Fall 2008 Experiments and Communication
Unit Operations Laboratory

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I. PERFORMING EXPERIMENTS

A. Experimental Procedure

1. What is the objective and what are the limitations of the objective? (e.g. The objective is to obtain the head loss coefficient of a ball valve. The coefficient will be valid from Re numbers between 1000 and 5000).
2. Plan ahead: What does the theory tell you to measure?
3. What equipment is available?
   a. What range of conditions will it provide?
   b. Calibrate/check it (don't trust anybody!)
4. What magnitudes of values do you expect to measure?
5. What magnitudes of error do you expect?
6. How much time is needed to reach steady state?
7. What assumptions are you assuming during your experiments and in your analysis? How will you test these assumptions?
8. What conditions (values of the variables) should you examine?
9. How many replicates should you run? What order?
10. How will you use the measurements & analyses to obtain the objective at hand?

B. Experimental Results and Analysis

1. Think carefully--does the equation apply?
2. Keep error analysis in mind:
   a. Standard deviations/confidence intervals
   b. Are differences significant?
   c. Evaluate suspected influence of unintended effects using propagation of error/ probable error
3. Compare experiments with theoretical predictions, others' results, common sense
4. Note: Figures and tables of results and experiment may be developed as a team.

II. GENERAL WRITING GUIDELINES

A. Audiences (all of the following will have access to the report)

1. Immediate supervisor who requested the work
   a. Familiar with the problem and technology
   b. Needs to be convinced that your conclusions are correct
   c. Wants to read the main report, but not the gruesome details
2. The supervisor's boss
   a. Doesn't know why the work was done
   b. Wants only the very essential information and results/conclusions

c. Only has time to read the abstract (executive summary)

3. Colleague doing similar work
   a. May pull your report out of the file cabinet 10 years from now
   b. Wants to know all assumptions made and calculation techniques employed
   c. Will read the appendix and compare your calculations to his/hers

B. Neatness/Organization
   1. Computer-drawn is better than hand-drawn.
   2. Tables and text in the Appendix may be handwritten, but neatly! (computer-written is better)
   3. Is your written report organized such that it is easy to follow? Did you identify the nomenclature used in the report?
   4. Spacing should exist between each section of the report!
   5. References should be used when appropriate. Include the year if referencing a website.

C. Grammar, spelling, and other thoughts!!!!
   1. Use 3rd person for full report. 1st or 3rd person may be used for all other reports.
   2. Have someone else proofread it! OR Read it aloud to someone else.
   3. For numbers, spell the number if ten or under. Write the number if 11 or greater. For equations, always refer to "Equation 6",etc.
   4. Use superscripts (10^6) rather than 10^6.
   5. All equations should be numbered (right justified)
   6. Don't copy MathCad equations into report since symbols are not universally used (e.g. the equals sign).
   7. Do not copy figures without referencing. Only include information in figures that will be discussed.

D. Language
   1. "There is no such thing as good writing, only good re-writing"
   2. Be clear: Say exactly what you mean, mean exactly what you say
   3. Be brief: Watch out for wordiness--work it over again.
   4. Be specific: words like "big", "better", "slightly", etc. leave the reader guessing
   5. Use past tense if referring to an experiment or something you did. Use present tense if describing equipment or a process that is currently in existence. Write in the 3rd person.
   6. Avoid phrases like "we will then" and avoid terms like "it", "they", etc. You need to identify what "it" and "they" are referring to.
   7. In all cases be specific. You are the expert.

III. PREPLAN REPORT (2- pages excluding figures, single space, either 1st or 3rd person)

A. The objective to be met is clearly defined. The objective should include both the general objective from the problem statement and your experimental objective that is related to the problem statement. For instance, the general objective may be to identify the best

loss coefficient method and the experimental objective will be to measure the head loss coefficient of a ball valve using two methods that will be compared.

B. Experimental methods are clearly and appropriately defined. There must be sufficient detail to make the experiment clear. Include what data you are going to collect, number of replicates, the order they were run, ranges of variables studied, and any experimental assumptions (i.e., steady state, constant T, etc). A table listing each experiment and the experimental parameters would be very valuable. Be clear on what data you will collect- don't just state that "data" will be collected. Avoid phrases such as "variable flow rates were tested", rather state the specific operating parameters and the associated ranges. Do NOT just refer to a website and provide no other detail.
C. If using a figure, provide a reference. Do not just copy a figure and then shrink the figure. All figure font sizes should be 10 pt. or greater. Only include pertinent information on the figure.
D. The theoretical analysis is outlined and is appropriate for utilization with the data. Show how you will use the data with the theoretical equations to meet the objective. Use a summary table or sentence structure for defining variables. An example sentence structure is "where P is the pressure,…"
E. Assumptions with validation are described for experiments. For instance, steady state will be validated once the temperature readings are within 0.5 degrees. Assumptions with validation are described for the theory. For instance, the ideal gas will be used since …….
F. Safety considerations are identified.

IV. EXECUTIVE SUMMARY

(1-page excluding figures, <u>single space</u>, either 1st or 3rd person)

A. Complete and stands on its own (includes purpose, what was done, <u>specific</u> results, conclusions, recommendations).
B. The objective to be met is clearly defined. The objective should include both the general objective from the problem statement and your experimental objective that is related to the problem statement. For instance, the general objective may be to identify the best loss coefficient method and the experimental objective will be to measure the head loss coefficient of a ball valve using two methods that will be compared. State the constraints for which the solution is valid.
C. Provide a brief summary of the experimental method used to obtain the results. Be clear enough that the reader can understand the general experiment.
D. Provide a summary of the results along with any statistical analysis. Write a few comments about the results (e.g. trends, agreement with literature, strange results, …). Do not just include your results without any comments. Usually very little discussion of theory is included (except as needed to explain results, conclusions, or recommendations).
E. State conclusions (with solution constraints- i.e. solution is valid for xx flow rates, etc.) and provide recommendations. The conclusions and recommendations should be based upon your results.

F. Remember that the executive summary must have continuity between all sections. This is not a cut-and-paste document. The summary is a document that you would give to a supervisor.

V. FULL WRITTEN REPORT (7-10 pages including figures/graphs, double space, 3rd person)

A. Format of a 7-10 page Report
   1. 7-10 pages double spaced, including figures and tables. Appendix (data and statistics) is not included in page limits. Number the pages. The letter of transmittal and the executive summary are not part of the page count.
   2. A blank line should exist between major sections. Major section headings should be 12 pt font with a distinguishable highlight (bold, italicized, …)
   3. The report should be Times New Roman font, 12 pt size, with one inch margins. Do not change the font size, font, or margins to meet the page guidelines.

B. Letter of Transmittal (attached to front of report- not included in page limitation)
   1. This is written in a memo format
   2. Identifies project and personnel
   3. Briefly summarizes objective of the report
   4. Briefly summarizes recommendation(s)
   5. Not part of the report —stapled to the front of the report

C. Executive Summary- DO NOT included in page limitations;
   1. Keep separate from main report
   2. See IV above for details.

D. Introduction Section
   1. State the objective, including details of the memo and the memo date. (i.e. WHAT you did). The objective should include both the general objective from the problem statement and your experimental objective that is related to the problem statement. For instance, the general objective may be to identify the best loss coefficient method and the experimental objective will be to measure the head loss coefficient of a ball valve using two methods that will be compared. Include appropriate background information to help set the stage for the reason as to why the objective is important to achieve- if necessary reference work of others. (i.e. WHY you did what you did)
   2. Briefly state the method you performed to solve the objective. Don't give major details. (i.e. HOW you did it). This brief statement provides a nice lead-in to the next section.

E. Experimental Methods Section
   1. Show a figure of the apparatus and describe the apparatus with enough detail so the reader understands the apparatus. Terminology in the figure and throughout the text should be the same. Do not just copy a figure and then shrink the figure. All figure font sizes should be 10 pt. or greater. Only include pertinent information on the figure that you will describe. If showing wires in the figure (i.e. connections to

Bailey), use dotted or dashed lines. If any part of a figure is copied, it must be referenced. Figure # and brief description should be included below the figure.

2. Discuss the experimental methods, referring to a figure when necessary (which is usually the case). The methods should be written such that another person can repeat the experiment(s). Be explicit as to what the experiment is for and what data you are going to collect. Avoid phrases such as "variable flow rates were tested", rather state the specific operating parameters and the associated ranges. Include information on the number of replicates, the order they were run, range of variables studied, data you will collect, safety aspects, etc. A table listing each experiment and the experimental parameters would be very valuable. A website citation is not sufficient.
3. State any assumptions in the data collection and why the assumptions are valid or how you will assess the validity. (i.e. the vessel is assumed to be at atmospheric pressure since …., the temperature is constant, …). If you state you will assess the validity, the assessment should be in the results section.
4. If equipment is mentioned, include in parenthesis the manufacturer, model, and company location. For chemicals, you only need to include the manufacturer and company location. If the list of equipment and chemicals is large, you may use a table.

F. Theory/Analytical Section

1. Show the equations you will use to achieve the objective or substantiate a conclusion. Always check your equations for mistakes. Some past reports have shown different equations among the same team members. State how you will apply the collected data to the equations. Include values of constants used in equations. State any assumptions or limitations of the equations and why they are valid or how you will assess the validity. An equation being valid in a given Re range is an example of a limitation. If you are going to assess the validity, you need to include the validity in the results section.
2. When typing an equation, use numbering (i.e. (1)) where the number is right justified. Have only one equation on each line. You can combine equations such as $hD/k=Nu=cRe^{n}Pr^{1/3}$. Use sentence structure for defining variables (i.e. where P is the pressure,…). If variables have already been defined, they do not need to be defined again. If there are numerous variables, a table of nomenclature placed at the end of the report may be beneficial.
3. Include any background information to make this section readable. The analysis should be clear to follow from beginning to end. Reference the work of others (except for common equations or general knowledge).

G. Results Section

1. Show figures and/or tables (it's rare to have a results section that has no figures or tables) that support your conclusions. If necessary, you can just report a value. Do not refer to specific tables or figures that are in the Appendix to support your conclusions, otherwise you need to include the table or figure in the report. Your conclusions are based on results presented in the main document and the appendix is only for supporting evidence. Describe the trends and the observations of the figures

and tables. Emphasize unique aspects of the figures or tables. You can state that the data is useful over one range and not useful over another range. The entire figure or table should be on one page (i.e. they should not be split between pages). Each figure and table should be labeled with a number and a title. Font sizes should be at least 10 pt. Do not connect data with lines (unless the line is a model). When lines are used with symbols, the lines are usually representative of models predicting the data. Figure # and brief description should be included below the figure. Table # and brief title should be included above the table.

2. Include information on "bad" results and, if applicable, reasons as to why the data was not used. State problems or limitations that occurred during the experiments and what was done to overcome them. (i.e. The available N_2 flow rate to flush the CO_2 was too fast so a dilution method was employed by …..). Don't throw out data if there is no valid reason- if possible, give some reasoning as to why certain data may not be valid.
3. Demonstrate the correct application of data to theory. Identify similarities/differences between theory and results. Provide possible reasons if differences are noted.
4. Include summarized statistical analysis (propagated errors, confidence intervals, error bars, and/or standard deviations, etc.) in the text. The Appendix should show the detailed calculations with appropriate headings so the reader can follow the analysis.

H. Discussion, Conclusions and Recommendations Sections.

1. Discuss your results (which may include good data, bad data, data application to theory, and/or statistics—see above Results Section). The discussion should lead to conclusions and recommendations that are supported by the results. The discussion may be in its own section or intermingled with the Results section. Either way, the discussion should be sufficient to defend your conclusions and recommendations.
2. State the conclusions and recommendations. The conclusions must be justified by your results. State any constraints related to your conclusions (e.g. the solution is valid from Re 10,000 to 100,000) and make sure your conclusions answer the objective. Provide recommendations, including experimental recommendations. (Examples: implement a solution, improve experiments, repeat experimental data, utilize new experimental methods, etc.)

VI. APPENDIX (One per team)

The appendix should be neat, readable, well organized and easy to follow. It should not simply be a collection of computer printouts stapled together and labeled as "Appendix". The appendix should include well-written analyses with sufficient notation for the reader to understand the details of the project. It should include the following sections:

A. Data Section

Include table(s) and/or graph(s) summarizing all pertinent raw data and operating data. Operating data may include room temperature and pressure, steam pressure, etc. Include a table of nomenclature that lists and defines all variables used in the

Appendix. Include tables with all raw data measured during the course of the project. If large quantities of data were collected and logged to a computer, list the location and names of the data files that are stored on the computer. These files must be accessible to the TA and the course instructors. Alternatively, a CD can be included with the Appendix that includes all of the raw data files. Make sure that all data are appropriately labeled and units are specified.

B. Sample Calculations Section

Include a sample calculation for each step of the data reduction and correlation. It is not necessary to keep repeating the same calculation using different data inputs. Units must be included. Make sure the calculations are easy to follow by including explanatory notes to help guide the reader through the calculations. Specify which step or steps of the analysis are included in a given sample calculation.

C. Statistical Analysis Section

Provide details of the statistical analysis of the measured data (means, standard deviations, t-tests, etc.). Don't just copy MathCad or Excel results. Make sure there is enough explanation that the reader can clearly follow the analysis. Correlate the statistical analysis with the corresponding raw data table, making sure that the reader knows what data in the table is being used in the analysis. Be consistent in the use of nomenclature.

D. Error Analysis Section

1. Identify the errors used for the error analysis and describe how the errors were quantified (i.e., The standard deviation from Table xx , row 1 was used as the estimate for the error of the temperature). Summarize the errors using a table that identifies each input (not calculated) variable, the associated standard deviation (σ) or error (δ), and the method used to obtain the error (standard deviation, 2.57 times last significant digit, equipment specification, etc.). The "input" variables may include measured variables, tabulated information, equipment specifications, etc.
2. Include sample calculations for each step of the propagation of error analysis. Make sure the calculations are easy to follow by including explanatory notes to help guide the reader through the calculations. Include, when possible, the fractional or percent error that each input variable contributes towards the total error of each calculated variable (i.e., the error associated with time measurements contributed to 3% of the error associated with the calculated diffusivity). This information can be included for each input variable in the error summary table described above. Remember that σ and δ have UNITS!!

E. Summary Section

Provide a summary of all calculated data and statistical analysis in table and/or graph format. Include a written description of the information contained in the summary table and/or graph.

VII. NOTEBOOK

A. Clearly note the dates and times of all experimental work. Enter information such that another person can comprehend the notebook entries at a later date. Include names and

signatures of team members performing the experimental work after each lab. Don't forget to include your own signature. Write in permanent ink with no large blank pages. The notebook should have numbered pages.

B. At the beginning of each project, write a brief description of the project and summarize the project objectives. Begin each project on a new page and note this starting page number in a Table of Contents at the beginning of the lab notebook.
C. Include a brief summary of the important details of each experiment that is performed on each lab day.
D. Include all raw data in a clear and easy-to-follow manner. If large amounts of data are stored by computer, either staple a print out of the data into the lab notebook or list the name and location of important data files that are stored on the computer. If the location of data files is listed in the notebook rather than the raw data, include a brief, hand-written summary of the key data in those files. Make sure that all data are appropriately labeled and units are specified.
E. Include pertinent experimental observations and conditions including room temperature and pressure, instrument calibrations, equipment specifications, a rough schematic (if you feel it is helpful), etc.
F. Record calculations performed during the experiment.
G. Note key conclusions at the end of the project.

Note: This information was written by Drs. Randy Lewis and Neil Giles using personal notes combined with notes written by Dr. Ken Solen.