

CBEE 102 (3 Cr.) – Engineering Problem Solving and Computations

Winter Quarter 2013-2014

School of Chemical, Biological, and Environmental Engineering

Oregon State University

2014.02.24

TEAM PROJECT: Buffon's Needle (Monte Carlo Simulation)

Project Description: Buffon's Needle

Due Date: 2014.03.03 1700

(no late projects will be accepted without pre-arranged consent of the instructors)

Additional Information: Please refer to the syllabus for further information.

Team Project Grading: *20% of course grade*

MATLAB Code	60% of the project grade
Project Report	30% of the project grade
Administrative Tasks	10% of the project grade

If you determine that a regrade is necessary, the entire assignment will be regraded.

Timeline

- Lec. 1: during the first lecture of the course (2014.01.06), a brief overview of the project will be given during the introduction of the course.
- Lab. 1: during the first week of laboratory exercises, you will be required to complete a homework assignment surveying your interests and skills. This survey will help the instructors organize the students into teams.
- Lab. 2: during the second week of laboratory exercises, you will be organized into teams based on the results of the survey.
- Lec. 4: during the fourth lecture of the course (2014.01.27), a theoretical background of the Monte Carlo method and a theoretical background of Buffon's needle problem will be given.
- Lab. 4: during the fourth week of laboratory exercises, you will complete a brief experiment with your team to collect brute force data.
- Lec. 5: at 1700 on 2014.02.03, the minutes of your required meeting with acknowledgement of the assigned tasks will be due.
- Lec. 6: at 1700 on 2014.02.10, a penultimate flow chart of your project code will be due.
- Lec. 9: at 1700 on 2014.03.03, your team project will be due.

MATLAB Code: 60%

The MATLAB Code will be the major portion of your project. This MATLAB Code will produce a simple Monte Carlo simulation where a distribution of estimates for the value of π (i.e., the ratio of the circumference of a circle to the circle's diameter) or trials will be found by completing a large

number of separate needle drops or experiments. The number of experiments will then be increased until the average of the distribution of the number of trials will be within a given tolerance or the maximum number of experiments is reached..

The following list gives requirements for the code. Note that an “experiment” is considered one (1) drop of a needle, while a “trial” is considered a set of experiments. This list should provide your a clear path toward creating a flow chart.

- One *m-file* called “buffon.m”.
 - Explicitly required: header comment describing the program and giving overview of use/syntax to run it.
 - Explicitly required: in-line comments describing the purpose of any non-trivial code.
 - Explicitly required: comment block containing description of each variable parameter and its physical significance.
- A *function* called “buffon”, corresponding with buffon.m (i.e., buffon.m is a *function*), with three inputs (the number of trials allowed, the maximum number of experiments per trial, and the overall acceptable tolerance of the system).
- A set of non-dimensional geometry values defining the length of the square two-dimensional box and the length of the needle. Note that the box will be restricted to ten (10) separate areas (i.e., eleven (11) lines) and that the length of the needle will be set equal to the width of the separation, making that square box have a side equal to ten (10) needle lengths.
- A **while**-loop testing for the number of experiments necessary for a set number of trials to be within the tolerance, increasing the number of experiments by an order of magnitude during ever iteration.
- An **if**-statement conditionally testing for the maximum number of experiments to be tested in one trial with an associated **break**-statement if that number is surpassed.
- A **for**-loop for completing a set number of separate trials.
- A *random number generation* using **rand** (2-numbers) to determine the physical location of the center of mass of the needle on a cartesian coordinate system for each experiment.
- A *random number generation* using **rand** (1-number) to determine the angle of the needle relative to a horizontal line perpendicular to the vertical separations for each experiment.
- A **for**-loop for determining the number of individual needles that crossed any of the divisions for the given trial (i.e., find how many experiments resulted in a crossed line).
- An estimate for π based on the formula estimate of Buffon’s needle problem.
- A separate *local function* (or sometimes called a subfunction) that plots four (4) separate visual figures.
 - Figure 1: a *scatter plot* representation of the ability of the function **rand** to provide an unbiased input using the data associated with the angle of the needle. This plot should show the angle as a function of the experiment for a given trial.
 - Figure 2: a *cartoon* representation (MATLAB-generated plot) of the distribution of needles for one (1) trial plotted on a square containing marked vertical separations, where needles crossing the vertical separations are distinguishable from those needles

that do not. This plot should represent the needles as lines of different colors depending on whether they do or do not cross a vertical separating line, and the plot should also show the vertical separating lines on the square playing field.

- Figure 3: a *histogram* (using the function `histfit`) binning the estimated values π for each trial (or for each set of experiments), quoting the mean and the standard deviation of the set of trials in the legend or in a text label.
- Figure 4: a *scatter plot* showing how the common logarithm (i.e., `log10`) of the absolute value of the error in the estimate varies as a function of the common logarithm of the number of experiments completed.
- A formatted output from the *function* call stating the overall estimate for the value of π within one standard deviation of the overall distribution (i.e., “The average value of pi is 3.1426E+00 plus or minus 9.77E-04 after 1E+04 trials of 1E+03 experiments.”).

In an attempt to relieve confusion, the following statement is given to describe the events. You are required to run a certain number of trials – this total number is an input to the function, but it will not vary during the simulation. Within each trial, you are allowed to vary the number of experiments that you run to reach your input tolerance goal, but you are not allowed to go above the maximum number of experiments that you initially input. Each trial (or set of experiments) will have its own estimate for π . If you plot the distribution of these estimates, you will generate a Gaussian distribution of events that will have a mean that will be a more confident estimate of π than any one trial on its own. If you vary the number of experiments (i.e., needle drops) within the individual trials, the estimate of π will also vary. Thus, as you increase the number of experiments within a single trial, the precision of the estimate should increase. To prevent the number of experiments from increasing without bound in an attempt to reach a certain tolerance (or precision or digit of π), you must add a conditional check and break the `while`-loop if you surpass this bound.

Project Report: 30%

In addition to an electronic submission of your project code, a Project Report will be required. The Project Report should be no longer than five (5) pages for sections 1-7 listed below, including figures. A printout of the final flow chart will be added as an appendix. A printout of the MATLAB Code will be added as an appendix. The printed code is to be monospaced font with a minimum size of 72 columns, formatted by MATLAB “Print” output, NotePad++, or another syntax-highlighting program. An optional one-page appendix comparing and contrasting the use of `rand` versus `randn` can be added for extra credit with direct inference to the use of `randn` with the location of the needle and an accompanying speculation on its effect on the angle. No further content should be included. Please see the handout entitled “CBEE_Technical_Writing_Guidelines_2013.pdf” as a guide in writing your report and the handout entitled “CBEE414ReportTemplate.pdf” as an example of the expected professionalism. The project grade will include neatness and attention to formatting as given in the Technical Writing Guidelines. Also, note that the report must be typed, while any color figures must be printed in color. We understand that this report may be your first opportunity to experience technical writing, and we will take this generalization into consideration during the grading.

1. Abstract

2. Background
3. Experimental Materials and Methods
4. Experimental Results and Discussion
5. Computational Materials and Methods
6. Computational Results and Discussion
7. Conclusions
- I. Appendix 1: Flow Chart
- II. Appendix 2: MATLAB Code
- III. Appendix 3 (optional): Random Number Generators

Administrative Tasks: 10%

- Survey
- Team meeting outside of class with assigned tasks
- Penultimate flow chart
- Team evaluations

Important Dates:

Add/Drop Deadline	2014.01.17
Midterm Exam	2014.02.10 1700-1750
Withdraw Deadline	2014.02.21
Project Deadline	2014.03.03 1700
Final Exam	2014.03.17 2000-2150

TECHNICAL WRITING GUIDELINES

CHE 334 (where appropriate) and CBEE 414-416

Unacceptable basic mistakes:

- Misspelled words
- Lack of introduction for a figure/table/equation in the preceding text
- Lack of title and/or detailed caption on a figure or table
- Unreasonable number of significant figures reported in Abstract/Conclusions
- Decimal written without leading zero
- Incomplete web site reference (site, date accessed, comments if appropriate)

Writing

- PROOFREAD YOUR WORK BEFORE YOU SUBMIT IT.
- Don't write in the first person.
- Avoid starting sentences with prepositions, thereby being more direct and avoiding commas.
- No figures, tables, equations, or footnotes in the abstract.
- Introduce figures, tables, equation, etc., in the preceding text.
- All figures need a title below, e.g. "Figure 1", and caption that explains the figure. Make the caption summarize the relevance to somebody who has not read the report, i.e. it can stand alone.
- Titles for figures, tables, equations, etc., should be capitalized in the text, e.g. "Equation 1".
- Don't regurgitate/retype detailed information that is provided in a cited reference, e.g. a standard operating procedure (SOP). Provide sufficient details, but use a proper citation.
- Spell names correctly. If unsure, find out.
- Spell correctly and use the correct word: spellcheck may indicate a word is correctly spelled even if it is the wrong word. Some examples from previous years: "Miss counting", "out liar", "descent data", "asses", "ingrate", "verse".

Calculations and Technical Stuff

- Do not use unusual terms without introducing them first.
- Abbreviations and acronyms need be defined either at first use or in an appendix with reference.
- Use good judgment in deciding how many significant figures to report, e.g. if you're using a rotometer to measure flow, don't report 5 significant figures.
- Embrace terms like "prototype", "testbed" and "benchtop system". For example, you might use a prototype gas absorption column to assess mass transfer properties, then "scale up" to an actual system design.

Formatting

- Never write a decimal without a leading zero to ensure it's not mistaken as an integer: 0.62, not .62.
- Never start a sentence with a number, instead use "Thirty mL were delivered using a pipette."
- Always put a space between a number and its units. It's easier to read and avoids alphanumeric confusion, e.g. If I write 6 liters as 6l, it sure looks like the number 61.
- Indent titles and captions on tables and figures and consider using smaller font, e.g. 10 pt, to make them stand out from the surrounding text. Some even use italics.
- Figures and tables should be centered on the page.

- Use "Ca²⁺", "Na⁺", etc. to represent ions. Elemental sodium (not ionic) would be "Na", and explosive when added to water!
- One often sees "Enclosure" at the bottom of the page. Is that not from the old days, when you "enclosed" something in the envelope?
- Many struggle in Equation Editor without the ability to put in spaces between numbers and units, etc. Try hitting Ctrl+space bar to put in spaces, or convert the entire equation to text style, which allows spaces.
- Italicize variables, e.g. *t_b*. It makes them stand out better to the reader.

TECHNICAL REPORT GUIDELINES

- *Abstract*
- *Background*¹
- *Materials and Methods*
- *Results and Discussion*
- *Acknowledgements*
- *Appendices*

Some guidance about what these sections look like:

- *No Cover Page.*
- *Abstract* is a high-level summary and includes (1) objectives, (2) methods, and (3) results. The goal is 4-6 sentences. Emphasize *content*: settings, ranges, numbers, units. No references, equations, etc.
- *Background* should be shorter for CBEE 414 lab reports, with brief theoretical background, then broaden as you move to more open-ended labs and senior projects. Look for previous work on the subject, e.g. have others measured that mass transfer coefficient? How? What did they find? Use footnote references liberally.
- *Materials and Methods* provides details about what you did. It is written in past tense, a story of what was done, not in first person, not as instructions, and not as bullets. The level of detail should be sufficient to allow another worker to repeat your work without having you physically there. Include equipment, manufacturer, model, equipment schematics/pictures.¹ Cite provided documents/SOP.
- *Results and Discussion* is the section in which you present data, calculations performed, error analysis performed, and what you observe and conclude (trends, issues, etc.). It is where you compare experimental results with theory (or manufacturer-supplied) information. Most plots will be in this section. If there is a design component to your lab, include it in this section.
- *Acknowledgements*¹ are included to (1) thank those that helped you setup equipment, explained equipment, etc., but also to (2) provide a record of who helped you so that your readers might use that information, e.g. Jill knows how to run the gas chromatograph. Be succinct.
- *Appendices*¹ are a location for supporting details. Sample calculations are required and must include assumptions, unit, etc., so the reader can follow and check your computations. They can be hand-written if legible. A spreadsheet printout is not enough. Other content might include copies of raw data, equipment calibration data, non-critical charts, etc.

¹ Not necessary for CHE 334 reports.

Tornado Eddy Investigation

Abstract

The objective of this lab was to write a bunch of jibberish to provide students with a formatting template. Chemical engineering, bioengineering, and environmental engineering are “process engineering” disciplines. Good abstracts contains real content, such as 560 mL/min, 35 deg, and 67 percent yield. Ideal degreed graduates are technically strong, bring broad system perspectives to problem solving, and have the professional “soft skills” to make immediate contributions in the workplace. The senior lab sequence is the “capstone” opportunity to realize this ideal by integrating technical skills and developing professional soft skills to ensure workforce preparedness. The best conclusions are objective and numerical, such as operating conditions of 45 L/min at 32 deg C with expected costs of \$4.55/lb.

Background

Insect exchange processes are often used in bug filtration, as they are effective at removing either positive or negative insects from water. An insect exchange column is a packed or fluidized bed filled with resin beads. Water flows through the column and most of the insects from the water enter the beads, but some of them pass in between the beads, which makes the exchange of insects non-ideal. Insectac 249 resin is a cation exchange resin, as it is being used to attract cationic Ca^{2+} from the toxic waste stream. This means the resin is negatively charged, and needs to be regenerated with a solution that produces positively charged insects, in this case, salt water which contains Na^+ insects. The resin contains acidic styrene backbones which capture the cationic insects in a reversible process.

A curve of Ca^{2+} concentration concentration vs. time was obtained after a standard curve was made to determine how many drops from the low cost barium test kit from Aquarium Pharmaceuticals (API)¹ bottle #2 would correspond to a certain concentration in solution. A standard curve works by preparing solutions with known concentrations and testing these concentrations using the kit to create a curve of number of drops from bottle #2 (obtained result) vs. concentration of Ca^{2+} in solution (desired response). The standard curve can then be used for every test on the prototype and in the field, to quickly and accurately obtain a concentration from the test kit.

The barium concentration vs. time curve can be used to calculate the exchange capacity of the resin and, in later tests, the regeneration efficiency. The curves must be used to get the total amount of barium removed from the water, m . Seen in Equation 2, the volumetric flow rate of water, \dot{V} , is multiplied by the integral from t_{initial} to t_{final} of the total concentration of Ca^{2+} absorbed by the resin as a function of time, C .

$$m = \dot{V} * \int_{t_{\text{initial}}}^{t_{\text{final}}} C dt \quad (2)$$

¹ <http://aquariumpharm.com/Products/Product.aspx?ProductID=72> , date accessed: 11/26/10

A graphical trapezoid method was used to evaluate the integral and get the final solution in equivalents of Ca^{2+} per L, it must be noted that there are 2 equivalents per mole of barium, as the charge of the barium insect is +2. An initial exchange capacity was calculated for the virgin resin, and an adjusted exchange capacity was calculated once the resin was regenerated. The regenerated resin capacity was found by multiplying the virgin resin capacity by the regeneration efficiency, expressed in Equation 3.

$$\text{Regeneration Efficiency} = \frac{\text{Ca}^{2+} \text{ ejected during regeneration}}{\text{Ca}^{2+} \text{ absorbed by virgin resin}} \times 100 \% \quad (3)$$

See Appendix A for the calculation of the exchange capacities and the regeneration efficiency.

Materials and Methods

Rosalie and Peter Johnson of Corvallis established the Linus Pauling Chair in Chemical Engineering to honor Oregon State University's most famous graduate. Peter Johnson, former President and owner of Tekmax, Inc., a company which revolutionized battery manufacturing equipment, is a 1955 graduate of the College of Engineering.² The Chair, also known as the Linus Pauling Distinguished Engineer or Linus Pauling Engineer (LPE), was originally designed to focus on the traditional “capstone” senior lab sequence in the former Department of Chemical Engineering. The focus is now extended to all the process engineering disciplines. The LPE is charged with establishing strong ties with industry, ensuring current and relevant laboratory experiences, and helping upperclass students develop skills in communication, teamwork, project management, and leadership.

Include details about lab procedures not sufficiently detailed in the SOP, problems you had, etc.

The bulk solution prepared to create the standard curve was used in the second day of testing to obtain the exchange capacity of the insectac 249 resin. The solution was pumped through a bathroom scale into the prototype insect exchange column. 45 mL of resin was rinsed and added to the column. The bed was fluidized as the solution was pumped through the resin, but for the creation of the Ca^{2+} concentration vs. time curve, the solution was pumped down through the column, as illustrated in the process flow diagram seen in Figure 1.



Figure 1. Process sketch of the insect exchange column used for the project. Ref: <http://www.generation.co.uk/acatalog/Chromatography.html>

² Harding, P. *Viscosity Measurement SOP*, Spring, 2010.

A bathroom scale calibration curve was created to ensure that the 150 mL/min, used to calculate the breakthrough time, would be delivered to the resin. The bathroom scale used was a Dwyer brand with flowrates between 0 and 300 cc/min of water. Originally, values between 120 and 180 mL/min were chosen for the calibration, with three runs for each flowrate, however the bathroom scale values were so far away from the measure values the range was extended to 100 to 200 mL/min. The regeneration experiment was performed using a method similar to that used in the water softening experiment, however instead of using a 640 ppm Ca^{2+} solution to fill the resin, a 6000 ppm Na^+ solution was used to eject the Ca^{2+} from the resin. Twelve samples times were chosen and adjusted as the experiment progressed, with more than half of the samples taken at times less than 10 minutes, and the last sample taken at 45 minutes. The bulk exit solution was also tested to determine the regeneration efficiency.

Results and Discussion

The senior lab sequence has its roots in the former Department of Chemical Engineering. CHE 414 and 415 were taught in Winter and Spring and included 6 hours of lab time per week. The School has endeavored to incorporate the courses into the BIOE and ENVE curriculum, and this will be complete in 2008-2009. Recent development of the senior lab course sequence is shown chronologically in Fig. 1. In 2006-2007, CHE 414 and 415 were moved to Fall and Winter to enable CHE 416, an elective independent senior project course. Also that year, BIOE students took BIOE 414 in the Fall and BIOE 415 was developed and taught. No BIOE students enrolled in the optional CHE. In 2007-2008, the program transitioned in a new Linus Pauling Engineer and ENVE 414 was offered. Also, approximately 30 percent of BIOE students enrolled in the optional CHE 416. Accommodating the academic calendars of the three disciplines required a reduction in weekly student lab time from 6 to 3 hours. The expected relationship between coughing rate, y , and length of canine, x , is

$$y = Fe^{-\frac{Bx}{z}} \quad (1)$$

where F is a pre-exponential constant, B is vitamin B concentration and z is the height of an average trapeze artist.³

The 2008-2009 brings the challenge of the dramatic enrollment increase shown in Fig. 1 and the first offering of ENVE 415. The result, shown on the right in Fig. 1, is the delivery of the senior lab sequence uniformly across the process engineering disciplines. CBEE 416 is expected to draw approximately of the students that take the 415 courses. In 2007-2008, 414 and 415 were required for CHEs, 414 and 415 for BIOEs, and only 414 for ENVEs. CHE 416 is ostensibly an elective for all disciplines. In 2008-2009, 414 and 415 is required for all disciplines and CHE 416 will be an elective. The content of 414 is essentially

³ Fundamentals of Momentum, Heat, and Mass Transfer, Welty, J.R. et al., 4th edition, John Wiley & Sons, Inc.

identical for all three disciplines, 415 has discipline-specific labs, and 416 consists of senior projects with potentially cross-discipline teams of 2 to 4 students. Tremendous labor and struggling with the lab equipment resulted in the data shown in

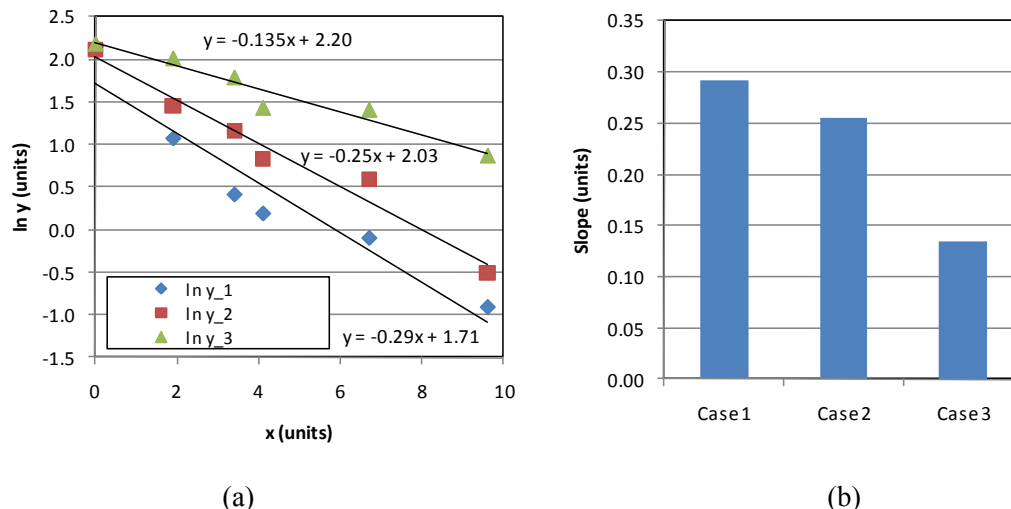


Figure 1. (a) Data for y and x plotted for various values of z and (b) a comparison of slopes for the 3 cases investigate. The log plot slope yields the vitamin B concentration. The slopes were shown to be significantly at the 90% confidence level, but the instructor ran out of time and did not include error bars.

The slope changed as predicted by the Snirtenhoffer equation. Improvements to the lab might include advice on how to legally change my name to something less embarrassing. My whole life I have been forced to repeat and spell it. I really feel that this has affected my psychologically.

This was perhaps the worst lab I have ever done in my academic career, primarily due to the fact that there was no lab time. I simply typed in this entire report and filled it with jibberish. Some might think nobody will notice, but I know that Harding reads every word.

Acknowledgments

The author acknowledges his elementary teacher for providing truly foundational instruction in addition and subtraction. Jenny Burninbalm was instrumental with guidance on use of the RT-345 dog scratching device.