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The teaching of enhanced distillation processes using a commercial simulator and a project-based learning approach

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ABSTRACT

When a multicomponent fluid mixture is non-ideal, its separation is difficult; thus, enhanced separation processes with several equipments are required. Commercial chemical processes simulators must be used to design these difficult separations, so ChE students have to learn them. This work shows the teaching methodology and outcomes of using computer labs with Aspen Plus to solve advanced distillation processes within a fourth year course of the ChE degree. Lectures on theoretical aspects are followed by seminars and then by computer labs. During lab computers, the professor initially solves a case, step by step; while the students do it at the same time. Then, they are asked to solve an industry relevant case using a project-based learning approach in order to force them to continue working with the simulator on their own, and to enhance the comprehension of the process. They have to deliver a report summarizing and critically analyzing the results. This assignment counts 25% the course total grade. A survey done to the students showed their satisfaction with the method. They were very favorable to the use of Aspen Plus as a tool for a better understanding of the enhanced distillation processes. Moreover, they found the tutorials very useful to improve their knowledge on this simulator. All students passed the course, 80% obtained good grades.

1. Introduction

Separation processes could be defined as the processes in which a multicomponent mixture is transformed into two or more different products. In case of fluid mixtures, the most common separation operation is distillation. In ideal binary mixtures, a single distillation column may suffice, but in case of multicomponent mixtures, more than one distillation column is required. Moreover, when the multicomponent fluid mixture is non-ideal, i.e. relative volatilities are too low or azeotropes are formed, its separation by a sequence of ordinary distillation columns will not be technically and/or economically feasible (Henley et al., 2011). For such mixtures, enhanced separation processes have been developed, including extractive distillation, homogeneous azeotropic distillation, heterogeneous azeotropic distillation, pressure-swing distillation, reactive distillation, supercritical extraction and membrane separations.

The analysis, design, control, and optimization of these separations involve phase equilibrium relationships and material and energy balances. In case of non-ideal mixtures these calculations often fail because of liquid-solution non-idealities and/or the difficulty of specifying feasible separations (Henley et al., 2011). In addition, calculations become too complex, due to the need of solving a set of non-linear algebraic equations and in most cases, the requirement of several separation equipments.

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Commercial chemical processes simulators include accurate thermodynamic packages coupled with sufficiently rigorous computational algorithms which enable engineers to solve rapidly these difficult separations. Currently, there are several commercial chemical process simulations available, such as Aspen Plus, CHEMCAD, SuperPro Designer, PROSIM, etc. Engineers at industrial practice use these simulators. Thus, their learning needs to be covered in chemical engineering education. An effective manner to learn them is through computer laboratories introduced in order of growing complexity as shown by Rockstraw (2005) or with the aid of interactive guides as demonstrated by Castrellón et al. (2009). Furthermore, these tools can be added to a lecture course and used to solve realistic problems to minimize the time necessary to train the students, as successfully experienced by Wankat (2002, 2006) in his own courses. The use of process simulation in ChE courses was analyzed by Dahm et al. (2002) concluding that computing is generally accepted as an integral component in teaching design but it has not significantly permeated the rest of the curriculum. So these authors recommend the implementation of mini-modules thorough the courses.

Azeotropic distillation has been generally studied in Chemical Engineering degrees succinctly, qualitatively, explaining the basics, without addressing the rigorous resolution. Moreover, there are few universities that have courses in Advanced Operations in Graduate Studies.

On the other hand, there are not many textbooks that rigorously explain enhanced distillation. The latest edition of the book “Separation Process Engineering” by Professor Wankat has a full chapter (number eight) dedicated to these operations (Wankat, 2012). The sizing of the columns is made with the approximate McCabe-Thiele method. An annex provides an introduction to the resolution with Aspen Plus. However, it is not enough for teachers and students who are not knowledgeable in this simulator. Other textbook that explains in detail the azeotropic distillation is the latest version of Henley et al. (2011), chapter eleven.

This work summarizes our experience in the design and put into practice a course in advanced separation processes that included computer lab practices with a commercial process simulator. We chose Aspen Plus because the Department of Chemical Engineering of the Complutense University of Madrid had the license; but other commercial simulators could also being used.

2. The course

Advanced separation processes are an optional six-credit (ECTS) course for the fourth year students of the degree of Chemical Engineering. It covers enhanced distillation operations, supercritical extraction, membrane separations and advanced drying operations. The course is divided into 30 h of lectures, 15 h of seminars, 12 h of laboratories, 3 h of tutorship, and 3 h of exams.

The student learning is evaluated through the projects they have to deliver after the lab practices and through several short exercises/solved problems that are collected after the seminars. In addition, a written test is done at the end of the classes to primarily evaluate the theoretical content of the subject.

The final exam counts 60% of the grade. The seminar exercises count 15% and the lab assignment, the remaining 25%. Lab attendance is obligatory. The grading scheme is the typical for the Universities in Spain: SS (fail) = <5; AP = 5–7; NT = 7–9; SB = 9–10. The complete syllabus of the course is available in http://quimicas.ucm.es/data/cont/media/www/pag-10534/2014-15/GIQ_Guia%20docente%20Ampliacion%20Operaciones%20de%20Separacion_2014_FINAL.pdf and from the author at lcalvo@ucm.es.

The students get to this course after completing a course in “Applied Thermodynamics” in the second year and after finalizing “Unit Operations” which is an obligatory subject for the third year students. In the latter, they learn the fundamentals of thermodynamics, mass transfer and equilibrium stages as well as the separations based on phase addition or creation: distillation, liquid–liquid extraction and absorption using approximated and rigorous computer aided methods. During the second semester, they study separations processes by barriers and solid agents as well those involving a solid phase.

The course is divided into two parts, each one leaded by a different professor. We are in charge of Enhanced Distillation and Supercritical Extraction. The objective of the present document is to describe the method and the outcomes of our experience in teaching this complex subject with the aid of computer labs using Aspen Plus and a project-based learning approach.

3. Teaching method

Lectures on theoretical aspects are followed by seminars and then by computer labs. A project-based learning (PBL) approach is used in the computer labs. Real separation cases are presented to the students to oblige them to integrate the theoretical knowledge previously given and to improve skills such as critical thinking and problem solving. Mills and Treagust (2003) studied the application of project-based learning (PBL) to engineering education using several examples. They concluded that students who participate in PBL are generally motivated by it and demonstrate better teamwork and communication skills. They have a better understanding of the application of their knowledge in practice and the complexities of other issues involved in professional practice. Consequently, these authors recommend the use of PBL as a key component of engineering programs since it is also appreciated by industry and accreditors alike. Engineering schools that have programs of a predominantly project-organised curricula in Europe are: Aalborg and Roskilde in Denmark; Bremen, TU Berlin, Dortmund and Oldenburg in Germany, Delft and Wageningen in Netherlands. More recently, PBL has been implemented in the curriculum at the department of Biotechnology and Chemical Engineering of the Helsinki Metropolia University (Fortelius et al., 2015). A positive response from the students in the form of augmentation of motivation and activity has been found. Team skills have improved as well as independent study capacity.

PBL may be also applied in individual courses. Joyce (2009) found excellent results on the use of PBL on an Engineering Design course at Newcastle University. Students commented positively on the creativity allowed them and the sense of ownership of their learning which this engendered.

3.1. *Description of the course*

The first lectures are devoted to show how to track a distillation following residue and distillation curves, and how to