermodynamic process.

Survey Statement	Score / Standard Deviation
A. Lab 1: Finding the cost of electricity for lighting and a shower was a good way to practice energy conversion calculations	4.58 / 0.51
B. Lab 1: Calculating the cost of a shower is **not** relevant to engineering thermodynamics	1.79 / 0.85
C. Lab 2: Measuring the outputs of the thermocouple & RTD at different temperatures gave me a better understanding of how temperature sensors work	4.21 / 0.63
D. Lab 3: Using the dead weight tester with the pressure gauge and electronic sensors gave me valuable experience with pressure instrumentation equipment	4.21 / 0.79
E. Lab 4: The R134 lab is a good exercise for analyzing the energy balance of a thermodynamic process	4.68 / 0.48
F. Lab 4: Calculations performed in this lab to determine thermodynamic property values gave a practical context for those concepts	4.53 / 0.51
G. Lab 4: The lecture homework problems assigned were enough to learn about thermodynamic properties, and the R134 lab didn't teach me anything useful	1.95 / 1.08
H. Lab 5: Calculating the power input to the air motor improved my understanding of energy calculations for ideal gasses (ie compressible fluids)	4.16 / 0.69
I. Lab 5: Calculating the power output of the gear-type water pump improved my understanding of energy calculations for incompressible fluids	4.32 / 0.48
J. Lab 5: Determine the system efficiency for the air motor/water pump system helped give context to the thermodynamic calculations for power in and out	4.42 / 0.61
K. Lab 5: The air motor lab does **not** seem relevant to the study of thermodynamics and should be discontinued	1.16 / 0.37
L. Lab 6: The air fuel ratio worksheet was interesting and should be expanded	3.79 / 1.03
M. Lab 6: The air fuel ratio worksheet didn't teach me anything useful and should be replaced.	1.58 / 0.96
N. Lab 7: Energy calculations for the central boiler / chiller plant helped tie textbook concepts to real world applications	4.32 / 0.82
O. Lab 7: The boiler plant tour was a waste of time and should be replaced	1.37 / 0.76

Table 8: Student Outcome Survey Results

The question with the strongest response (smallest variance) was question K about the air motor lab. By their response, students feel that it is a relevant lab. One of the surveys included a comment about the need to run this lab in a more time efficient manner, due to the bottleneck caused by a having only two sets of equipment for 6 or 7 lab groups. This can be addressed by scheduling time for each group to take their turn.

For the Air-Fuel worksheet, one student commented that this activity "...was interesting but did not meet the effort level expected for a typical lab." This activity is a work in progress and needs to be expanded, or perhaps incorporated into the lecture part of the course.

By the scores, students confirmed that the boiler tour was worth continuing though one student commented that "the boiler plant tour was great but I had a really hard time hearing..." the orientation lecture by the facilities engineer, which has been done outdoors adjacent to the plant.

In future an orientation lecture will be conducted in the classroom to better prepare students for the tour.

The surveys included two general comments that bear repeating. One senior wrote that "these labs not only gave us understanding of thermodynamics, but also combined much of what we have learned in other classes to create valuable experiments (eg, physics and electricity)". A junior included a comment stating that "the labs were interesting and required a formal write up that improved my lab write up skills".

Conclusion

Over the past 18 years the suite of lab activities in the MET314 thermodynamics lab has been revised to focus the lab topics on relevant experiments for this introductory course. The introduction of new equipment with greater resolution has allowed for development of new procedures and better precision in the experimental data. Some existing experiments have been rescheduled in the syllabus to better align with lecture topics, and some have been dropped in favor of other activities. An on-campus field trip has been added to give students exposure to industrial scale equipment utilizing thermodynamic principles.

The thermodynamic labs give students practical experience with the topics they study in the course. They gain familiarity with the use of measuring instruments and data collection. Lab calculations reinforce the relevance of homework problems on related topics. These lab activities help many of the thermodynamic properties and processes come to life for the students, and are a valuable part of the educational experience. Many students graduate from CWU's MET program and go on to use thermodynamic concepts in their jobs, utilizing concepts and test equipment first introduced to them in this set of thermodynamics labs.

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Appendix: Current Lab Assignments

MET 314LAB Applied Thermodynamics Lab
Lab 1: Energy Consumption Analysis

Objective: To gain an awareness of electrical energy consumption rates of common objects, and to gain experience in measuring and calculating energy use and cost, including unit conversions and uncertainties in results due to data accuracy & precision.

Tasks:

1. Compare the energy consumption & expense of lighting in the new lab classroom, Hogue 205, with all lights turned on, vs old Hogue 215.
    a. Count the number bulbs in new lab room; assume old lab was using 196 bulbs @ 40 W each; new Hogue bulbs are 32 W ea
    b. Calculate maximum power consumption per hour for both rooms.
    c. Calculate annual cost for each room based on Ellensburg E-100 rates, 50 hrs/week
2. Determine the cost of resources consumed in taking a shower
    a. Assume typical shower flow rate of 2.5 GPM +- 0.5 GPM
    b. Determine the amount of time water is flowing (length of your shower)
    c. Determine your comfortable shower temperature using a thermocouple and tap water; assume cold water temperature is 54 F (12 C).
    d. Document your assumptions and report data with appropriate accuracy
    e. Calculate total energy consumed (in Joules and kW-hr) to heat water and total cost per shower for electricity, including error analysis based on assumed precision of data
    f. Estimate cost of water based on volume consumed and city utility rates

Note: Electrical Power = V x I = 1 volt x 1 amp = 1 Watt = 1 Joule/second
Electrical energy is sold in kW-Hr increments; 1 kW-hr = 3600 kJ
Use Ellensburg electric rates for E-100 residential service (on internet)

Lab Memo: Due in one week. Summarize results in a one page memo, with a paragraph for each topic. Use the memo format outlined in the Lab Report Guidelines. Remember to state any assumptions you made in gathering data and accuracy of data values measured, and attach all support documentation (data taken, calculations and conversions) in appendix pages. Address the following questions in the memo body:

A. How much lighting energy is conserved in new Hogue lab without significantly affecting users? Express in kW, % reduction, and $/week savings.
B. For the shower data, what is the energy used and energy cost per shower. Also address sources of uncertainty (variance) in the result and calculate (as a % of total) based on data accuracy for flow, temp, and time.

Lab grading:		
	10	Format
	10	Grammar
	20	Technical Content
	10	Effectiveness
	50	Total

MET314 Energy Consumption Lab Typical Data & Results

Room Lights Data:

Assume 35 wks/yr, 10 hr/day x 5 days per week = 1750 hr/yr
Local Electricity E100 Rate = \$0.0593/kw-hr
Energy Before, Room 215: 196 bulbs @ 40 W ea = 7840 W
Cost before = 7.84 kW x 1750 hr/yr x \$0.0593/kW-hr = \$813.60/yr
Energy After, Room 205 (building remodel): 56 bulbs @ 32 W = 1792 W
Cost After = 1.792 kW x 1750 hr/yr x \$0.0593/kW-hr = \$185.96

Shower Energy Data:

Mass = (10 +- 1 min) x (2.5 +- .5 gpm) = 25 gal x 3.7854 lit/ 1gal x .990kg/lit = 93.69 kg
Energy Q = m Cp dT = 93.69 kg x 4.18 kJ/kg-C x (30 +-2 C) = 11749 kJ = 3.263 kW-hr
Estimated Energy Cost =3.263 kW-hr/shower x \$0.0593/kw-hr = \$0.193 / shower
Energy Cost Variation = Time x GPM x Temp = 1.10 x 1.20 x 1.067 = 1.408 --> + 40.8%
= .90 x .80 x .933 = 0.672 --> - 32.8%
so cost varies \$0.193 + 40.8% - 32.8% -> \$0.13 --> \$ 0.27

Shower Power Demand:

dQ/dt = dm/dt Cp dT = 9.369 kg/min x 4.18 kJ/kg-C x 30 C x 1 min/60 sec x 1 kW/(1 kJ/sec)
= 19.6 kW = 82 Amp draw @ 240 V

Water resource consumption & cost

10 min x 2.5 gpm = 25 gallons consumed; W110 rate: \$1.61 per 1000 gallons;
Water cost = 25 gallons x \$1.61/1000 gallon = \$.0403

Summary table:

<table>
<tr><td>Classroom</td><td>Bulbs</td><td>Pwr / bulb</td><td>Total Pwr</td><td>kW-hr /yr</td><td>Cost / yr</td><td>Savings</td></tr>
<tr><td>Before, Room 215</td><td>196</td><td>40 W</td><td>7840 W</td><td>13,720</td><td>$ 813.60</td><td>Baseline</td></tr>
<tr><td>After, Room 205</td><td>56</td><td>32 W</td><td>1792</td><td>3136</td><td>$ 185.96</td><td>77.1%</td></tr>
<tr><td>Shower Data</td><td colspan="2">Time = 10
+- 1 min</td><td colspan="2">(T2 - T1) = 30 C
+- 2C</td><td>Flow = 2.5 GPM
+- 0.5 GPM</td><td>Energy =
3.263 kW-hr</td></tr>
<tr><td>Data Uncertainty</td><td colspan="2">+- 10%</td><td colspan="2">+- 6.7%</td><td>+- 20%</td><td>Total + 41%
- 33%</td></tr>
<tr><td>Shower Cost</td><td colspan="4">3.26 kW-hr x $0.0593/kW-hr + $.04 water</td><td>Range</td><td>$0.17 - $0.31</td></tr>
</table>

MET 314 Applied Thermodynamics Lab
Lab 2: Temperature Measurements Lab

Objective: To gain an understanding of methods used to measure temperature: Type K thermocouples, RTD sensors and Platinum temperature standards. You will also determine the boiling temperature from pressure data by interpolation of the values of temp & pressure data from a table. For all measurements, record data with appropriate significant digits, and also note the precision of the reading. For general information on how different temp sensors work (and their limitations and advantages), see
http://www.omega.com/ techref/measureguide.html .

Equipment: Equipment needed for these measurements is a

K-type bead thermocouple and FLUKE 52 Digital Thermometer
K-type thermocouple with bare leads crimped onto a pair of voltmeter leads
FLUKE 8808A DMM (or similar, with resolution of .001 mV)
Stopwatch
Consumer grade kitchen RTD sensor with voltmeter adapter.
Containers with ice water and room temperature
Hot plate & Pot with boiling
NIST Reference Table for Type K thermocouples
(try http://www.omega.com/ thermocouples.html for a copy)

Tasks

1. Barometric Pressure & Boiling Temperature
    a. Record atmospheric pressure in Room 215 during lab period using FLUKE pressure sensor
    b. Determine boiling point from saturation pressure/temperature data
    Interpolate the saturation temperature for water (boiling point) for this pressure from saturation table data for water (data in Table 1) or use EES software.
2. K-type Thermocouple Response (Nickel-Chrome and Aluminum-Chrome alloy wires)
    a. K-Type Thermocouple with **random** reference (junctions at room temp)
    With a high accuracy voltmeter (capable of measuring .001 mV), measure & record voltage output of a K-type thermocouple probe at freezing, boiling and tap water temperature (use 200 mV range; readings will be in .001 to 4.000 mV range; watch the polarity sign) (Note: keep the lid on the boiling pot)
    b. K-type thermocouple with **ice bath** reference point (junctions in ice water)
    I. Record voltage of K-type TC in ice water and boiling water.
    II. Convert voltage to temperature using data table of voltage-to-temp conversion
    References: For K-type voltage-temp conversion, see
    http://www.omega.com/temperature/z/pdf/z218-220.pdf
    c. Using FLUKE handheld thermocouple meter and K-Type TC sensor,
    Record indicated temperatures for freezing, boiling, and room temp
3. Record output from kitchen RTD sensor at freezing, boiling, and room temps.

4. Settling Time Activity: Using the FLUKE handheld thermometer, probe and bead style K-type TC, determine the amount of time that it takes to change (ie, settling time)

a. Note bead temp in hot water; move bead to ice water and wait until it reads 5 C.
b. When probe reads approx 0C, move it to boiling water and record time to 95C
c. Repeat 5 times, record the times, and report average value of the 5 readings;
d. Repeat process for Type K probe and RTD sensor.
(Note: 95% change corresponds to 3 time constants on exponential curve)

Lab Report (due in one week): Write individual report in Lab Report format per lab report guidelines (Intro, procedure, data, results, discussion, conclusion, appendix). Address the following questions in the discussion section:

1. How much did the boiling temperatures measured differ from the temperature predicted by the tables?
2. How does the voltage range (ΔV from ice to boiling) compare for K type TC between the random reference and the ice bath reference tests?
3. How closely do the values from different methods compare in measuring the same temperature? (ie, boiling temp results for voltage tables and FLUKE thermometer)
4. How long does it take the Type K bead TC to settle into a reading? K Type probe?

Lab grading:	20	Format
	20	Grammar
	40	Technical Content
	<u>20</u>	<u>Effectiveness</u>
	100	Total

MET 314 Lab 2: Data Tables for Temperature Measurements Lab

Barometric Pressure Method/Equipment Used		Day & Time	

Saturation Temp	Atmospheric (Barometric) Pressure
95.0 C	63.4 cmHg
96.0 C	65.8 cmHg
97.0 C	68.2 cmHg
98.0 C	70.7 cmHg
99.0 C	73.3 cmHg
100.0 C	76.0 cmHg
101.0 C	78.8 cmHg

Table 1: Saturation temp of water vs atmospheric pressure
(data from http:/hyperphysics.phy-astr.gsu.edu/ hbase/kinetic/watvap.html#c1)

Lab Section	Temperature Sensor Type	Ice Bath	Tap water	Boiling Water
2a.	K-Type Thermocouple Voltage, Random Reference Precision: $\pm$			
2b.I	K-Type Thermocouple Voltage, Ice Point Reference Precision: $\pm$			
2b.II Table Data	Temperature of K-type TC According to NIST Table			
2c.	K-type TC meter reading From Fluke TC Meter Precision: $\pm$			
3	RTD sensor resistance			

Table 2: Experimental Data

Sensor type	K-type bead	K-type probe	RTD Sensor
4. Settling Times, 95% change:			

Table 3: Settling times for readings

Notes:

MET 314LAB Applied Thermodynamics Lab
Lab 3: Pressure Measurements Lab

Objective: To compare some of the methods used to measure pressure, and gain familiarity with the different methods. Also to measure internal pressure in a latex balloon to get a intuitive sense of pressure.

Note: For all measurements, record data with appropriate significant digits. Also note the precision of the reading (ie, how sure are you of the last digit, +- 1 or +-5)

Equipment: Ashcroft 1305 Dead Weight Pressure Calibration Unit & calibration weights
Fluke Multimeter & PV350 Pressure Sensor
Fluke Process Calibrator & 700 series Pressure Sensor
Bourdon High Accuracy Mechanical Pressure gauge
Latex Balloons

Procedure: For this lab, a pressure calibration unit will be used to compare readings between a simple bourdon type pressure gauge and electronic pressure sensors used with a FLUKE voltmeter and Process Calibrator. The pressure calibrator has a piston with a precision ground diameter and a known mass, which generates a known pressure within the oil in the system. Adding weights increases the system pressure. You will then inflate a latex balloon and use the PV350 determine the internal pressure of the balloon.

1. Calibration of bourdon tube style pressure gauge using pressure calibration unit
   a. Remove excess weights and release all system pressure by opening release valve
   b. Note pressure reading on pressure gauges
   c. Close release valve on gauge calibrator and carefully pump fluid into pressure cavity until 5.0 psig calibrated pressure piston rises
   d. Release oil slowly through release valve until piston is **floating** in oil and not pushed against top stop or sitting against bottom seat. Gently spin piston to release any sidewall friction generated by O-ring seals that might affect the pressure reading
   e. The pressure will now be generated by the floating piston only, and is at the calibrated pressure indicated on the piston weight (5.0 psig)
   f. Record pressure reading on gauge and sensors, including uncertainty in reading
   g. Add calibration weights to piston and repeat steps c through f to get a new calibrated pressure for two or three additional pressure readings 20 psi to 120 psi

2. Internal Pressure of a Latex Balloon
   a. Plug in a pressure sensor attachment into a FLUKE multimeter and zero the reading
   b. Inflate a balloon and attach it to the pressure sensor
   c. Read and record balloon internal pressure
   d. Repeat steps b & c with same balloon inflated to larger diameter

Lab Report - Due in one week

Write individual report in Lab Report format (Cover page, introduction, procedure, data, results, discussion, conclusion, references & raw data). Address the following questions in the discussion section:

1. What is the accuracy of the bourdon tube pressure gauge? Is it precise?
2. What is the accuracy of the FLUKE electronic pressure sensor?
   Is it precise? Does it compare to the cal weight and the bourdon tube gauge?
3. Review equipment specs; Is the data within spec according to readings?
4. For a given balloon, does the diameter that it is inflated to affect the internal pressure?

Lab grading:		
	20	Format
	20	Grammar
	40	Technical Content
	20	Effectiveness
	100	Total

MET 314 Lab 3: Data Tables for Pressure & Density Lab

Calibration Pressure (Determined by weights) Accuracy:	0.0 psig			
Pressure Gauge Reading Accuracy:				
Fluke PV350 Transducer Reading Accuracy:				
Fluke 901 Process Calibrator Pressure Module Accuracy:				

Table 1: Pressure Measurement Experimental Data

Balloon Diameter				
Balloon Pressure				

Table 2: Balloon Pressure Data

MET 314 Applied Thermodynamics Lab
Lab 4: R134a Refrigerant Expansion Energy Balance

Objective

To perform an energy balance on a control volume from the R134a refrigerant under pressure in a "air duster" can. The escaping vapor takes energy with it as it leaves the system. Because the can is insulated, the energy absorbed to vaporize the liquid comes from the energy within the fluid & can, and reduces the temperature of the system. Based on the thermodynamic properties of R134a listed in Table A-11/12/16, these energy values can be calculated and compared.

Tasks

1. Measure the initial mass of the air duster can + valve + R134a, and an empty can & valve
2. Attach a bead style K-type thermocouple (or two) to the can with adhesive tape, about ½ to 1 inch from the bottom of the can (below liquid surface level)
3. Insulate the can with approx. 1 cm of polystyrene foam packaging sheeting or equivalent
4. Take initial temperature reading of can.
5. With can upright, open valve and blow off "air duster" for 30 - 60 seconds
6. Swirl can, watch & wait for temperature to stabilize at new value (approx 2 minutes) and take new temperature reading.
7. Measure final mass of can without thermocouple & insulation

Lab report: Due in 1 week. Include cover sheet, introduction, procedure, data, results, discussion, and conclusion sections, along with calculations in appendix. In the discussion section address the following questions:

A. What are the initial and final pressures in the can based on pressure data and R134a tables?
B. What is the "Quality" x of the liquid/vapor mixture in the can before and after the blow off (ie, what % of total mass is vapor)? Does this make sense? Discuss
C. Make a summary table in the results section showing total energy before and after:

	Initial	Final
R134a in can		
R134a cloud	0 (no cloud)	
ΔE Can & valve		0 (at low temp)
Total Energy		

D. What is the energy balance error as a % of the total initial energy calculated? What are some possible sources for this experimental error?

Lab grading:		
	20	Format
	20	Grammar
	40	Technical Content
	20	Effectiveness
	100	Total

Note 1: The proper chemical name for R-134a refrigerant is 1,1,1,2-tetrafluoroethane
Note 2: R134a is the most common replacement for R12 (dichlorodiflouromethane), a common refrigerant which was a major culprit in the depletion of high altitude ozone. R12 was banned in 1989 through an international treaty called the Montreal Protocol (see Wikipedia article about Montreal Protocol for more info). R134a has a high global warming potentiat (GWP) and is being replaced by R1234yf refrigerant in many applications

Typical Data Sheet for Lab3: Vaporization & Latent Heat of R134a Refrigerant

Data	Before Blow Off	After Blow Off
Temperature, T	25.6 C	-23.5 C
Internal Pressure (from table A-11/12/16), P	660 kPa	119.3 kPa
Total Mass of Can, Valve, & R-134a, M_1	425.2 g	326.6 g
Mass of Can (steel mass), M_2	98.0 g	98.0 g
Mass of Valve Assembly, M_3	98.2 g	98.2 g
Mass of R-134a Vapor & Liquid, M_4 $M_4 = M_1 - M_2 - M_3$	229.0 g	136.4 g
Volume of can (based on water weight), V	.000397 m3	.000397 m3
Enthalpy of Saturated Liquid, h_{liquid} (kJ/kg)	84.33 kJ/kg	19.91 kJ/kg
Enthalpy of Saturated Vapor, h_{vapor} (kJ/kg)	260.97 kJ/kg	233.16 kJ/kg
Enthalpy of vaporization, h_{fg} (kJ/kg)	176.6 kJ/kg	213.25 kJ/kg
Specific Volume of Saturated Liquid, v_{liquid}	.0008284 m3/kg	.0007304 m3/kg
Specific Volume of Saturated Vapor, v_{vapor}	.03075m3/kg	.1694 m3/kg
Calculations		
Actual Specific Volume, $v_{total} = V/M_4$ (m^3/kg)	.001754	.00291
Quality of Mixture, x (aka vapor mass %)	.0303	.0129
System Enthalpy per unit mass, h_{total}	89.688	22.66
Total Enthalpy in can, $H_{total} = M_4 h_{total}$	20.54 kJ	3.09 kJ

Formulas:

Can energy lost = mCp,steel(T1-T2) = 0.098 kg (0.500 kJ/kg-K) (25.6 - -23.5 C) = 2.405 kJ

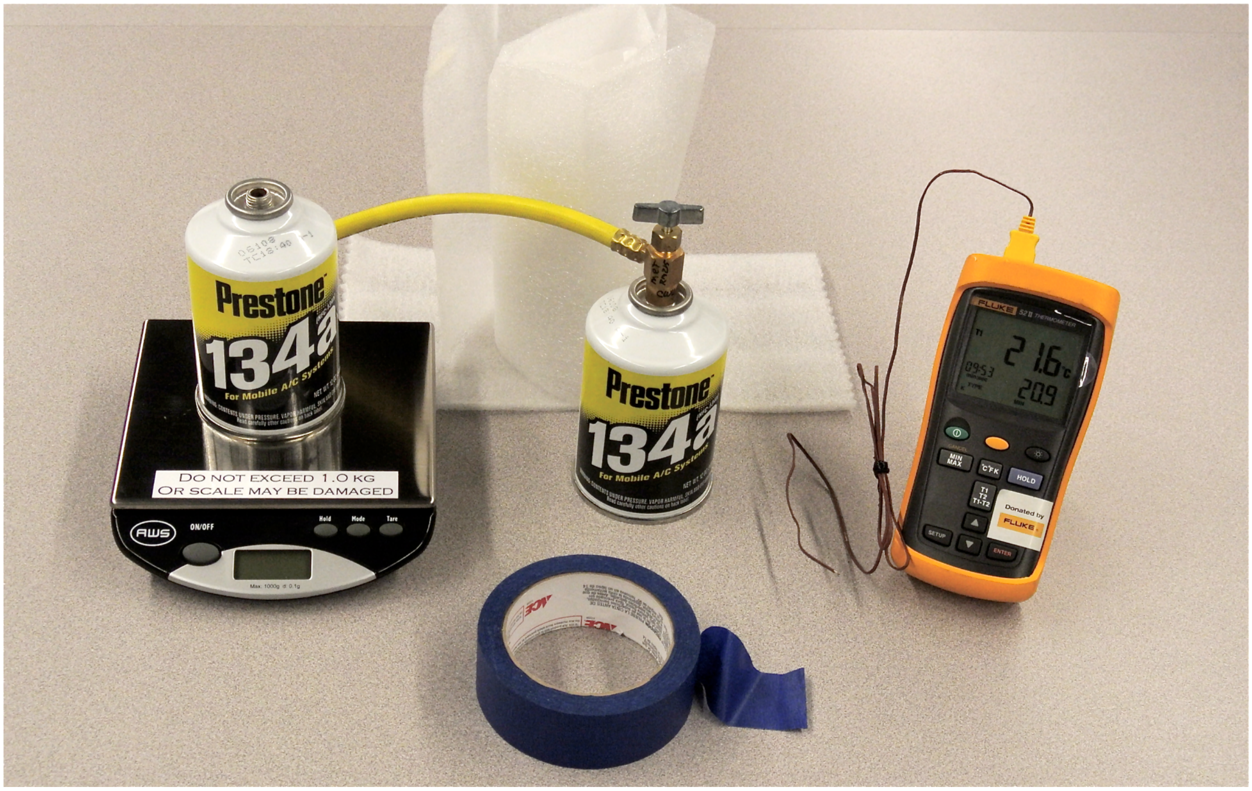
Valve Energy Lost = mCp,brass(T1-T2) = .0982kg (0.700 kJ/kg-K) (49.1C) = 3.375 kJ

------> note: get better values for valve & tubing M & Cp

Energy missing from can: dE = 20.54 - 3.09 kJ + 2.405 kJ + 3.375 kJ = 26.32 kJ

Energy carried away by Vapor = m_{vapor} h_g = 0.0926 kg (252.6 kJ/kg) + 3.09 = 26.49 kJ

Error in energy balance: (26.49 -26.32) /26.32 = 0.65 % Error



Refrigerant Energy Balance Lab Equipment

State	Temperature	R134a in can Total Enthalpy	R134a released Total Enthalpy	Can + Valve Energy	Total Energy Content
Before	+25.4 C	7.79 kJ	0 kJ	3.37 kJ	11.16 kJ
After	- 24.4 C	1.02 kJ	9.85 kJ	0 kJ (ref state)	10.87 kJ
				Total Energy Balance Error:	2.63% error

Energy Balance Lab Results 2010

State	Temperature	R134a in can Total Enthalpy	R134a released Total Enthalpy	Can + Valve Energy	Total Energy Content
Before	+25.6 C	20.54 kJ	0 kJ	5.78 kJ	26.32 kJ
After	- 23.5 C	3.09 kJ	23.4 kJ	0 kJ (ref state)	26.49 kJ
				Total Energy Balance Error:	0.65 % error

Energy Balance Lab Results **2008**

MET 314LAB Applied Thermodynamics Lab

Lab 6: System Efficiency for Air Motor powered Water Pump

Objective: The objective of this experiment is to determine the overall steady state efficiency of an air motor-gear pump system.

Equipment: Vane type Air Motor: WW Grainger pn 4Z231, Gast Model 4AM-NRV-130
Gear Pump for water: WW Grainger pn 1P777, TEEL brand
Pressure Meters1 FLUKE 701 Process calibrator with pressure module (psia)
2 FLUKE DMM plus PV350 pressure modules (water pressure)
Temperature meters: 2 FLUKE 52 two channel K-type thermocouple meter
Water & Air Variable Area Flow Meters of appropriate flow rate
Shaft RPM tachometer (SHIMPO reflective tachometer,)

Description: In this experiment, our system is a vane type air motor running on compressed air powering a gear pump to pump water. A valve on the outlet of the pump will produce a restriction and create a pumping load. Compressed air delivers energy to the air motor, turning the pump.

Each group will be assigned a shaft RPM to perform the lab with, ranging from approx 400 RPM to 1400 RPM. At the assigned RPM, each group will take data for pump pressures of 0, 20, 40, 60, and 80 psig. Each individual group will do a lab report for their own data set (RPM) only. The water pressure created by the pump x water volume flow rate is the power output. The change in enthalpy of the air determines the energy input to the system, Pwr in = $(dm/dt)(h_{out} - h_{in})$. A change in enthalpy for an ideal gas is $dh = C_p\, dT$. Your power units should eventually convert to Watts, even though the data is taken in english units.

For water pump, $Power_{out} = dW/dt = \Delta P\, (dVol/dt)$
$= $ (Pressure change of water) x water flow rate

For the air motor, $Power_{in} = dQ/dt = dm/dt\, ((h_{out} - h_{in}) = dm/dt\, \Delta h$
$= (Vol_{air}\, P_{abs,air} / R_{air}\, T_{abs,air}\,)\, C_{p,air}\, (\Delta T_{\text{air motor}})$

System efficiency $\eta_{system} = Power_{out} / Power_{in} = Power_{water} / Power_{air}$

Use values of $C_{p,air}$ and R_{air} from table A-2E, or other equivalent data source. The main issue for finding the energy flow is determining the mass flow rate of the air. The air volume flow rate is given by the exhaust flow meter, but the specific volume v is dependent on pressure and temperature.

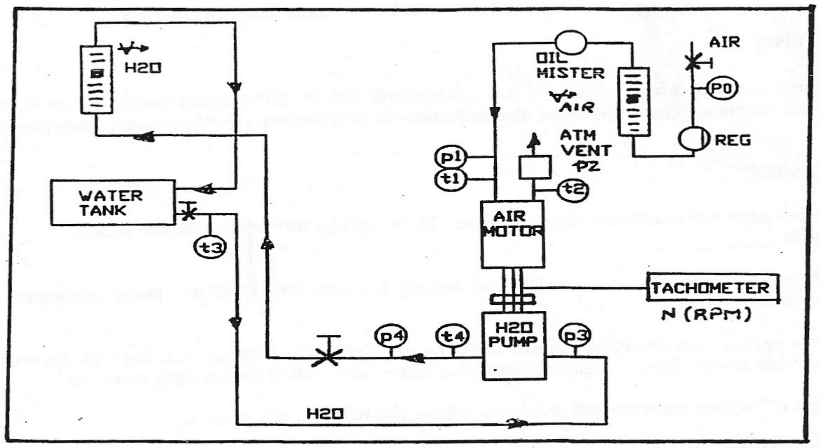
Lab Procedure: This lab requires a group of three (or more) to operate equipment, watch and read data, and record readings.

ATTENTION!: Do not exceed a maximum of 1600 RPM for this experiment.
ATTENTION!: Do not allow pump pressure to exceed 100 psi

1. Hook up water tank hoses to gear pump and compressed air source to air motor. Connect air motor Thermocouples (type K) to temp meter and pump pressure taps to pressure sensors. There

will be three temp measurements (Air motor in & out, air temp at air flow meter) and three pressure measurements (Pump in & out, absolute pressure at the air flow meter.

2. With pump outlet valve wide open, turn on air supply slowly to start pumping water through system with water outlet. Check for leaks and proper data equipment set up.



3. Follow instructions given for data to be taken by each lab group (each group will take readings for one RPM set point). Wait for temperature readings to stabilize before taking data for each data point (ie, let the system reach steady state (ie, data readings stable), approx 30-45 seconds or more). Take readings for RPM, water pump pressure in/out, water flow rate, air motor temp in & out, air volume flow rate, & air flow meter temp & pressure.

Lab Report: Due in one week. Write a lab report   (include cover sheet, introduction, procedure, data, results (with summary table & graph), discussion, and conclusion sections, raw data and calcs in appendix.

1. Calculate the power in and power out (in Watts), and net system efficiency for each data point.
2. **Summarize** these results in a table in the results section.
2. Graph $\text{Power}_{\text{out}}$ vs Power_{in} (y axis vs x axis) in Excel and insert graph image in results section.
4. Graph System Efficiency vs Power_{in} (y axis vs x axis) in Excel and insert graph results

In the discussion or results section, address the following questions:

a. Does the efficiency of the total system vary at the different data points?
b. Do you see trends in the data or calculations? Does the graph show efficiency?
c. What are some of the sources of error in this experiment?
d. Add any general observations about the experiment procedure or the results

Lab grading:	20	Format
	20	Grammar
	40	Technical Content (questions addressed, Pwr graph, results summary)
	20	Effectiveness
	100	Total

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	MET 314.109 Air Motor/Pump Lab data Nov 2011										RB	Nov	18.0	2011
2		<----------------- Experimental Data ---------------------------->										<------ Calculated Results --------		
3			psi				air	air	air			Air Motor	Pump	System
4		Shaft RPM	Pump c	GPM	Tin, C	Tout, C	CFM	Temp, F	P, psia		RPM	Power in	Power Out	Efficiency
5		400	0.79	1.05	22.3	17.4	2.3543	70.88	14.109		400	4.6	0.36	0.078
6	Group A	416	20.96	0.75	22.3	15	2.8252	69.98	14.145		416	8.3	6.84	0.820
7		402	40.6	0.5	22.1	12	4.1201	67.46	14.193		402	17.0	8.83	0.521
8		417	60.1	0.3	22	8.1	5.4444	64.22	14.267		417	31.2	7.85	0.251
9		401	77	0.15	21.9	5.4	6.4744	61.88	14.373		401	44.6	5.03	0.113
10							CFM	Temp, F	P, psia			Watts	Watts	
11		600	0.86	1.5	22.2	13.1	2.8841	66.74	14.123		600	10.7	0.56	0.053
12	Group B	622	20.7	1.3	22.1	10.5	4.0024	65.66	14.167		622	19.0	11.71	0.618
13		595	42.7	1.1	22.1	5.8	5.8858	63.14	14.297		595	39.7	20.44	0.515
14		603	60.1	0.9	22	4.3	6.3567	61.16	14.326		603	46.9	23.54	0.502
15		581	79.2	0.6	22	2.4	7.9459	58.28	14.515		581	66.1	20.68	0.313
16							CFM	Temp, F	P, psia			Watts	Watts	
17		799	0.5	1.85	22.3	11.8	3.5315	17.1	97.65		799	20.7	0.40	0.019
18	Group C	840	20.5	1.77	22.2	9.2	4.8264	17.5	98.08		840	35.2	15.79	0.449
19		790	40.35	1.4	21.9	4.7	5.5915	15.2	98.38		790	54.5	24.58	0.451
20		795	60.21	1.43	21.8	-1.8	9.2996	13.6	99.41		795	126.4	37.47	0.296
21		788	80.1	1.11	21.6	-1.3	8.9465	11.2	100.8		788	120.7	38.69	0.321
22		Shaft RPM	Pump c	GPM	Tin, C	Tout, C	CFM	Temp, F	P, psia		RPM	Power in	Power Out	Efficiency
23		1005	3.3	2.4	21.3	6	5	17	98.02		1005	42.9	3.45	0.080
24	Group D	1070	20.64	2.3	21.4	4.6	7	16.2	98.7		1070	66.6	20.66	0.310
25		1030	40.2	2	21.2	1.6	8	15	99.3		1030	89.8	34.99	0.390
26		997	60.2	1.7	21.2	-1.2	9.2	13.9	100		997	119.3	44.54	0.373
27		1014	79.65	1.55	21.2	-4.2	11	11	101.5		1014	165.8	53.73	0.324
28							m3/hr	deg C	kpa			Watts	Watts	
29		1152	3.98	2.65	21.6	6.7	5.2	11.9	98.14		1152	44.3	4.59	0.104
30	Group E	1163	24.83	2.45	21.7	3.6	7.1	12.1	98.9		1163	74.0	26.47	0.358
31		1146	45.31	2.15	21.6	0.7	8.7	11.9	99.9		1146	105.9	42.39	0.400
32		1165	65.56	2	21.4	-2.7	10.8	10.8	101.48		1165	154.5	57.06	0.369
33		1170	84.78	1.85	21.3	-4.8	12.1	10	103.35		1170	191.5	68.25	0.356
34							m3/hr	deg c	kpa			Watts	Watts	
35		1304	1.35	3	21.6	3.7	7	13.4	98.6		1304	71.6	1.76	0.025
36	Group F	1306	21.1	2.7	21.3	1	8	12.1	99.34		1306	94.0	24.79	0.265
37		1317	40.97	2.6	21.3	-1.8	9.5	11.4	99.9		1317	128.0	46.36	0.364
38		1290	60.7	2.3	21.2	-4	11.1	10.5	101.9		1290	166.9	60.75	0.365
39		1306	80.6	2.2	21.3	-8	19	7.8	105.3		1306	346.6	77.16	0.224
40							m3/hr	deg C	kpa					
41		1450	1.72	3.3	21.3	0.8	8.7	11.8	99.78		1450	60.8	2.47	0.041
42	Group G	1450	21.5	3.15	21.2	0.2	9.2	11.3	100.2		1450	66.2	29.47	0.445
43		1450	41.3	3	21.3	-2.2	10.5	10.2	101.37		1450	85.9	53.92	0.628
44		1450	61.1	2.8	21.1	-4.8	11.2	9.1	103.35		1450	103.4	74.45	0.720
45		1450	84.9	2.5	21.1	-7.6	13.9	5.9	106.3		1450	147.9	92.36	0.625
46												Units = Watts		

Typical data & results from MET314 System efficiency lab

Name: ______________________________

MET 314L Applied Thermodynamics Lab
Lab #8: Air – Fuel Worksheet

1. Balance the equation for burning hydrogen and oxygen:

_______ H_2 + ______ O_2 $\rightarrow$ _______ H_2O

2. Balance the equation for burning H_2 in air: (Note: on molar basis, air has 79 N_2 : 21 O_2)

_____ H_2 + _____ O_2 + __________ N_2 $\rightarrow$ ________ H_2O + ______N_2

3. Balance the equation for burning Propane and air:

_______ C_3H_8 + ______ O_2 + _____ N_2 $\rightarrow$ ______ CO_2 + ______H_2O + ________N_2

4. Air Mass/Fuel Mass ratio for Propane Combustion Equation (stoichiometric equation)

5. Balance the equation for burning Iso-octane (1,3,5 isopentane) in air:

________ C_8H_{18} + ______ O_2 + ______ N_2 $\rightarrow$ ______ CO_2 + ______H_2O + ________N_2

6. Find Air/Fuel mass ratio for Iso-octane combustion equation (stoichiometric equation)

MET 314 Applied Thermodynamics Lab

Lab #7: Boiler Plant Visit

Objective: To observe the operation of the boiler in the CWU centralized heating/cooling plant and learn about the various systems in an operating plant. Meet at 3:00 pm at the door to the campus boiler plant, in the parking lot across from (west of) the new science building, near the shipping/receiving dock. (in case of rain, meeting place will be the foyer of New Science).

Tasks: Observe the different heating and cooling systems in the boiler/chiller plant and note operating pressures, temperatures, etc, total energy usage, etc, especially

Steam supply to campus: Pressure/Temperature? Saturation state or superheated?
Boilers: How many at what output capacity?
Chiller plant: what is the refrigerant used?
Chiller compressors: How many at what capacity? What is the campus total capacity?
Thermal Storage Unit: What is it? How big? What is the advantage?

Lab Report in single page Memo format : Due in one week

Write a memo-type lab report (one page) addressed to me. The context: you are evaluating the capacity and equipment of the CWU system as part of the process for comparing alternatives. The memo should be brief but address the questions below. You may also add any other information you discover on the tour that you find interesting. Add a sheet of hand calculations to support any of your data as an appendix. Questions to address in your memo are :

1. Is the main steam line operating near saturation point, or does it transport superheated steam?
2. What are the temperatures & pressures involved in the steam system?
3. What is the energy source for the boilers? Is there only one source?
4. What mass rate of steam can be produced by the plant? How many BTU/hr?
5. Does all the combustion energy get absorbed heating the steam? What efficiency?
6. What is the chiller plant capacity in tons of regrigeration? in BTU/hr?
7. What is the point of the thermal storage unit? How much can it store (in BTUs)?

Note: Lab reports should **not** have references to your impressions and opinions ("I saw the temperature rise some when I closed the valve a little more"), but should report facts as you find them ("The fluid temperature increased as the valve was closed as shown in Table XX"). However it is appropriate to summarize your opinions of what you see in the conclusion a trip report memo.

Lab grading:	4	Format
	4	Grammar
	8	Technical Content (questions addressed)
	4	Effectiveness
	20	Total

MET314 Thermodynamics Lab Assessment Survey Document

MET314 Thermodynamics Lab Survey - This survey seeks your anonymous response to questions about the lab activities you participated in. Please review the list of labs and the objectives for each lab to remind yourself about the lab topics, then take survey that follows. Thank you for participating.

Lab Activity Titles	Work Product
1. Energy Calculations	Technical Memo
2. Temperature Measurements	Lab Report
3. Pressure Measurements	Lab Report
4. R134a Energy Balance (Group Lab)	Lab Report
5. Air motor/Gear Pump System Efficiency	Lab Report
6. Air/Fuel Ratio Lecture and Worksheet	Worksheet
7. Central Boiler/Chiller Plant Tour	Trip Report Memo

Lab 1: Energy Calculations
Objective: The objective of this activity is to gain an awareness of electrical energy consumption of common objects and activities (ie classroom lights and shower), and to gain experience in taking data and applying data to develop cost estimates.

Lab 2: Temperature Measurements (Zeroth Law Experiment)
Objective: To gain insight into temperature sensor characteristics, including output characteristics and settling times. (ie, type K thermocouple and RTD sensor outputs)

Lab 3 - Pressure Measurements Lab
Objective: To compare mechanical and electronic methods used to measure and calibrate pressure (ie, dead weight tester & electronic sensors). Using a pressure sensor, determine the internal pressure in a latex balloon.

Lab 4 - R134a Energy Balance (First Law Experiment)
Objective: The objective of this lab is to analyze the first law energy balance of a container of R134a refrigerant.

Lab 5 - Air Motor/Gear Pump Lab (System Efficiency Experiment)
Objective: To calculate the power input, power output, and system efficiency of a water pump driven by an air motor.

Lab 6 - Air-Fuel Worksheet
Objective: To introduce combustion chemistry, balance stoichiometric combustion equations, and use that information to calculate stoichiometric air/fuel mass ratios.

Lab 7 - Central Boiler Plant Tour
Objective: To expose students to the scale of large industrial equipment used for steam production and refrigeration in HVAC applications.

MET314 Lab Survey

For the following statements, please circle the number that best reflects your opinion.
A value of 1 means you strongly **disagree** with the statement;
A value of 5 means you strongly **agree** with the statement.

	Disagree Agree
A. Lab 1: Finding the cost of electricity for lighting and a shower was a good way to practice energy conversion calculations	1 2 3 4 5
B. Lab 1: Calculating the cost of a shower is **not** relevant to engineering thermodynamics	1 2 3 4 5
C. Lab 2: Measuring the outputs of the thermocouple & RTD at different temperatures gave me a better understanding of how temperature sensors work	1 2 3 4 5
D. Lab 3: Using the dead weight tester with the pressure gauge and electronic sensors gave me valuable experience with pressure instrumentation equipment	1 2 3 4 5
E. Lab 4: The R134 lab is a good exercise for analyzing the energy balance of a thermodynamic process	1 2 3 4 5
F. Lab 4: Calculations performed in this lab to determine thermodynamic property values gave a practical context for those concepts	1 2 3 4 5
G. Lab 4: The lecture homework problems assigned were enough to learn about thermodynamic properties, and the R134 lab didn't teach me anything useful	1 2 3 4 5
H. Lab 5: Calculating the power input to the air motor improved my understanding of energy calculations for ideal gasses (ie compressible fluids)	1 2 3 4 5
I. Lab 5: Calculating the power output of the gear-type water pump improved my understanding of energy calculations for incompressible fluids	1 2 3 4 5
J. Lab 5: Determine the system efficiency for the air motor/water pump system helped give context to the thermodynamic calculations for power in and out	1 2 3 4 5
K. Lab 5: The air motor lab does **not** seem relevant to the study of thermodynamics and should be discontinued	1 2 3 4 5
L. Lab 6: The air fuel ratio worksheet was interesting and should be expanded	1 2 3 4 5
M. Lab 6: The air fuel ratio worksheet didn't teach me anything useful and should be replaced.	1 2 3 4 5
N. Lab 7: Energy calculations for the central boiler / chiller plant helped tie textbook concepts to real world applications	1 2 3 4 5
O. Lab 7: The boiler plant tour was a waste of time and should be replaced	1 2 3 4 5

Comments: