# Using Your Unit Operations Laboratory

**Valerie L. Young**
**Department of Chemical Engineering, Ohio University**

Abstract

Through planned exposure to the unit operations laboratory, students in introductory courses gain a deeper understanding of chemical engineering. In the "Energy Balances" course at Ohio University, students worked in groups to design a system to preheat the feed to the distillation column in the unit operations laboratory, using waste heat from the column. In their anonymous end-of-course review, many students named this project as the one they learned the most from, citing the need to tie together multiple concepts, and the feeling they were working on a real problem. Performance on the project suggests that students are competent in the technical content of the course, but need to develop a systems approach to engineering analysis and design. Providing more explicit guidance will make the project a more valuable learning tool.

## Introduction

Considerable space and resources are devoted to working demonstrations of concepts and process equipment in a unit operations laboratory. It typically stands empty except during the "Unit Operations Laboratory" course, which appears late in the curriculum. Until then, process equipment is treated as "a box on a page". Many students succeed with this abstract approach, some only because test questions fail to expose fundamental misconceptions. Stories abound of students who believe the two streams entering the heat exchanger mix inside and then magically separate when exiting. Because it is often idle, equipment in the unit operations laboratory can be used to reinforce and extend course content in undergraduate classes, without interfering with the laboratory course. Wankat and Oreovicz[1] note that visits to local facilities are an underutilized teaching method. However, they also point out the loss of time to cover content, and the failure of some students to take the trip seriously since it is not covered on an exam. The author has addressed these drawbacks by incorporating "field trips" into graded projects designed to reinforce course content.[2,3]

The project described in this paper uses the distillation column in the Ohio University unit operations laboratory to reinforce concepts of sensible heat, latent heat, and binary vapor-liquid equilibrium in an introductory chemical engineering course. Its limited scope is appropriate for use as an introductory design project. Thus, the project contributes to meeting "technical content" objectives for the course and broader "a-through-k"[4] objectives for the curriculum.

## Motivation

"Mass Balances" and "Energy Balances" are a two-quarter sequence of introductory chemical engineering courses at Ohio University. Their content is largely based on the classic text by Felder and Rousseau.[5] Phase equilibrium, Raoult's Law, and T-x,y diagrams are introduced in

Material Balances. Sensible and latent heat calculations are introduced in Energy Balances. Students who master the course content should, for example, easily complete an equilibrium flash calculation or determine the heat duty for a condenser. However, instructors in subsequent courses felt students had not mastered key concepts in phase equilibrium and phase change. Analysis of student performance in "Energy Balances" suggested students could solve problems that were readily identifiable with a particular section in the text, but were perhaps less adept at applying these concepts in the context of larger problems.

An increased emphasis on multi-component phase equilibrium and the associated energy changes in Energy Balances was warranted. However, working more textbook problems was unlikely to resolve the students' difficulties. A problem was needed that was not readily identifiable with a particular section in the text. The author's experience supervising the continuous distillation column experiment in the Unit Operations Laboratory course suggested an appropriate topic. Fortunately, the author had already included a group design project in the Energy Balances syllabus. By basing a group design project on the in-house continuous distillation column, the author hoped to harness group learning to improve student mastery of technical content, and introduce students to process design to meet an objective.

## The Problem

The column in the unit operations laboratory is a three-story column with twelve bubble-cap trays, a total condenser, and a partial reboiler. Students were given a "tour" of the column and a simplified explanation of distillation; equilibrium stage operations are covered in detail in our curriculum the following year. The assignment is reproduced below. Operating conditions were taken from a student lab report. Equilibrium data were not provided, in keeping with our goal to produce engineers who can identify and seek out the information they need to solve problems.

> A distillation column is used to separate a mixture of methanol and water. The mixture to be separated has a flow rate of 0.26 gallons per minute and a density of 0.9059 g/ml. It is 41.6 wt% methanol. Its temperature is 19 ºC. The distillate composition is 88.6 wt% methanol and the distillate density is 0.8242 g/ml. The distillate flow rate is 0.10 gallons per minute. The reflux flow rate is 0.318 gallons per minute. The bottoms product is 16.7 wt% methanol with a density of 0.9714 g/ml. The bottoms flow rate is 0.16 gallons per minute. You may assume the column boil-off is a saturated vapor at its dew point, and the bottoms product is a saturated liquid at its bubble point. The column will operate best if the feed enters the column as a saturated liquid at its bubble point. You have cooling water available at 10 ºC. You have saturated steam available at 45 psig.
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> Design a system that will use energy from the column boil-off to preheat the feed. The feed should enter the column as a saturated liquid at its bubble point. The reflux should return to the column as a saturated liquid at its bubble point. The distillate product should also be a saturated liquid at its bubble point. Report your design in a memo. Specify the types of equipment you will need (e.g. pumps, condensers, boilers) and the number of each and the flow rates of steam and cooling water required to run the distillation column as you have designed it. Provide a flow sheet of your design. Note your assumptions and describe your calculations briefly, but do not submit your calculations. Do have them available in case I need to see them.

## Student Progress

Initially, this was to be the third of four group projects. However, the number of visitors during office hours quickly demonstrated that students were struggling, and few groups would complete the project on time. Group project 3 became a progress report on the design, allowing the instructor to identify difficulties and provide direction. The final design was submitted as group project 4.

In general, the progress reports demonstrated student competency in the technical content of the Mass and Energy Balances courses. Students handled the missing equilibrium data well. Most assumed ideality, and used the Antoine coefficients in the text to calculate vapor pressures. Two groups used vapor-liquid equilibrium data from a handbook to determine bubble point and dew point temperatures. Students correctly calculated the heat to be removed in the condenser and the heat to be added in the feed preheater. More importantly, the students went beyond the mechanics of the calculations. They correctly noted that the temperature of the vapor boil-off from the column was only 76 °C, and therefore could not heat the column feed to 85 °C. Students benefited from this opportunity to review and synthesize course material, and most seemed sufficiently prepared in technical content for the subsequent courses.

Students were bothered by the problem being over-specified, so the component material balance does not close exactly. This was their second exposure to such a situation in this course. (The first was the discovery that the heat lost by the hot side of the heat exchanger in the unit operations lab does not exactly equal the heat gained by the cold side, due to the uncertainty in the thermocouples.) Our seniors are expected to reconcile the numbers themselves. The sophomores are clearly uncomfortable with “correct” numbers being “uncertain”, but this reaction is expected. Textbook problems rarely provide such exposure, which must be repeated throughout the curriculum if our graduates are to deal with such situations confidently.

The real difficulty was in getting students to consider the system as a whole rather than a collection of details. The first indication of this came in calculating the heat required in the reboiler. Students tend analyze each component of a process sequentially rather than grouping them and writing an overall balance. Most textbook problems can be successfully solved sequentially, although a balance on grouped components may be faster. However, isolating the reboiler does not work for this problem, because the students cannot determine the liquid and vapor flow rates at the bottom of the column. Several groups needed encouragement to try different system boundaries until they lumped the reboiler with the column. At that point, they were able to write and apply conservation equations to find the energy requirement of the reboiler.

A system approach was clearly lacking in the designs. Most decided to superheat the column boil-off, thus providing the temperature driving force to raise the column feed to 86 °C. Rather than transferring the latent heat of vaporization from the column boil-off to the feed, they specified the preheater so the boil-off would exit at its dew point, then used the original condenser as if there were no change to the process design. Because they were using only the energy released by temperature change, the required temperature for the boil-off entering the preheater approached 300 °C! Of eight groups, five used this approach in their progress report. These five also superheated the column boil-off with a "magic heater", which added a defined amount of energy from no particular source.

Graded progress reports were returned with comments about overall efficiency and using the considerable energy available as latent heat. Grading was lenient, as this was a draft and not a final report. However, final reports showed little improvement in the overall design. Although the "magic heaters" disappeared, four groups still superheated the column boil-off, transferred this sensible heat to the column feed, then condensed the boil-off. One group introduced a complex scheme that used additional house steam to vaporize part of the bottoms product, then used this stream to preheat the feed.

## Student Evaluation

Fourteen of twenty-four students named the distillation column design as the group project they learned most from. They stated that it required them to review, synthesize, and apply concepts from both the Mass and Energy Balances courses. Several students noted a sense of accomplishment in attacking what seemed like a "real" problem.

## Conclusions

Based on student comments, this project was successful in reinforcing technical content. Their performance shows that the majority of students can complete calculations involving multi-component phase equilibrium, sensible heat, and latent heat. Unsatisfactory performance in subsequent courses is probably not caused by failure to master these technical skills. The students' weakness is a tendency to complete each calculation in isolation. Clearly, students need to practice a wholistic approach to problem solving. This ability cannot be developed in a single course, and therefore cannot be left to the senior design course. However, students do not improve by repeating their mistakes. It was particularly disappointing to see little improvement from the progress to the final reports. Both practice and more effective guidance are needed.

Two simple changes to the project will make it more effective. First, the goal of efficiently using existing energy sources must be explicit. Sophomores have not yet learned that efficiency is always a goal for engineering design. Our graduates should consider efficiency automatically; our sophomores need direction. Second, the focus of the progress report must be explicit. The progress reports here were an after-thought, and were graded to satisfy the syllabus requirement for four group projects. Grading was lenient, although comments were extensive. Apparently, students took the lenient grading to mean the comments were minor, and paid them little heed. Several groups were shocked by their low final report grades. In the future, progress reports will be marked but not graded. This strategy has worked for previous group projects. Students are attentive to comments when the opportunity to improve their grade is clear. Overall, this project provides a useful learning and assessment tool for an introductory chemical engineering course.

Bibliography


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VALERIE YOUNG
Valerie Young is in her third year as an assistant professor of chemical engineering at Ohio University. She received her B.S. in chemical engineering from Lehigh University in Bethlehem, Pennsylvania, and her Ph.D. in chemical engineering from Virginia Polytechnic Institute and State University in Blacksburg, Virginia. Prior to her faculty appointment, Valerie spent four years as a research associate at the Centre for Atmospheric Chemistry, York University, Toronto, Ontario, Canada. Her research field is atmospheric chemistry and air quality.