Enhancement of the Engineering Measurements Laboratory for Semester Conversion

Dr. Michael J. Schertzer, Rochester Institute of Technology

Michael J. Schertzer received the Bachelor of Engineering and Management and Master of Applied Science degrees from the Department of Mechanical Engineering at McMaster University in Hamilton, Ontario, Canada. He earned his Doctorate in the Department of Mechanical and Industrial Engineering at the University of Toronto for his work characterizing the motion and mixing of droplets in Electrowetting on Dielectric Devices. Before joining the Mechanical Engineering Department at RIT, Dr. Schertzer held a Postdoctoral Fellowship in the Department of Mechanical and Industrial Engineering at the University of Toronto where he focused on integrating his individual contributions into a point of care medical diagnostic device. During this time, he also had the opportunity to collaborate with a small medical diagnostic company in the Toronto area while examining surface tension related phenomena in DNA Microarrays.

Dr. Schertzer has had the opportunity to develop relationships that have led to research contracts and grants with companies and governmental organizations in Public Health, Medical Diagnostics, and Large Scale Fluid Dynamics for Applications in Power Generation. He hopes to continue his experiences in collaborative research by developing relationships with academic and industrial partners in and around RIT.

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Abstract

This work will discuss the enhancements made to the Engineering Measurements Laboratory at the Rochester Institute of Technology during a conversion from a quarter-based to a semester-based calendar. This conversion increased the duration of the course from 10 to 15 weeks. As a result, the syllabus was expanded to include an additional independent study lab that focused on experimental design. In this independent study, students were tasked with the characterization of a system by (1) identifying a practical real world engineering system, (2) performing multiple experimental trials under multiple operating conditions, and (3) analyzing the results. The addition of multiple data sets at multiple conditions gave students an appreciation for statistical analysis of measurement uncertainty and repeatability. In addition to the change in the content of the course, the Toyota A3 report format was used for all labs to expose students to a wider variety of tools for technical communication and to foster a spirit of creative and innovative problem solving. This paper will present data regarding student performance, feedback from students and instructors, and recommendations for similar efforts.

Introduction

A recent change from quarters to semesters for the beginning of the 2013 academic year provided an opportunity for a critical review of all courses in the Mechanical Engineering curriculum at the Rochester Institute of Technology (RIT). Thermal Fluids Lab I was one of the courses that received significant modification. In previous offerings, this course consisted of four guided labs. Material for each lab was delivered in a two-week cycle where a lecture on theory was presented in week one and students performed the lab in week two.

The change to a semester-based system increased the number of weeks in the term from 10 to 15, which allowed for the introduction of new material to the course. It was decided that the new material should give students the opportunity to design their own laboratory experiment. The goal of this independent study would be to (1) identify a practical problem, (2) develop and commission a test facility, and (3) analyze experimental results. It was the hope of the instructors that this exercise would give students practical experience in problem solving while providing hands-on experience in experimental investigation. The focus of the independent study was to design a test facility, determine the measurements necessary to validate a hypothesis, and examine the uncertainty and repeatability of the experimental data. The name of the course was changed from Thermal Fluids Lab I, to Engineering Measurements Laboratory to reflect this additional focus. The enhancements to Engineering Measurements Lab provide more extensive preparation for higher-level courses where students are responsible for modeling a physical system, designing an experimental test facility, and comparing empirical and theoretical results.

Technical communication skills are often cited as one of the most desirable hiring criteria for graduates of engineering programs in the United States[1,2]. The changes to the Engineering Measurements Lab provided an opportunity for the instruction team to examine the tools for technical communication that were used in the course. An A3 reporting format was instituted in the course. A3 reports are used as the standard reporting format at Toyota Motor Corporation and consist of a single-sided A3 paper (11.7" x 16.5")[3,4]. The limited footprint available in these reports requires that authors summarize critical ideas in a project in a clear and concise manner. This forces students to develop concise, high-quality figures that convey their message with little or no text. In an effort to give students the opportunity to develop the iterative problem-solving skills often associated with A3 reports[3], a peer feedback process was also introduced. On the day before the final reports were due, draft reports for each group were circulated in their section to receive written peer feedback on the form provided in Appendix A. It is the hope of the instruction team that having the opportunity to give constructive feedback will improve critical thinking skills.

Student feedback on course enhancements was collected in a survey at the conclusion of the semester. Students were given a series of statements and asked to provide their opinion using a Likert scale. The results presented here are based on 52 responses. The questionnaire is included as Appendix B.

Lab Experiments

After an introduction to measurement accuracy, error estimation, and error propagation, the students performed four guided experiments initially developed for the course. Material for each experiment was delivered in a two-week cycle where a lecture on theory was presented in week one and students performed the lab in week two. Teams of 2 or 3 students conducted the experiments in a 2-hour session. Table 1 lists the lab experiments and schedule for the semester.

Each investigation emphasized a concept from thermodynamics or fluid mechanics, as well as a concept or purpose of experimentation. The Vortex Tube Characterization explored the utility of empirical studies in the absence of complete theoretical explanations (Fig. 1). As such, emphasis was placed on the proper presentation and interpretation of the measured and reduced data. Temperatures and flow rates were measured for a variety of operating conditions set by system pressure and cold-side mass flow rate, and the corresponding cooling capacities were calculated.

Table 1: Lab Experiments and Schedule for the Semester

Week	Experiment
1	Course introduction and measurement accuracy and error estimation
2&3	Vortex Tube Characterization
4&5	Vapor-Compression Refrigeration
6&7	Centrifugal Pump Rig
8&9	Reynolds Pipe Flow
10&11	Independent Study proposal
12&13	Independent Study Experiments
14	Independent Study A3 report
15	Presentation

In the Vapor-Compression Refrigeration experiment (Fig. 2), theoretical idealizations were reconciled with the actualities of real systems. The typical thermodynamic analysis of the refrigeration cycle is quite basic, with only four highly idealized components, four state points, and two main system pressures. In contrast the real system was instrumented with 14 thermocouples, four pressure gages, and a variety of other instruments for characterizing the performance. The students were tasked with reconciling the larger set of information against the simpler theoretical model, in the interests of retaining the latter's descriptive parameters such as coefficient of performance and isentropic compressor efficiency.

In the Centrifugal Pump Rig investigation (Fig. 3), students explored the performance of two identical centrifugal pumps when operated either independently, in series, or in parallel. In each scenario, the pumps were operated over the full available range of flow rates by use of throttle valves, and the corresponding pressures were measured, in order to generate curves of developed head vs. flow rate. As part of the submitted report, students were tasked with creating a descriptive explanation of how to run the experiment, given the plurality of valving and so forth required for switching between scenarios. Thus, the creation and description of experimental

Figure 1: Vortex Tube Experiment

Figure 2: Vapor-Compression Refrigeration Experiment

protocols were explored as another aspect of experimentation in an engineering context. Also, instrument errors were formally developed, and basic error propagation was used to characterize measurement uncertainties in calculated results.

Finally, in the Reynolds Pipe Flow experiment (Fig. 4), classical concepts of pipe flow were explored: laminar and turbulent flows, fully-developed pressure drop, entrance lengths, and velocity profiles. Students measured pressure distribution along a pipe for low and high flow rates of a Shell carnea oil. To fully characterize the system, oil density, viscosity, and weight flow rate were also measured. All measurements were made with accompanying uncertainties, and all calculations were made with propagated errors (and there were quite a few calculations to make, of various levels of difficulty). This investigation is arguably the most important of the course, as it develops a complete ability to detail and comprehend the uncertainties in measurements, and the subsequent effects on analyses that utilize the measurements.

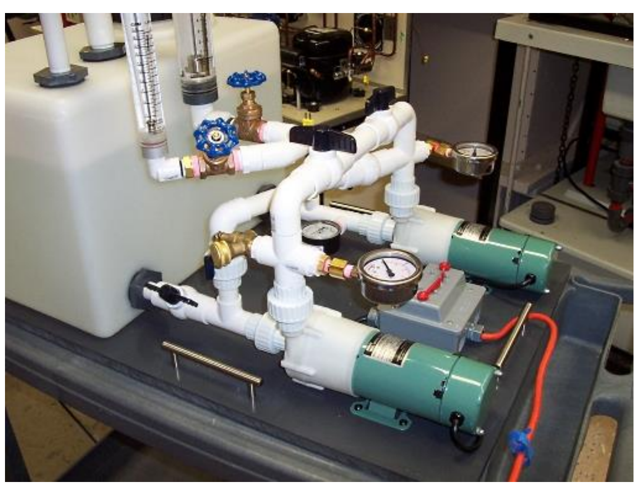

Figure 3: Centrifugal Pump Experiment

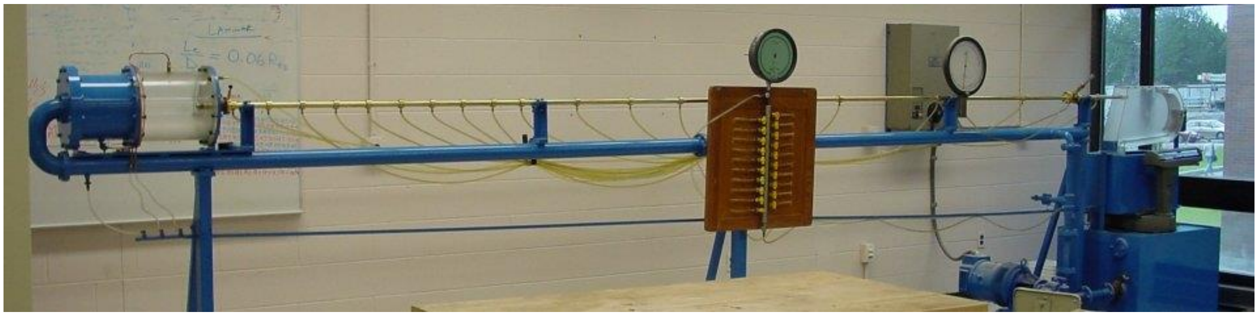

Figure 4: Reynold's Pipe Flow Experiment

At the end of each experiment, each group of students prepared a laboratory report for each investigation following an A3 reporting format that emphasized specific deliverables in each case (some as indicated above). The final component for each lab included peer-reviewed sessions where students were commenting on other students' work.

Independent study

The last six weeks of the semester were dedicated to an independent study (Table 1). For this project, the students worked in groups of two, three, or four to identify a system, device, or component to study by commissioning a test facility and making detailed measurements of the operation. The goals of this final experiment were:

- to independently apply the principles from the previous investigations,
- to gain experience in the concepts of experimental design, and
- to prepare students for the follow-on course of Engineering Applications Laboratory. The latter course is structured entirely around testing and analysis of a system as well, but in a much more detailed fashion, and with a theoretical model that is entirely student-developed and comprehensive.

Each group of students had to generate an initial proposal that included the following information:

- A description of the system.
- A detailed discussion of the basic concepts (simplified theory) of the system.
- A list of resources needed for the project.
- A timeline of the steps required to complete the testing, including a delineation of which group member would work on which steps.

Feedback on the initial proposal was provided based on project feasibility and group preparedness. In the event that an initial proposal was insufficient or infeasible, the instructional team assigned a project topic to the group. All groups were expected to generate a final proposal addressing instructor feedback. The second submission of the proposal document was graded for content and further changes to the scope of work had to be approved by the instructional team.

Each group of students had two weeks to develop a test facility, collect the data, and analyze experimental results. Each group prepared and presented an A3 report, similar to the previous investigations for the course, which summarized the key concepts, findings, comparisons, and conclusions from the project. An initial draft of the report was peer-reviewed in class following the critique process outlined in Appendix A. Following peer review, each group developed a final version to make a presentation to the class during the appropriately scheduled time within the last week of the semester.

A list of independent study topics covered in this course is included in Table 2 and sample reports for independent study projects are also provided in Appendix C.

Table 2: Independent Study Laboratory Topics

Group	Independent Study Topic
1	NeverWet's Effect on Buoyancy
2	NeverWet's Buoyancy in Tap Water vs Salt Water
3	NeverWet's Effectiveness vs Water Temperature
4	NeverWet's Buoyancy in Different Density Liquids
5	Pipe Flow Velocity Profile Project
6	Heat Transfer Coefficients
7	Energy Loss in a Spring
8	Reynold's Pipe Flow Transition Region Project
9	Buoyancy Force Test
10	CPU Heat Dissipation
11	Quantification and Analysis of Material Specific Heat
12	Convection Coefficient Measurement
13	What is the fastest way to cool a soda?
14	Vapor-Compression Refrigeration System
15	Drag Coefficient Experiment
16	Water Impact Experiment
17	Raoult's Law for Non-Ideal Fluids
18	Manometer Dynamics

Pictures of the experimental facilities of the independent study projects of the fall semester 2013 can be found in Appendix D.

Assessment

The Engineering Measurements Laboratory was offered in the fall semester of 2013. A total of 55 students took the course. The following section outlines some comments and assessment results from these students regarding the course.

Most of the students (73%) agreed that the independent project added significant value to the course and 77% agreed that the guided lab experiments helped them design their own laboratory experiment (Fig. 5). This suggests that the independent study was a valuable experience and should be retained in future offerings.

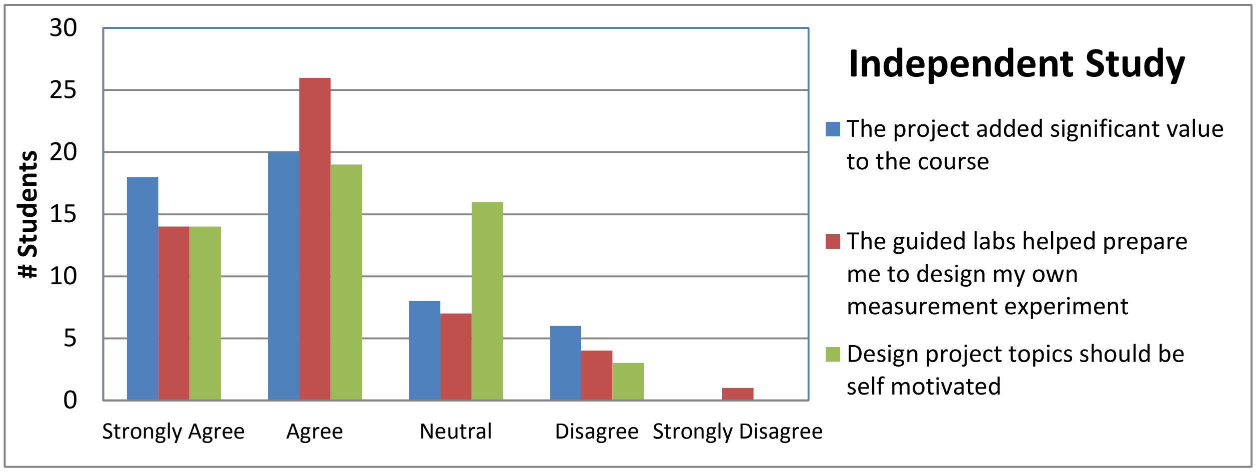

Figure 5: Results regarding the independent study.

The instructional team also solicited feedback on whether project topics should be assigned or developed by student groups. Only 6% of respondents reported that they would prefer assigned topics.

Group Dynamics

Twenty groups of randomly assigned students were created over five laboratory sections. The dominant group size was 3 students, with occasional groups of 2 based on section size. The groups were not given guidelines for breaking up work load, ice breakers, or training on how to work well within a group.

While the majority of the groups worked well together, approximately 25% of students experienced group dynamics issues that persisted beyond the initial lab report. The issues were great enough to pursue changes to the grading structure. A grade item was added to push a greater emphasis on personal responsibility and the number of graded events per lab investigation was increased from one to three to improve engagement. While a plurality of students were neutral regarding these additions to the course, the instructional team believes that

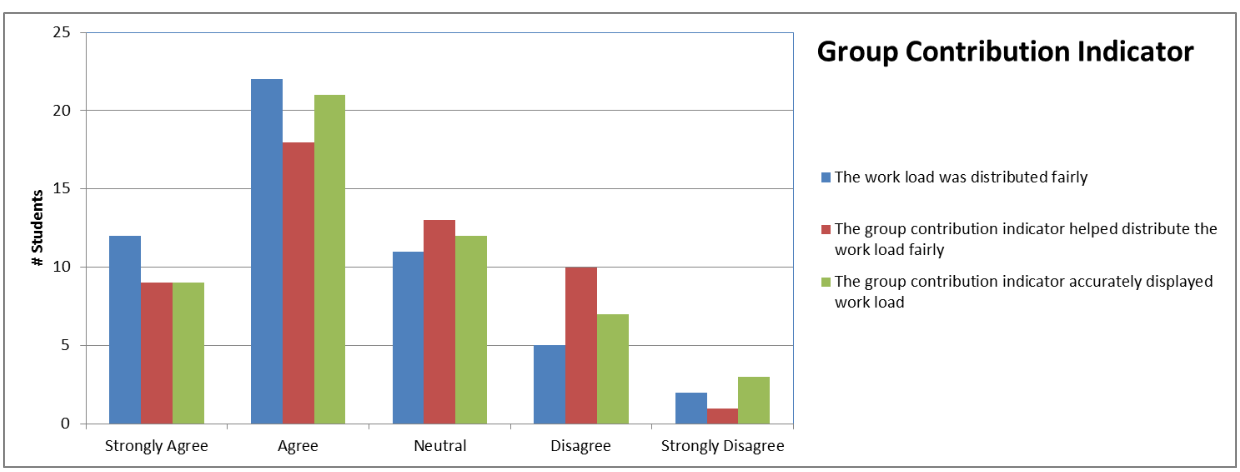

Figure 6: Results regarding the group contribution indicator.

their addition could benefit groups that experience difficulties during the semester.

In an effort to get the groups to be forthcoming on how they were working throughout the course rather than just a survey at the end of the course, the instructional team asked that each report include a group contribution indicator. It was up to the group to decide how to represent their contributions, and what it would be based on. No units or values were required, simply an image. Many groups chose to use a pie graph, although others used a bar graph.

Survey results regarding group contribution are presented in Figure 6. The majority of the students reported that the work load was fairly distributed (65%). Most students (53%) reported that including the group contribution indicator helped with the work load. The implementation seemed to go fairly smoothly. While the minority, the instructional team was surprised to see that 3 students strongly disagreed and 7 disagreed (combined 19% of the class) that the group contribution indicator was accurate representation of work load.

A3 Reports

End of semester surveys were also used to gauge the effectiveness of the A3 report format in this course (Fig. 7). In general, the implementation of this report type was well received with the majority of students finding that:

- they were a good way to convey results (92%),
- adequate information could be provided (87%),
- they were an industry standard tool they were likely to see again (70%),

The majority of students preferred the A3 report format to traditional reports (87%) and felt that using this report format helped them prepare better figures (81%) and focus on key results (86%)

Students were also asked for their feedback on the peer review process. The instructional team is considering grading the A3 draft reports and peer feedback provided on draft reports in an effort to improve preparedness. Interestingly, while the majority of students agreed that giving (88%) and receiving (75%) peer feedback was beneficial, only 17% felt that this feedback should be

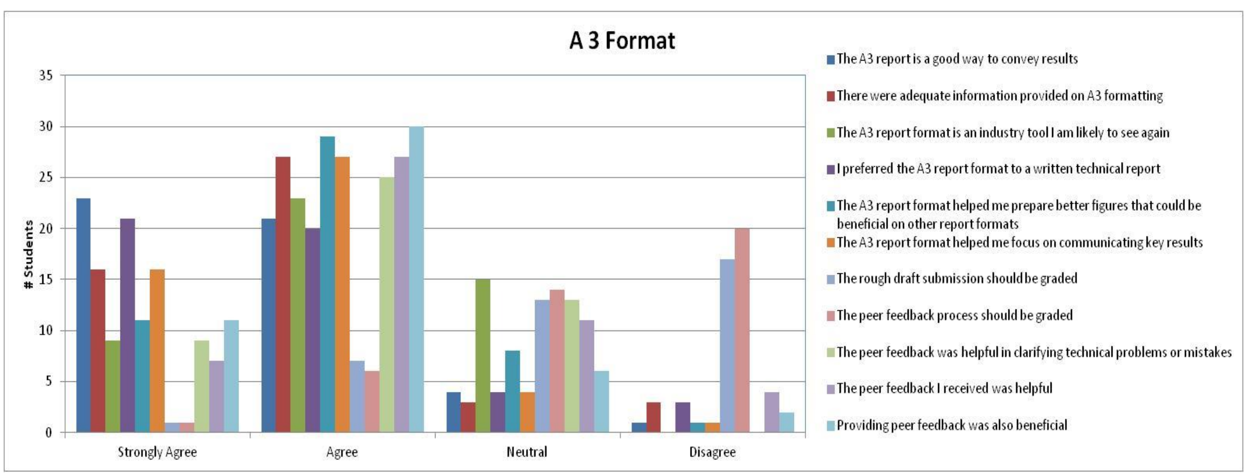

Figure 7: Results regarding the A3 report format.

graded. This suggests that students felt that the feedback they received was sufficient to be beneficial. That only 14% of students wanted the draft A3 reports graded also suggests that they found the peer feedback to be beneficial.

Conclusions

This work examined the effectiveness of enhancements made to the Engineering Measurements Laboratory during a conversion from a quarter-based to a semester-based calendar. The introduction of both the A3 report format and the independent study were well received by students in the course. Students preferred the A3 format to a traditional lab report and felt that it allowed them focus on creating high quality figures that highlighted key findings of their experiments. The majority of students felt that the independent study added value to the course and that the guided labs adequately prepared them for designing their own experimental facility. The instruction team felt that these additions to the course allowed students to develop technical and communication skills that will better prepare them for higher level engineering courses.

Although the additions to the course were generally well received, a portion of the class reporting experiencing issues related to team dynamics. This prompted the instruction team to require that all reports include a graphical group contribution indicator. While a majority of students felt that this addition helped balance the workload between group members, some felt that the published indicator did not accurately portray individual contributions. The instruction team is currently examining strategies to improve team dynamics in future course offerings.

Acknowledgements

The authors acknowledge the financial support received for this work from the Rochester Institute of Technology. They also acknowledge the use of the images from projects in the class (Appendix D).

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Appendix A: Peer Review Form

Author Group:________________

What is the first thing you notice about this report?

____

Content

Is the report technically sound? If no, why not? _____ Yes _____ No

Has the report sufficiently addressed the detailed outcomes listed in the problem statement? If no, why not? _____ Yes _____ No

Structure

How would you rate the overall organization of the report?
_____ Satisfactory _____ Could be improved _____ Poor

Are the theory and background satisfactory?
_____ Yes _____ No (explain)

Are symbols, terms, concepts and equations adequately defined? If not, please identify items that require further definition.
_____ Yes _____ Not always _____ No

Detailed Comments

Please use this space to explain overall ratings or to go into further detail on ratings from the Content and Structure sections.

____
____
____
____
____
____
____
____

What aspect of this report was done very well?

____
____
____
____
____
____

Appendix B: Student Feedback Survey

ENGINEERING MEASUREMENTS LAB SURVEY

Please provide your thoughts on some of the novel aspects of this lab.

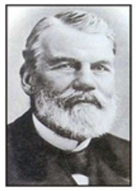
Statement	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
A3 Report					
The A3 report was a good way to convey results.					
There was adequate information provided on A3 formatting					
The A3 report format is an industry tool I am likely to see again.					
I preferred the A3 report format to a written technical report					
The A3 report format helped me prepare better figures that could be beneficial on other report formats.					
The A3 report format helped me focus on communicating key results.					
The rough draft submission should be graded					
The peer feedback process should be graded					
The peer feedback was helpful in clarifying technical problems or mistakes					
The peer feedback I received was helpful					
Providing peer feedback was also beneficial					
Team Dynamics					
3 person teams is the proper size					
A team building exercise would be beneficial					
The group contribution indicator accurately displayed work load.					
The work load was distributed fairly					
The group contribution indicator helped distribute the work load fairly.					
My team would have benefited from a designated team member responsibilities.					
Individual contribution should be a significant portion of the grade (~25%).					
I was adequately prepared coming into lab time.					
Design Project					
The project added significant value to the course.					
The guided labs helped prepare me to design my own measurement experiment					
Design project topics should be self motivated					

What aspects of the course were done well?	What aspects could be done better?

Appendix C: Sample Independent Study Reports[5,6]

Raoult's Law – Student Driven Project

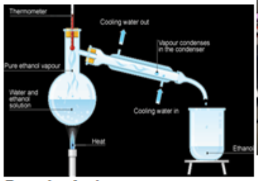
Assumptions:
1.) No leaks in system
2.) No heat loss
3.) Pure distilled water and 200 proof ethanol

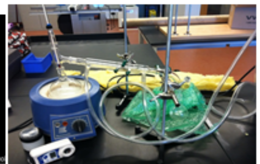


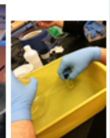
December 4 2013

Background & Importance:

Raoult's law of Thermodynamics states that the vapor pressure of an ideal solution is directly dependent on the vapor pressure of each chemical component and the mole fraction of the component present in the solution. In this experiment Raoult's law is disproved by means of a non-ideal solution: ethanol and water. A still will be utilized in order to physically separate the mixture of these two liquids based on volatility. The non-ideal mixture will boil in a round-bottom flask. As it boils, a vapor of a different mole fraction evaporates out and passes through the condenser where it liquefies. The mole fraction will increase in the more volatile compound, A. The ratio of the two liquids remaining in the initial flask has changed from its original. The ratio of the liquid mixture is changing due to the still and will result in a richer liquid in compound B, the resulting liquid once condensed.







Data Analysis:

Water	Ethanol	R.I.	Fraction	Fraction	Solution Dilution (R.I.)
(mL)	(mL)	(Brix readings)	wt% EA	mol % EA	1 mL Solution +2 mL water
10	0	0	0.00	0.00	-
10	2	6.2	0.14	0.06	-
10	4	11	0.24	0.11	-
10	6	14	0.32	0.16	-
10	8	15.7	0.39	0.20	5.8
10	10	16.8	0.44	0.24	6.3
8	10	17.7	0.50	0.28	6.6
6	10	18.7	0.57	0.34	7.3
5	10	19.2	0.61	0.38	7.8
4	10	19.6	0.66	0.44	8.6
3	10	19.9	0.72	0.51	9.3
2	10	20.1	0.80	0.61	9.9
1	10	19.8	0.89	0.76	10.5
0	10	18.3	1.00	1.00	

$$\log_{10} p^* = A - \frac{B}{T + C} \qquad p^* \text{ in mm Hg}, \quad T \text{ in °C}$$

$$x = \frac{P - P_2^*(T)}{P_1^*(T) - P_2^*(T)} \qquad y = \frac{xP_1^*(T)}{P}$$

Equations Used:

$$T_{boiling} = \frac{B}{A - \log_{10} P} - C$$

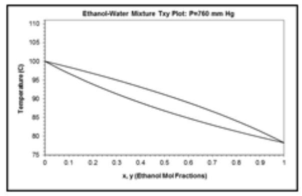
Antoine Equation Constants				
Component	Name	A	B	C
1	Ethanol	8.1122	1592.864	226.184
2	Water	7.96681	1668.21	228

- Interpolated to find mole fraction when needed

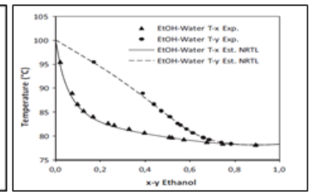
Sources of Error:
- Ethanol evaporates easily
- Residue possibly left behind from other experiments
- Possibly using an incorrect pipette to transfer fluids
- Results being compared to performed on distillation tower, ours on different distillation apparatus, could yield different results

Procedure:
1. Take 100 mL of water to 200 mL of ethanol
2. Mix in large 500 mL beaker
3. Using plastic pipette, remove 1 mL and place onto Refract meter. Measure refractive index
4. Compare to known value, if corresponds continue
5. Pour mixture into the large round bottom flask inside of *Electromantle*
6. Turn on water source.
7. Turn on heating device by moving the dial to highest setting – 10
8. Read thermometer – (23 °C) Read pressure gauge in the room (1 atm)
9. Boil until the mixture vaporizes and then condenses in the second beaker (80 °C). Wait until at least 3 mL have accumulated in the second beaker.
10. Remove second beaker. Transfer liquid to a vile.
11. Cool down for 5 minutes in a container of cold water. Use plastic pipette to collect 1 mL sample and place onto Refract meter. Measure refractive index
12. Remove 1 mL of solution from the sample vile and place into vile 2.
13. Add 2 mL of distilled water to vile 2 and mix together.
14. Use plastic pipette to collect a1 mL sample from vile 2 and place onto Refract meter. 15. Measure refractive index of diluted sample.
16. Remove large round bottom flask and pour liquid into a large beaker. Add 100 mL of distilled water to the beaker and mix.
17. Repeat steps 3 through 15.
18. Remove large round bottom flask and pour liquid into a large beaker. Add 100 mL of distilled water to the beaker and mix.
19. Repeat steps 3 through 15

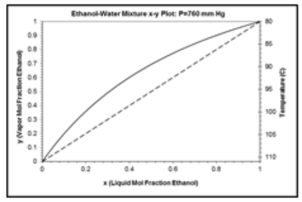
Ideal Situation for Raoult's Law – Ethanol & Water



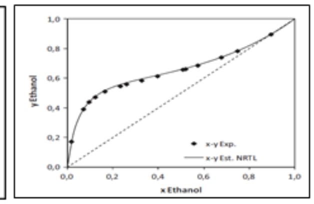
Actual Situation for Raoult's Law – Ethanol & Water



Mole Fraction Vapor vs. Liquid Mole Fraction – Ideal Situation

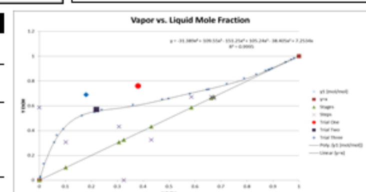


Mole Fraction Vapor vs. Liquid Mole Fraction – Actual Situation



DATA

Trial	Mole Fraction Liquid	Mixture	Observed Approximate Boiling Point	Refractive Index	Refractive Index After	Diluted Sample Refractive Index	Mole Fraction Vapor
1	[illegible]	200 mL Ethanol 100 mL Water	[illegible] °C	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	+100 mL Distilled Water	[illegible] °C	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	+100 mL Distilled Water	[illegible] °C	[illegible]	[illegible]	[illegible]	[illegible]



Conclusion:

1.) To derive the ideal Raoult's Law graph of the water and ethanol system first the boiling points of the two liquids were found using Equation 1 which is a derivation of Antoine's equation where A, B, and C were found in a reference table and P was the pressure. The range between the two boiling temperatures was split up evenly to form data points. Then P2* and P1* were calculated using Equation 1 Solved for P at each of the temperature data points. These values were then used to calculate the x and y values using equations 2 and 3.

Equation 1: $T_{boiling} = \frac{B}{A - \log_{10} P} - C$

Equation 2: $x = \frac{P - P_2^*(T)}{P_1^*(T) - P_2^*(T)}$

Equation 3: $y = \frac{xP_1^*(T)}{P}$

2.) We proved that our mixture was not an ideal solution through testing. Our data points follow somewhat of the non-ideal vapor vs. liquid mole fraction data taken from a different distillation process used by the Chemical Engineering Department. The reason as to why our data points did not exactly follow the trend was due to the different still process. We are confident in our results because they do follow the trend somewhat and are repeatable if tested again.

References: Data from Chemistry Department from previous experiments like ours, Data from Dr. Weinstein on an ideal situation for Raoult's law, First Year Chemistry Textbook, Wikipedia/Internet Sources

Independent Lab - Manometry

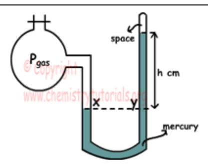
Engineering Measurements Lab Section 03

Lab Performed: 11/22/13
Report Submitted: 12/4/13

Background

For this lab, groups were required to come up with their own experiment. Our group decided to build our own manometer. A manometer consists of a half filled u-shaped tube that has ends exposed to different pressures. The liquid rises or falls until its weight is in equilibrium with the difference in the pressures. Typically, one side of the manometer is a known pressure and the change in height of the liquid is measured and used to determine the pressure of the other end. For ours, we are using a CO_2 tank with a regulator valve to manage the pressure on one side, and the other end will sealed. Using the measured change in height and the known pressure from the CO_2 tank, we will determine the pressure in the sealed end.

Procedure and Setup



Procedure for capped-end manometer
Cap one end of the manometer so pressure can build up. On the regulator side, pressure will be increased from 0 psi to 30 psi in increments of 2 psi. In each increment, the fluid displacement will be measured and recorded and the pressure on the capped end will be calculated.

Assumptions and Equations

- Assume no head loss for air
- Assume constant diameter
- Assume no oil leakage
- Assume pressure gages show gage pressure
- Assume Newtonian liquids

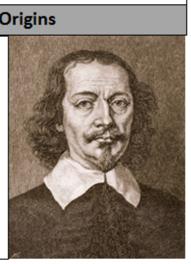
$$dP = \rho g h$$

$$\Delta dP = \sqrt{\Delta\rho^2 \frac{\delta P^2}{\delta \rho} + \Delta h^2 \frac{\delta P^2}{\delta h}}$$

Testing Rig

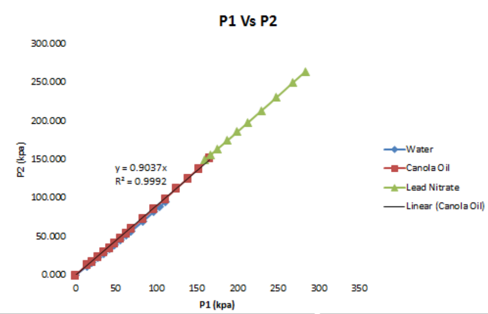
Origins

Otto von Guericke 1602 – 1686
- German Inventor and philosopher
- Invented manometer in 1661



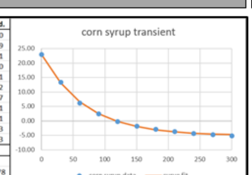
Independent Lab - Manometry

Pressure Results



Transient

t [s]	h [in]	exp fit	resid.
0	23.00	23.05	0.00
30	13.40	13.09	0.09
60	6.20	6.66	0.21
90	2.50	2.49	0.00
120	-0.13	-0.20	0.01
150	-1.80	-1.94	0.02
180	-2.80	-3.07	0.07
210	-3.70	-3.79	0.01
240	-4.35	-4.26	0.01
270	-4.75	-4.57	0.03
300	-5.13	-4.76	0.13
Model:	h=A*e^(t/B)+C		
A	28.175		
B	68.811	SSR	0.578
C	-5.125	τ	68.8



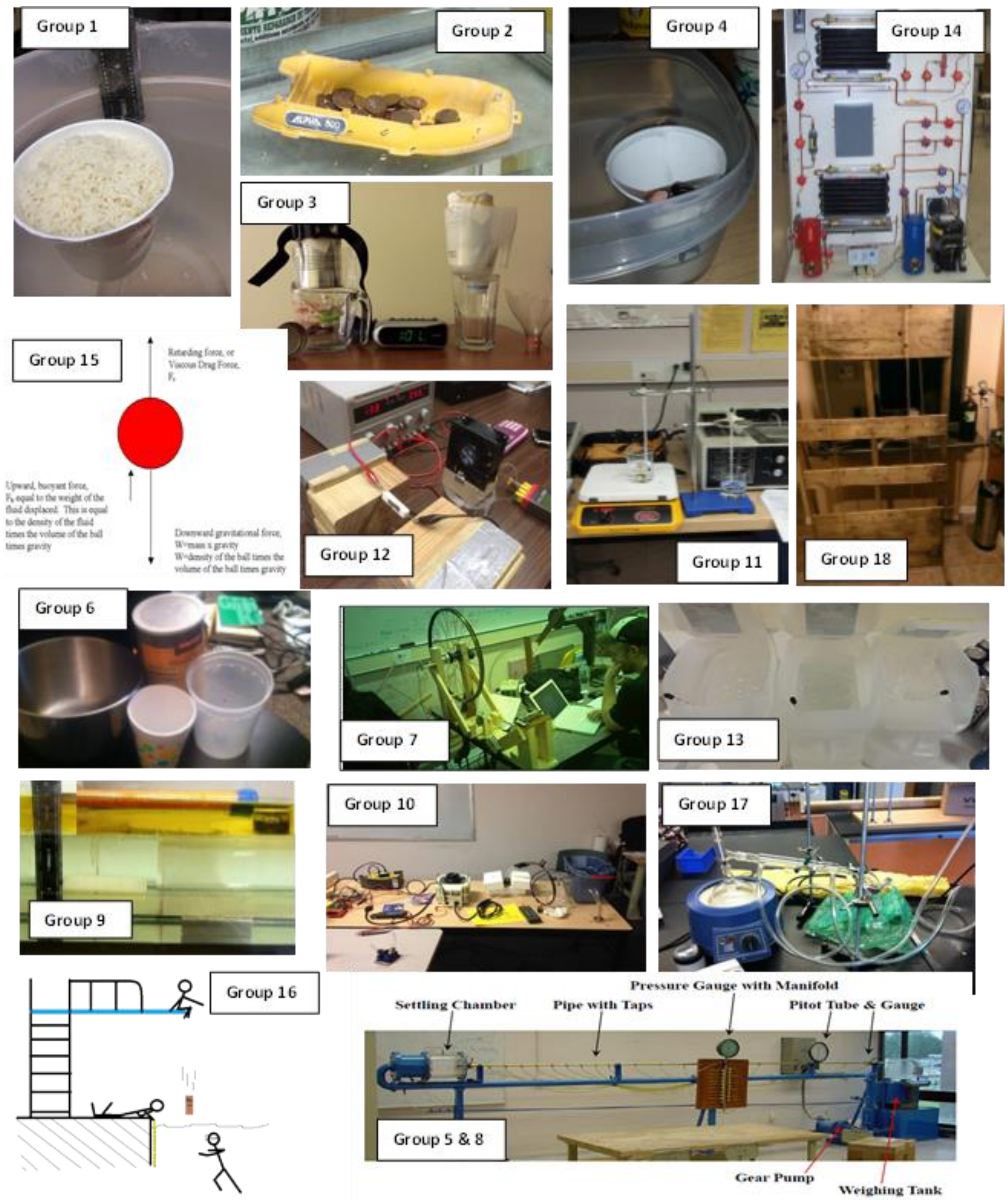
Contributions

Yevgeniy	Conclusions, data collection, Theoretical analysis
Doug	Procedure and setup, lab, charts, compiled report
Owen	Background, Data analysis, data collection
Tom	Error Propagation and data analysis

Conclusion

Our experiment confirmed the accuracy of the hydrostatic equation for a variety of fluids. The results presented less than 10% error globally, with the uncertainty of some measurements being as low as 1%. The error was minimized by using a fluid with low viscosity and low density. Pressure increments between two high pressure reservoirs provide the most reliable readings, while the same increment between near-atmospheric pressures yields more uncertainty. Due to the flexible piping, the diameter expanded slightly as the pressure was increased, resulting in a "loss" of fluid when the fluid level on the left and right were summed. The decrease of the summed levels was measured to be roughly 10 mm/psi, which correspond to .02 mm/psi diameter expansion. This is a 7% elastic expansion of the pipe thickness, which is reasonable for flexible polyurethane. However, this did not affect the uncertainty of the readings, because only the elevation difference was used to find fixed pressure.

Appendix D: Experimental Set-up of the Independent Study Projects



Group 1: NeverWet's Effect on Buoyancy; **Group 2:** NeverWet's Buoyancy in Tap Water vs Salt Water; **Group 3:** NeverWet's Effectiveness vs Water Temperature; **Group 4:** NeverWet's Buoyancy in Different Density Liquids; **Group 5:** Pipe Flow Velocity Profile Project: **Group 6:** Heat Transfer Coefficients; **Group 7:** Energy Loss in a Spring; **Group 8:** Reynold's Pipe Flow Transition Region Project: **Group 9:** Buoyancy Force Test; **Group 10:** CPU Heat Dissipation; **Group 11:** Quantification and Analysis of Material Specific Heat; **Group 12:** Convection Coefficient Measurement; **Group 13:** What is the fastest way to cool a soda?; **Group 14:** Vapor-Compression Refrigeration System; **Group 15:** Drag Coefficient Experiment; **Group 16:** Water Impact Experiment; **Group 17:** Raoult's Law for Non-Ideal Fluids; **Group 18:** Manometer Dynamics