Guidelines for Laboratory Reports

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1 Introduction

A Laboratory Report is a document that presents the gathered data, analyzes the information, and discusses conclusions and recommendations for further work. These guidelines are intended to provide a systematic framework for writing a lab report on experimental findings.

The formats are not fixed standards; they must be interpreted as proposed guidelines that may be altered whenever necessary to improve the clarity and legibility of the report. However, any alterations must produce a more persuasive and better-structured report. This guide is based on prior guidelines prepared by Drs. Oscar Crisalle [1, 2] and Kirk Ziegler [3] and the BYU Chemical Engineering Department [4].

2 Suggested Report Structure

2.1 Title Page

You should avoid uninformative titles, such as "*Experiment No. 1.*" Use descriptive titles, such as "*Determination of heat-transfer coefficients in a recovery boiler.*" On the other hand, it is also important to avoid excessively long titles. In addition to the title, the title page should contain number of your group, names of all the authors, dates of the experiments, and the date of submission.

2.2 Table of Contents

The Table of Contents should be placed after the title page and list each major section and subsection as well as their page numbers.

2.3 Abstract

Every report should begin with a brief (250-300 words) abstract providing a succinct description of the work. The abstract must be written as a single paragraph and include a short statement of the purpose of the experiment, methods and conditions used in the experiment, summary of the results, and conclusions. The abstract must be self-contained and allow one to understand the essence of the entire report. Therefore, do not refer to figures and tables located in other sections of the report. Avoid including symbols or acronyms; however, if

it is necessary to include them do not assume that the reader can unambiguously identify undefined symbols.

2.4 Introduction

The *Introduction* presents the basic knowledge, relevance, and applications that a reader needs to understand prior to reading the remainder of the report. This section should start from a well-accepted or generally understood position and logically present the key aspects of the field so that the contributions from the experimental work can be appreciated in the broader context. None of your experimental work should be presented here; however, the bulk of the citations appear in this section. This section can be completed prior to conducting any experimental work. After reading this section, the reader should understand exactly why this report is relevant.

2.5 Objectives

This short section describes the objectives, which serve as a guide to the results. In many cases, it is useful to formulate a hypothesis that relates causes (variables that are deliberately adjusted by the experimentalist) to effects (observed responses). The objectives section must be self-contained. Do not make references to figures, tables or equations found elsewhere in the report and try to avoid the use of mathematical symbols. Avoid using using vague and imprecise statements, such as 'characterize' and 'performance' that may have many interpretations.

Poor objective statements

- Characterize the heat-transfer coefficient of an evaporator.
- Characterize the performance of a chemical reactor.

Better objective statements

- Determine the dependence of the heat-transfer coefficient on the pressure drop across the evaporator.
- Determine the yield and selectivity of a chemical reactor.

2.6 Theoretical Background

This section should contain theoretical background relevant to interpretation of the gathered data. It should justify why the experiment is of importance, characterize all key variables, and explain why certain measurements are needed. Identify all physical phenomena, relationships, and equations relevant to the experiment. **Do not include theoretical discussions or equations that are not relevant to the experiment.** Avoid including broad generalizations and seek to be succinct but complete. Refer the reader to the Appendix for all auxiliary information.

Describe applicable equations and their assumptions. Establish that these assumptions are reasonable for this experiment. **Do not derive any equations that can be found in a textbook, a handbook, a journal publication, or a lab manual posted online.** Simply state the equation and include a reference to a reliable source. This section should also contain a description of application of the theory to analysis of your experimental data. In particular, it is necessary to specify which calculations are performed with the measured quantities and describe goals of these calculations.

2.7 Experimental Procedure

The section includes details about the experimental methods used in the project, what measurements were taken, what procedural protocols were followed, and what materials and equipment were used. In some cases, subsections may aid the presentation of this material (e.g., *Materials, Equipment*). A key concept to keep in mind is that this section should contain enough information to allow a competent experimentalist to determine without ambiguity what resources are needed and what procedures must be followed to reproduce the experiment without further consultation with the report author. This criterion should be implemented in a fashion that avoids verbose discussions. A succinct yet sufficiently complete exposition is preferred.

Write a paragraph describing all the materials and equipment used for measurements. It may be useful to place all relevant properties of the materials into a table. Consider including photographs or schematics of the equipment or certain aspects of the measurements if these make the equipment description or measurements more precise. Describe all equipment needed to carry out the experiment in a fashion what would allow the reader to unambiguously reproduce the hardware set up by referring only to the text in this report. Include information on precision and range of measurement of all relevant data in the experiment.

Describe the protocol of your experiment, i.e. provide specific details on the sequence of steps involved in preparing initial conditions, performing the experiment, and collecting the data. Include a summary of any safety issues and how these issues were mitigated.

Describe contribution of each of the group members in running the experiment. Ideally, all group members should take turns in performing each of the procedures involved in the experiment.

2.8 Results and Discussion

This section of the report contains detailed discussions of your work, including supporting data, figures, tables, equations, etc. This should be the bulk of your report. Specific structure of this section may vary from report to report but in all cases it should be logically organized, typically following inductive or deductive logical steps. To aid comprehension, this section often has several levels of subsections.

The Results and Discussion can be either presented in the same section or two different sections. You should choose the approach that provides the clearest and most succinct description of the results.

2.8.1 Results

Include all figures, tables and relevant details that document your final results and analysis. Whenever possible, perform statistical analysis of the uncertainty of measurements and provide error estimates for the reported data. Show only final results that address the objectives of the experiment. All raw data and other findings of relevance, but of lower importance, must be relegated to the *Appendix*. If possible, present the results in the same order that you listed the objectives. Do not present the results by referring to "run numbers" of experiments.

2.8.2 Discussion

The *Discussion* (sub)section should contain an interpretation of your experimental observations. Discuss significance of all elements (tables, figures, *etc.*) of the *Results* section. Address each table and figure in the order that they were presented. Describe effects of control parameters on outcomes of your experiments. Compare results of the experiments with predictions of the theory discussed in the *Theoretical Background* section. When appropriate, refer to equations in the *Theoretical Background* section to explain why the relevant

variables produce the observed effects. Be sure to cite literature references whenever it is relevant to do so. If you proposed a hypothesis in *Objectives*, discuss whether the data confirm or reject the hypothesis. If necessary, propose and discuss an alternative hypothesis.

Provide plausible explanations if the experiments and the theory disagree. If you believe that the experimental results are invalid, discuss what went wrong. Be specific. Do not use vague statements such as "human error". Describe what can be improved for the next trial, including what remedial measures to take if the experiment is invalid or if the results deviate from expectations.

2.9 Conclusions

The *Conclusions* section presents a brief statement of the primary contributions of the report, ideally framed by the *Introduction* and *Objectives* sections. Only data or discussion that was presented in the *Results and Discussion* section(s) should be described. Unlike Abstract, this section need not be a stand-alone summary of your report and may refer to other portions of the report if necessary. This section should highlight the most important conclusions of the report and its importance to the broader field.

2.10 Acknowledgements

This section should acknowledge anyone who played a specific and substantial role in the experimental work but is not an author. Typical examples include other students, faculty, and staff.

2.11 References

List all the literature sources that are cited in the report.

2.12 Appendix

The *Appendix* serves as a repository of information that is relevant but is either too rich in details or too lengthy to include in the body of the report. Organize the *Appendix* in subsections. Each subsection must be self-contained and referred to in the body of the report. An introductory paragraph should be used to inform the reader of the contents of each subsection. The following subsections are recommended:

- **Data Records**. Include a sample *Data Records Sheet* designed to gather the experimental data, including the values of all inputs, outputs, control variables, and all other relevant information, such as the run (or trial) number, dates and times of experimental work, *etc.*

- **Raw Data.** If the data are too extensive, submit a separate spreadsheet file containing all the information. Make sure to provide sufficient comments in the spreadsheet file.

3 Formatting Guidelines

Headings and subheadings should be clearly separated from the rest of the text by using a larger font size and/or bold or italic font.

Pages should use the standard 1 inch margins on the top, bottom, left, and right. Page numbers should be centered at the bottom of the page. They should start with lower-case Roman numeral i on the title page and Arabic numeral 1 on the first page after the front matter (the title page and the table of contents). However, neither the title page nor page number 1 should have a number on it (first numbers should be ii and 2 for the front matter and the report, respectively).

3.1 Figures and Tables

Introduce the reader to each figure and table with a brief paragraph indicating what variables are plotted or tabulated. No figure or table should appear before its introductory paragraph. Preferably, they should appear on the page where they are first discussed, but often they will appear on later pages because of space limitations. Unreferenced figures and tables are not acceptable. Figures and tables should be numbered according to the order in which they appear in the report.

Each figure and table must have a caption providing enough detail so that the figure/table is understandable without reading the surrounding text. Captions should appear below the figure and be clearly separated from the text. This can be achieved by indenting the captions from the normal margins or using a different font (e.g., bold or italics). Page breaks should not occur in the body of caption text. Leave blank space between the caption and the figure/table and between the figure/table and the next line of text.

3.1.1 Figures

Whenever possible, figures should have mirrored axes for both the ordinate (y-axis) and the abscissa (x-axis). Tick marks should be included and, if possible, all tick marks should appear on the inside of the axis. Axis labels should include dimensions placed on the same line as the label but in parenthesis, e.g. "time (s)". Legends should be included when possible. While use of color is encouraged, all lines and symbols must be distinct in ways other than color so that the figure is still interpretable after black and white photocopying or printing.

3.1.2 Tables

Use the same font for the text in tables as for the normal text. Table headings should be set apart from the data using horizontal lines. Page breaks should not appear within a table unless the table is longer than one page. Do not use shading unless necessary since shaded text often does not photocopy well.

3.2 Equations

Equations should be centered on the page and numbered sequentially in the right. The font used for variables in equations should differ from that used for normal text so that references to variables appear clearly different from normal text in a sentence. For example, if a appears in a sentence discussing an equation, the font and the italics help a reader understand that it refers to the variable a, not to the word "a". Scalar variables in equations should be italicized, even if they use Greek symbols. Function names for logarithms, sine, cosine, exponentials, *etc.* should be in the same font but not italicized. Avoid using unconventional or non-standard scientific symbols, such as "*alphazero*" or "$a\wedge 2$" to denote α_0 and a^2, respectively.

3.3 Referring to Equations, Figures, and Tables

When referring to a specific equation the word "equation" should be capitalized, as in "*The heat transfer can be determined by Equation (1)*". Generic references to an equation should not have "equation" capitalized, as in "*The equation assumes...*". The same rule applies to figures and tables.

4 Useful MS Word Tools

MS Word provides a number of tools that automate mundane tasks involved in writing reports, such as creating a table of contents, numbering figures, tables, and equations and updating references to them.

4.1 Automatic Generation of Table of Contents

To automatically generate a table of contents, headings of sections and subsections should be created using the "Styles" group of the "Home" menu tab. Click on "Heading 1" for a first-level heading (i.e. heading of a section), "Heading 2" for a second-level heading (subsection), *etc.* To automatically generate the Table of Contents, go to the "References" tab and choose one of the options in the "Table of Contents" drop-down menu. If necessary, you can easily update the Table of Contents by pressing the button "Update Table".

4.2 Creating Figure and Table Captions

Numbering of figures and tables is automated by using the "Insert Caption" option in the "Reference" menu tab. MS Word will automatically set the figure/table number consistent with already existing figures and tables and, if necessary, adjust numbers of other tables and figures. To avoid page breaks in the caption text, use the "Keep Lines Together" feature.

To automate updates of references on figures and tables, use the "Cross Reference" feature of the "References" tab to create a reference to a figure/table. Note that only the label and number should be inserted, not the entire caption. Unfortunately, the default in MS Word is to insert the entire caption. Use a drop-down list in the upper right corner of the dialog box to indicate that the entire caption should not be inserted.

4.3 Equations

It is recommended to type equations using the MS Equation system built into MS Office starting with the 2007 version. The advantage to this is that equations can be directly copied between MS Word and many mathematics programs (e.g., Mathematica). Insert an equation by pressing the "Equation" button in the "Insert" menu tab.

It is suggested to create a three-column, one-row table for each equation. The equation should then be contained in the center column (which should be much wider than the left and

right columns). The left column should be left blank and the right column should contain the equation number. The cell borders of the table should be invisible.

Numbering equations automatically in MS Word is not as convenient as numbering figures and tables. To provide for automatic equation numbering, first create a new label under "Insert Caption" (press the "New Label" button). The new label should be a single opening parenthesis, i.e. "(". A closing parenthesis should be added after the equation number is inserted. You can then refer to the equation by inserting a cross reference similar to tables and figures, but by including the caption in the cross reference rather than just the label and number, as in Equation (1).

5 General Comments on Writing Style

- Reports should be written using complete sentences, with correct spelling and grammar.
- Define all symbols on their first use.
- State units of all variables.
- Avoid inconsistent verb tenses throughout the document, such as "*The pressure drop is measured using two methods. The first method was based on....*" Instead, write "*The pressure drop is measured using two methods. The first method is based on....*"
- Avoid redundant expressions, such as "*The calculation of pressure is given in the following calculation.*"
- Avoid starting sentences with acronyms or symbols.

References

[1] O. D. Crisalle. *Guidelines for Writing Laboratory Reports.* Department of Chemical Engineering, University of Florida, 2006. Revision 8.

[2] O. D. Crisalle. *Guidelines for Writing Experiment-Design Reports and Final Experiment Reports.* Department of Chemical Engineering, University of Florida, 2013. Revision 5.

[3] K. J. Ziegler. *Guidelines for Laboratory Reports.* Department of Chemical Engineering, University of Florida, 2013. Revision 1.

[4] Department of Chemical Engineering, Brigham Young University. *Writen Report Template*. http://uolab.groups.et.byu.net/files/ReportTemplate.docx.