AC 2011-1851: A COURSE ON PROCESS DESIGN AND OPERATION IN AN ENGINEERING TECHNOLOGY PROGRAM

Vassilios Tzouanas, University of Houston - Downtown

Vassilios Tzouanas is an Assistant Professor of Control and Instrumentation in the Engineering Technology Department at the University of Houston-Downtown. Dr. Tzouanas earned a Diploma in Chemical Engineering from Aristotle University, the Master of Science degree in Chemical Engineering/Process Control from the University of Alberta, and the Doctor of Philosophy degree in Chemical Engineering/Process Control from Lehigh University. His research interests focus on process control systems, process modeling and simulation, artificial intelligence and expert systems. His professional experience includes management and technical positions with chemicals, refining, and consulting companies. He has published and presented a number of papers on advanced process control, real-time optimization systems, adaptive control, artificial intelligence and expert systems. He is a member of AIChE.

A COURSE ON PROCESS DESIGN AND OPERATION IN AN ENGINEERING TECHNOLOGY PROGRAM

Abstract

This paper discusses a new course on Process Design and Operation offered to Control and Instrumentation Engineering Technology students at the University of Houston –Downtown. The objective of this course is the computer aided design and optimization of process operations. Processes are selected from major industrial sectors such as chemical, refining and bio-processes. Modeling and simulation of these processes is facilitated by using the Aspen Engineering suite of tools. Such tools are widely used by the process industries to design and optimize process operations. By completing this course, students learn about different processes, equipment and optimization techniques. Groups of three to four students work together on team projects. The organization, execution, and results from such projects demonstrate the skills acquired by the students.

I. Introduction

To build a foundation on process modeling and simulation, undergraduate students are offered an introductory course on the subject, ENGR 3410. Typically, students take this course in the junior year. This course provides an introduction to material and energy balances in engineering applications, including chemical, environmental and biological systems. Use of software tools such as Matlab and Excel is made to solve engineering problems. The textbook by Felder and Rousseau[1] is used and the following topics are covered in ENGR3410:

1. Introduction to Engineering Calculations
2. Typical Processes and Process Variables
3. Fundamentals of Material Balances, Total Mass and Component Balances
4. Single-Phase Systems, Simple Countercurrent Processes
5. Multiphase Systems, Binary Distillation Column Calculations
6. Energy and Energy Balances, Energy and Thermal Properties
7. Energy Balance Calculations
8. Balances on Nonreactive Processes
9. Balances on Reactive Processes

Although the students learn about engineering calculations and how to setup and solve equations involving material and energy balances, their knowledge about process operations is shallow. If the objective is to train students in control and instrumentation technologies, they will be more effective as control systems engineering technologists if they know, in detail, and understand the process they attempt to control. Thus, the need exists for students to further their engineering background on different industrial processes from a design and operation viewpoint. Having a strong background on control systems coupled with an in depth knowledge of process operations helps the students be better prepared to meet the needs of the large regional industry and thus be more marketable in the current difficult business environment. Furthermore, they will be better prepared for graduate studies, if this is the career path they choose.

This paper is organized as follows. Section II describes the objectives of the new course. Section III discusses the teaching approach and how team projects are executed. Section IV presents the results from one such student projects. Section V summarizes the main points from teaching this course in Fall 2010.

II. The New Course on Process Design and Operation

To meet the previously identified need, a new course on process design and operation was introduced. The course is ENGR 4402 and is titled Process Design and Operation. It is a senior level course and was taught for the first time in Fall 2010. The course uses the textbook by Seider et al.[2] Typically, such a course is taught widely by many chemical engineering programs. However, it is rarely included in Engineering Technology programs. The primary objective is to teach students what is known about process design and operation and the tools used in this technical field. The expectation is that students will build a strong background on process operations, modeling and simulation which will help them become effective control engineering technologists and be better prepared for industrial and/or graduate type of work.

More specifically, the course covers the following topics

1. Review of Process Modeling and Simulation Concepts
2. Introduction to Aspen Engineering Suite of Tools (Aspen Plus)
3. Physical Properties using Process Simulators
4. Distillation Process Design, Modeling and Simulation
5. Heat Exchanger Design, Modeling and Simulation
6. Reactor/Bioreactor Systems Design, Modeling and Simulation
7. Pump Design, Modeling and Simulation
8. Modeling and Simulation of Integrated industrial Processes
9. Engineering Economic Analysis
10. Computer Tools for Optimization – Linear Programming

It aims to:

1. Teach students how to use commercial packages for modeling, simulation, and optimization of major components of industrial processes from several sectors (petroleum, chemical, renewable energy, bioengineering.)
2. Teach students different problem solving approaches (how to define the problem, what data/ information is needed, how/where to obtain the needed information, consider alternative approaches to solve the problem, and select and implement the best approach to obtain a practical solution.)
3. Provide exposure to different process units through class lectures and individual study during team project execution.
4. Develop students' skills for technical communications/presentations in a team environment.
5. Provide a learning environment that stimulates students' curiosity and interest in addressing important engineering problems through practical solutions.
6. Provide a learning environment that encourages students to conduct their professional activities in a manner consistent with the engineering code of ethics.

with the expectation that the student taking this course will learn to:

1. Apply engineering principles to model, simulate, and optimize the operation of major industrial processes
2. Research and obtain needed information/data for solving problems
3. Make an economic analysis of alternative process designs and optimize process operation based on an economic objective function
4. Simulate an industrial process using a commercial process simulator
5. Effectively analyze and troubleshoot results obtained from process simulation models
6. Develop project management skills
7. Prepare effective reports and give effective oral presentations

III. The Teaching Approach

As it is apparent from the previous section, the course aims to teach technical skills but also help students develop project management skills and practice communication and presentation skills. Classroom teaching is combined with laboratory exercises. Heavy emphasis is placed on teamwork. At the end of the semester, the students must present a team project. The project is of sufficient complexity and workload that it is very difficult for one student to complete it alone in a semester's time frame.

To illustrate the teaching approach, the topic of distillation will be presented. In this typical session on distillation process design and operation, the students learn about the concept of distillation, how to design a distillation to achieve desired product specifications, simulate a distillation process and consider the impact of certain operating variables on its operation. By considering the McCabe-Thiele diagram (see Fig. 1), the total number of trays can be estimated to achieve desired product specifications. Along with the McCabe-Thiele diagram, the concept of vapor-liquid equilibrium is reviewed.

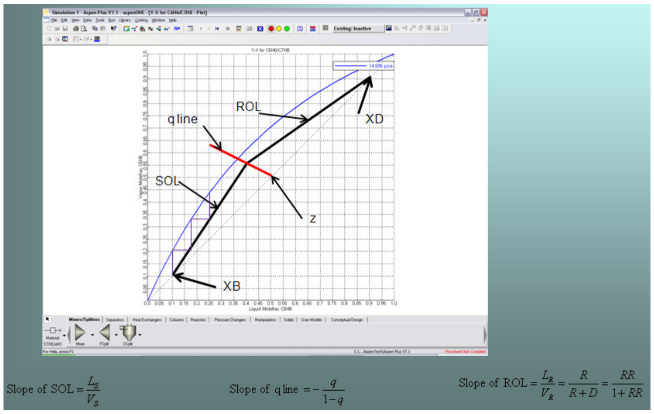
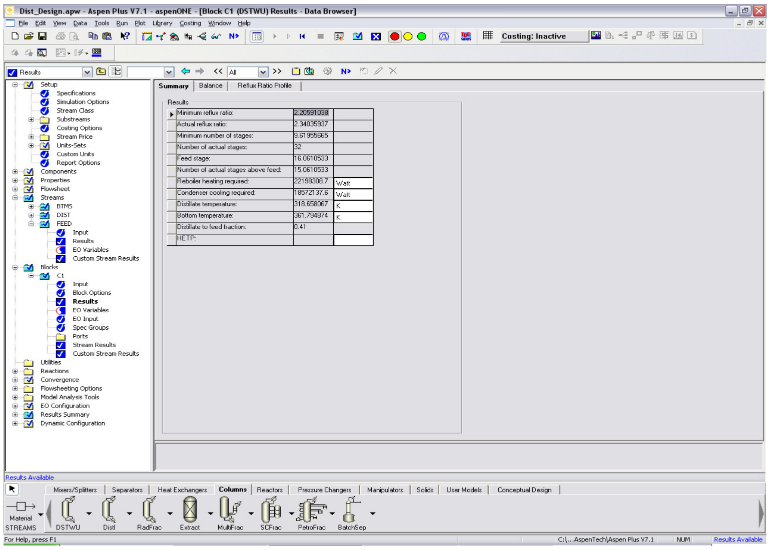


Fig. 1: McCabe-Thiele Diagram for a Binary Distillation Process

At the same time, Aspen Plus tools are used to design a distillation column to achieve the same separation considered when the McCabe-Thiele design diagram was discussed. Thus, the students learn how to use commercially available software tools to design processes. Fig. 2 shows results from Aspen Plus for the design of a distillation process which separates propane and iso-butane.

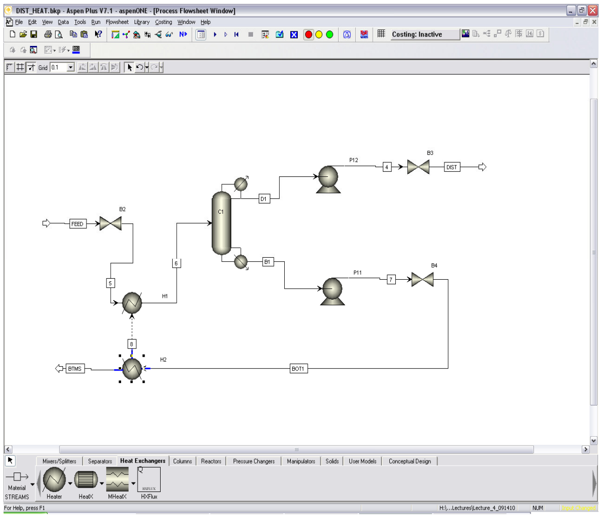


Results

Minimum reflux ratio:	2.20591038	
Actual reflux ratio:	2.34035937	
Minimum number of stages:	9.61955665	
Number of actual stages:	32	
Feed stage:	16.0610533	
Number of actual stages above feed:	15.0610533	
Reboiler heating required:	22198308.7	Watt
Condenser cooling required:	18572137.6	Watt
Distillate temperature:	318.658067	K
Bottom temperature:	361.794874	K
Distillate to feed fraction:	0.41	
HETP:		

Fig. 2: Design Results for a Distillation Process Using Aspen Plus

Likewise, the Aspen Plus software is extensively used to simulate the behavior of many processes commonly encountered in industry. For example, Fig. 3 shows the simulation of a distillation processes with feed preheat while Fig. 4 shows the simulation of an ammonia process which involves reaction, flash separation, mixing, and compression.



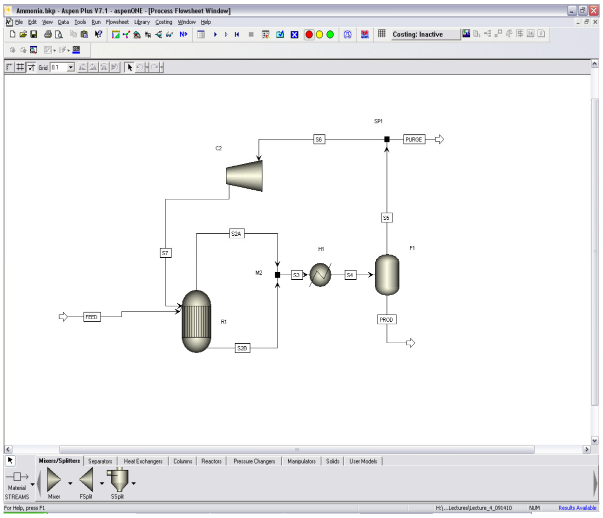
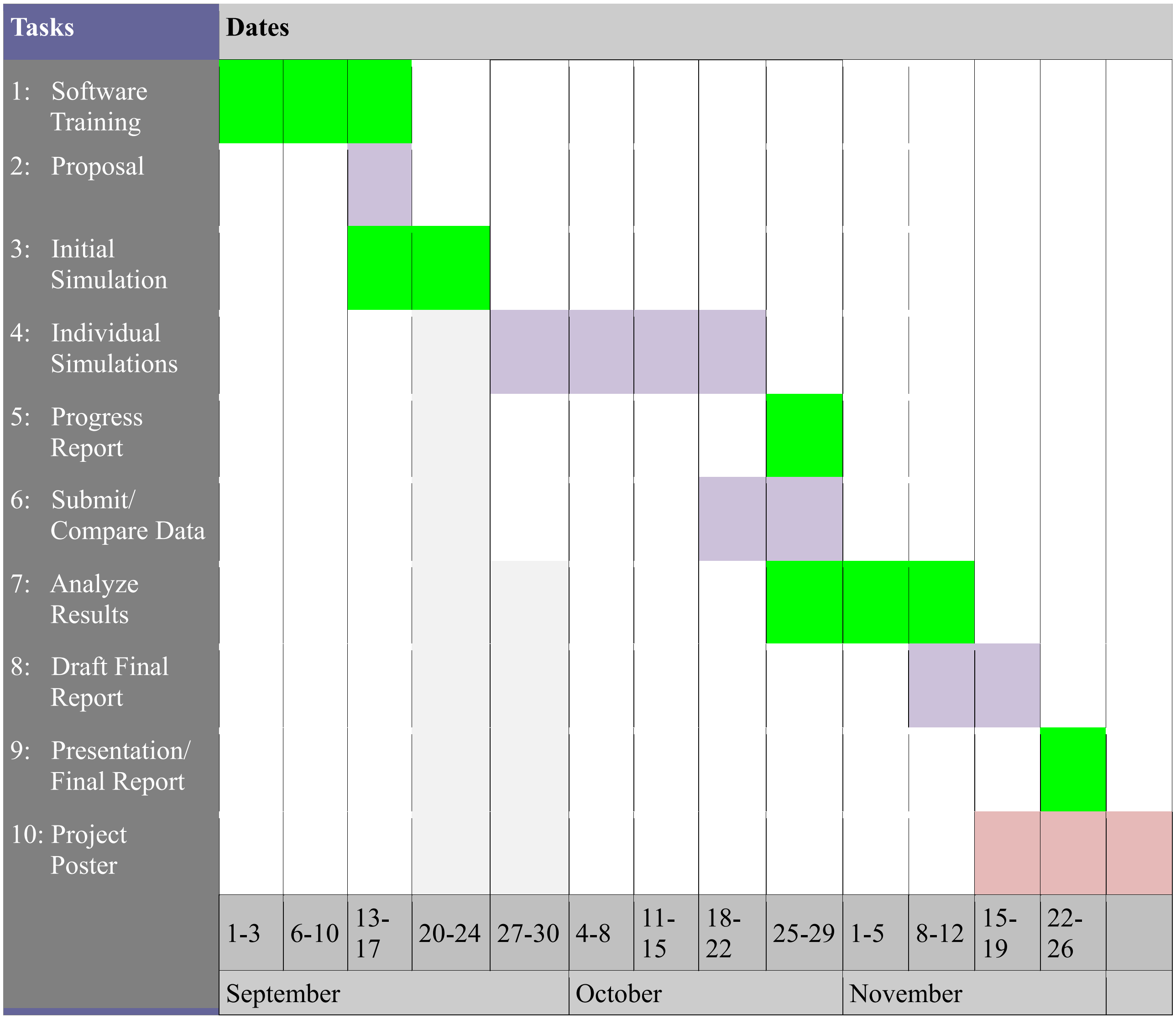


Fig. 3: Simulation of Distillation with Feed Preheat **Fig. 4:** Simulation of an Ammonia Process

Even though classroom teaching is combined with hands on experiments on the simulation of industrial processes, a lot is learned by working on a major team project. To achieve significant results in the short period of a semester course, the student teams must work efficiently and effectively. Thus, a lot of emphasis is placed on team organization. The teams are self directed. Even though students may take more active role on driving the completion of certain project activities, there is not a team leader. All students are jointly responsible for the success of the project. Also, students on the same team may not get the same grade for the course. Membership is limited to three to four students per team. Students are given the option to select their teammates. Since many of our students work while pursuing studies, this approach helps minimize scheduling conflicts among themselves. Each student team must develop and present for approval a project proposal. The proposal outlines specific objectives, required resources, time-table of project execution, roles and responsibilities. Team effectiveness is also judged by the timely completion of project deliverables. The project execution plan is the basis of assessment. Fig. 5 shows such an execution plan. Informal project updates occur on a weekly basis. A formal mid-term project status update is part of the course grade. Final project presentation and reporting occur at the semester end. This requirement aims at improving writing and presentation skills.



Tasks	**Dates**													
1: Software Training	🟩	🟩	🟩											
2: Proposal			🟪											
3: Initial Simulation			🟩	🟩										
4: Individual Simulations					🟪	🟪	🟪	🟪						
5: Progress Report									🟩					
6: Submit/ Compare Data								🟪	🟪					
7: Analyze Results									🟩	🟩	🟩			
8: Draft Final Report											🟪	🟪		
9: Presentation/ Final Report													🟩	
10: Project Poster												🟥	🟥	🟥
	1-3	6-10	13-17	20-24	27-30	4-8	11-15	18-22	25-29	1-5	8-12	15-19	22-26	
	September					October				November				

Fig. 5: Typical Project Execution Plan

IV. A Student Team Project: Heat-integrated Distillation Configurations for the Ternary Separation of Benzene, Toluene, and m-Xylene

In this section, we present one project completed by undergraduate students as part of ENGR 4402. The objective is to demonstrate the rigor of the course, the wide technical concepts mastered by the students, and that such advanced topics are appropriate for engineering technology programs. The results of the following project are indicative of the work accomplished.

Project Objective

The objective of this project is to use concepts taught in ENGR 4402 to select the configuration of distillation towers that yields the least energy consumption for the ternary separation of benzene, toluene, and m-xylene. It involves the simulation of heat integrated columns and demonstrates the benefits of heat integration in distillation operations. This study was conducted by re-evaluating some of configurations reported in the 1985 work by Cheng and Luyben[3].

Introduction

This project replicated the distillation column configurations of the Cheng and Luyben study via Aspen Plus software. The work took place during a semester's timeframe and was carried out as a two part study in which a base case was simulated and evaluated and then used for comparison with three more complex and heat integrated configurations. In the end, the most energy efficient configuration was chosen and compared to the Cheng-Luyben selection. For many technical details and process data, the reader is referred to the Cheng-Luyben original paper.

Base Case Study

This configuration is considered a Light Out First (LOF) in which the bottom product of the first column is the feed to the second column. Feed to the first column was pre-heated by the overhead vapor of the second column and then by the bottom product stream of the second column. Benzene was the top product of the first column. Toluene was the overhead product of the second column, and m-xylene was the bottom product of the second column. In Aspen Plus, the flowsheet for the base case is shown in Fig. 6. This case is considered to be non-heat integrated because it relies on external heat alone for the reboiler sections of both distillation columns.

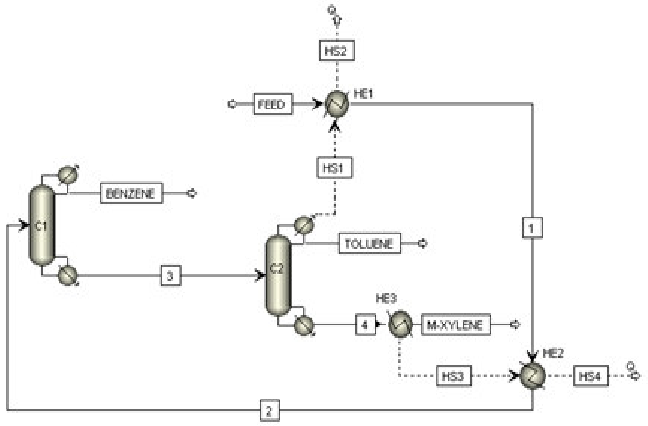


Fig. 6: Aspen Plus Flowsheet Design for Base Case

The stream results obtained from the Aspen Plus simulation closely resemble the results from the Cheng-Luyben study. These were recorded as the base case results to which all heat-integrated configurations were compared to in order to evaluate the energy consumption of each of them. The final overall heat duty of both reboiler units in the distillation columns was *5.13 x* 10^6 *kcal / hour*. These results are illustrated in Table 1.

Table 1: Base Case Steady State Stream Results

	Feed	**1**	**2**	**3**	**4**	**m-xylene**	**benzene**	**toluene**
Component Mole Flow (kmol/h)								
Benzene	75.00	75.00	75.00	0.70	0.00	0.00	74.30	0.70
Toluene	150.00	150.00	150.00	149.29	0.22	0.22	0.71	149.07
m-Xylene	75.00	75.00	75.00	75.00	74.78	74.78	0.00	0.22
Component Mole Fraction								
Benzene	0.25	0.25	0.25	0.00	0.00	0.00	0.99	0.00
Toluene	0.50	0.50	0.50	0.66	0.00	0.00	0.01	0.99
m-Xylene	0.25	0.25	0.25	0.33	1.00	0.99	0.00	0.00
Mole Flow (kmol/h)	300.00	300.00	300.00	224.99	74.99	74.99	75.01	150.00
Pressure (mmHg)	843.60	1140.00	1140.00	955.00	985.00	1105.00	760.00	760.00
Temperature (°C)	15.50	100.80	113.60	127.94	151.09	110.80	80.05	111.40
Heat Duty (10^6 kcal/h)	---	---	---	2.20	2.93	---	---	---
Total Heat Duty (10^6 kcal/h)	***5.13***							

Heat Integration Case Studies

Three heat integration case studies (shown in Fig. 7 through Fig. 9) were considered. These configurations are reported as cases 2, 8, and 11 in the Cheng-Luyben[3] study. The stream results from this case are not included for the sake of brevity. Table 2 summarizes the total energy consumption for all column configurations considered.

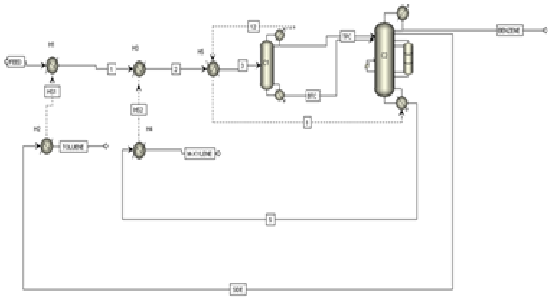


Fig. 7: Case 1 Aspen Plus Flowsheet

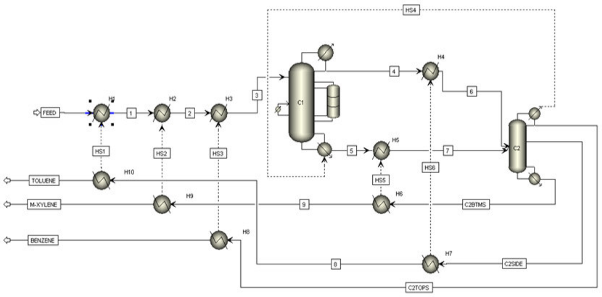


Fig. 8: Case 2Aspen Plus Flowsheet

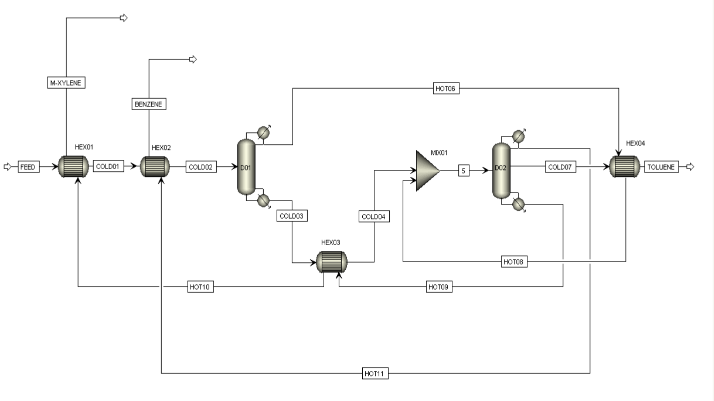


Fig. 9: Case 3 Aspen Plus Flowsheet

Table 2: Total Energy Consumption for Distillation Column Configurations

CASE	Total Energy Requirement (10^6 kcal/hr)
Base Case	**5.13**
Case 1	**2.84**
Case 2	**2.32**
Case 3	**2.76**

Discussion

By comparing the overall reboiler heat duties between the two cases, it is very apparent that the heat-integrated system is much more energy efficient than the non-heat integrated system.

Furthermore, the results obtained using Aspen Plus are in agreement with the Cheng-Luyben study.

From a students' viewpoint, this course provided an opportunity to learn about a wide range of processes and equipment such distillation columns, chemical reactors, heat exchangers, pumps, compressors, etc. The study was approached from a design and an optimization viewpoint. Understanding of the different topics was greatly facilitated by a combination of theory and practical exercises. The team project has been extremely beneficial. It provided an opportunity to work on a challenging design and process optimization project. Developing a project proposal with clear deliverables, completion deadlines, and roles and responsibilities helped the team deliver quality results in a timely manner. Modeling of complex process configurations has been facilitated by using the Aspen Plus software, commonly used by the process industries for design and operation purposes. There is a learning curve involved with the use of Aspen Plus but the time investment in the basic skills development is returned extensively through the time reduction of future simulations and evaluations. Modeling, simulation, and optimization of such complex distillation processes can be done in a semester's timeframe.

V. Conclusions

This paper presented details on a new course on process design and operation in an engineering technology program. The objectives of the course were outlined along with the teaching approach. By completing this course, students learn about a number of process operations, how to use commercially available software tools to design and optimize a process, and improve their project management and presentation skills. Working effectively in teams is considered necessary and critical to completing the work load of the course. The student project demonstrated the rigor of the course and the fact that students in engineering technology can meet the challenges of the course. The course helps students build a strong foundation on process operations. Teaching of the course is facilitated by using commercially available software tools, the Aspen Engineering suite of tools. Major project work is required for the students to master process operations concepts but also make students proficient in the use of commercial modeling tools.

Acknowledgements

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