Modeling, Simulation, and Control of Heat Integrated Distillation Columns: A Case Study

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AC 2012-3500: MODELING AND CONTROL OF HEAT INTEGRATED DISTILLATION COLUMNS: A CASE STUDY

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Enrique Barbieri received the Ph.D. in electrical engineering from the Ohio State University in 1988. He was on the faculty of the School of Engineering at Tulane University as Assistant Professor in the Electrical Engineering Department (1988-1994), and as tenured Associate Professor (1994-2002) and Chair (1996-1998) of the Electrical Engineering and Computer Science Department. In August 2002, he joined the University of Houston as Professor and Chair of the Department of Engineering Technology, College of Technology (2002-2009). He served as Associate Dean for research and graduate studies for the College of Technology (2009-2010) and returned to full-time faculty in fall 2010. He was Director of the Center for Technology Literacy (2006-2010), and a member (2006-2011) and Chair (2007-09) of the Executive Council of the Texas Manufacturing Assistance Center. In Jan. 2012, he joined the University of North Texas as Professor and Chair of the Department of Engineering Technology, College of Engineering. His teaching and research interests are in the control systems engineering technology area. He is a member of the ASEE and a Senior Member of the IEEE - Control Systems Society.

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Introduction

Nearly 40% of the energy consumed in the chemical and refining industries is used by distillation processes. Thus, understanding the behavior of distillation processes, predicting their response under a wide range of operating conditions, and operating them under reduced energy consumption conditions while making products of desired quality are worthwhile industrial objectives.

This paper is concerned with the modeling, simulation, and control of heat integrated distillation columns. The widely used industrial separation of benzene, toluene, and m-xylene is considered as a case study. The impact of heat integration was analyzed from an energy savings viewpoint.

Heat integrated distillation columns are generally more complicated from a control viewpoint because of the greater degree of interaction among the columns. Thus, different control structures, ranging from feedback only to more sophisticated ones such as feed forward and cascade, and tuning methods are devised and compared from a performance viewpoint when product composition setpoint changes or feed rate and feed composition disturbances are introduced.

Furthermore, extensive use of Aspen Engineering tools was made to facilitate project execution. AspenPlus was used for steady state simulation while Aspen Dynamics was used for dynamic model development and control structure evaluation. These tools are exactly the same used by major industries for the design, optimization and retrofitting of important processes.

From a learning point of view, this type of work requires a sound technical background encompassing several disciplines, namely: unit operations, steady state and dynamic modeling, industrial modeling and simulation tools, and process control. Key results shown below demonstrate the breadth and depth of the required technical knowledge as demonstrated by Engineering Technology students at two sister universities: the University of Houston – Downtown and the University of Houston.

Process and Steady State Simulation

The separation of benzene, toluene, and m-xylene was also studied by Cheng and Luyben[1] from a steady state point of view. Initially, it was verified that the original case 8 of the Cheng/Luyben study was the least energy consuming heat integrated column arrangement. AspenPlus was used to perform the steady state analysis and process arrangement selection. This step of the study was conducted by undergraduate students at the University of Houston – Downtown in partial fulfillment of the requirements of the Process Design and Operation course, ENGR 4402.

The process configuration is shown in Fig. 1.

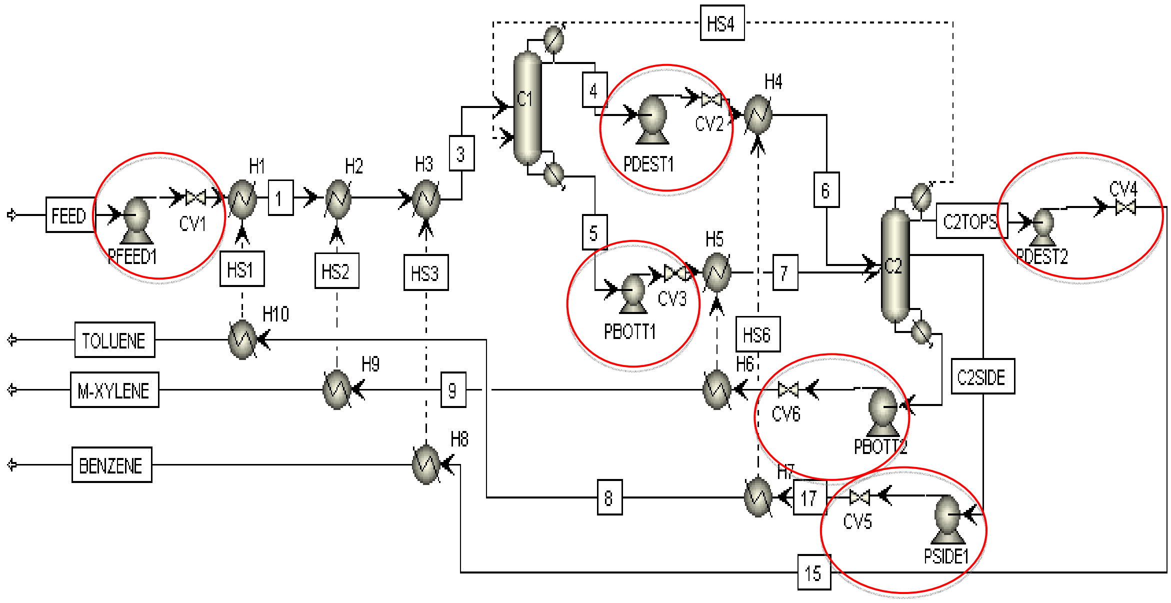

Fig. 1: Case-8 Process Configuration in Aspen Plus

Dynamic Process Simulation and Basic Controls

This part of the study was conducted by a University of Houston master thesis student in the process automation laboratory of the University of Houston – Downtown in partial fulfillment of the master thesis requirements at the University of Houston.

Using the steady state design mentioned in the previous section, a rigorous dynamic process simulation was developed using Aspen Dynamics. The use of Aspen Engineering tools to dynamically predict process behavior and evaluate control structures is not yet widespread in academia even though such tools (at least the steady state ones) are extensively used by the processing industries. It was decided to use such tools because of the rigor of the results produced and the marketing advantage for our students upon graduation.

Fig. 2 shows a snapshot of the dynamic process simulator along with basic controllers for material balance and proportional/integral (PI) controllers for product composition control.

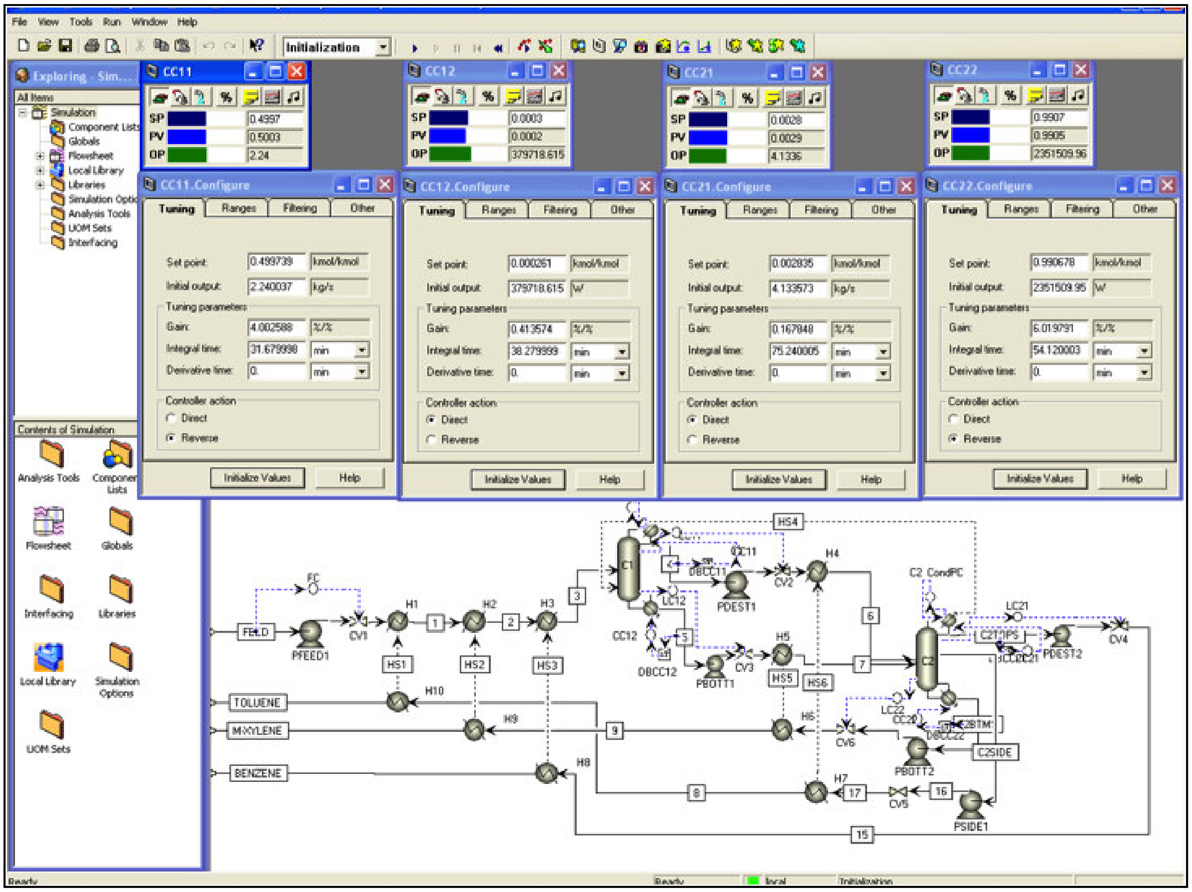

Fig. 2: Dynamic Simulation and Product Composition Control

Model Identification and Controller Design

Controller design was based on empirical models relating controlled and manipulated variables. Such models were developed using data gathered from the dynamic simulation by perturbing the manipulated variables (e.g. reflux, heat input) in a stepwise manner. These empirical models were first order or second order plus time delay models. An example model which relates the reflux to the benzene composition of the distillate product of the first column is given below, along with its equivalent using Pade approximation:

$$G_{R1D1}(s) = 0.1291\frac{e^{-36s}}{828s+1} = -1.559x10^{-4}\frac{(s-0.0556)}{(s+1.208x10^{-3})(s+0.0556)}$$

MATLAB® software will be used for designing controllers. The methodology is based on root locus theory and using SISOTOOL. Fig. 3 shows the root locus for the transfer function G_{R1D1}(s) while Fig. 4 shows the closed loop system response to a setpoint change for benzene in the distillate product when the PI controller is:

$$G_{CR1D1}(s) = 0.0470\frac{(1+2x10^{3}s)}{s}$$

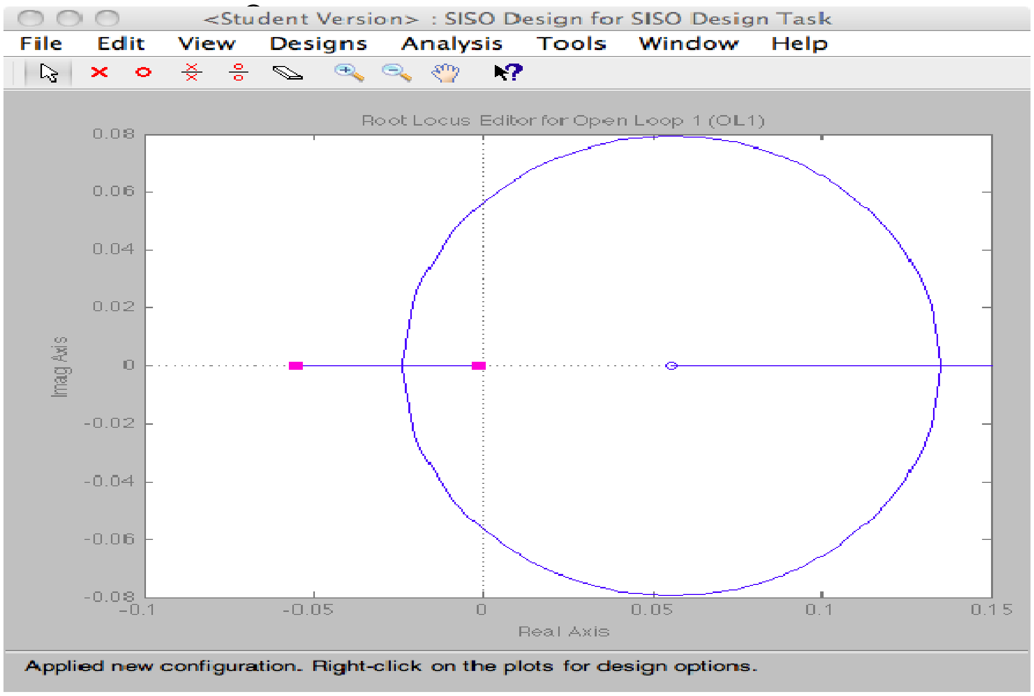

Fig. 3: Root Locus for $G_{R1D1}(s)$

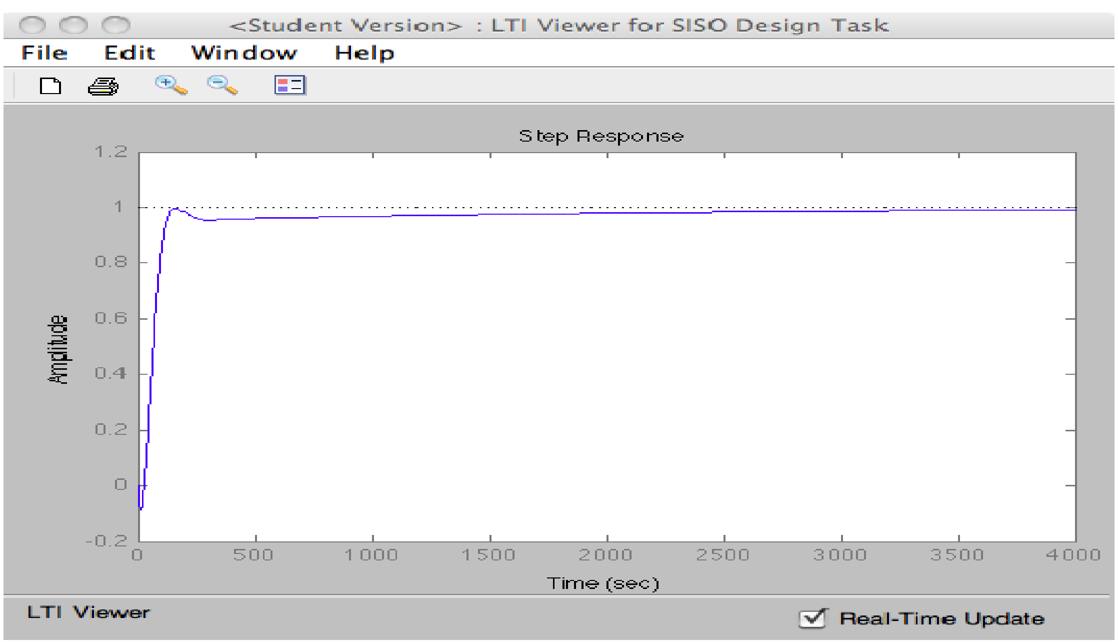

Fig. 4: Step response of the system $G_{R1D1}(s)$ in the presence of a PI controller

Conclusion

This paper demonstrates the modeling, simulation and control of heat integrated distillation columns. Heat integration reduces energy consumption but increases process interactions and thus the complexity of control systems. Modeling and control system design were performed by using Aspen Engineering tools, commonly used in process industries. This type of work solidifies the process control background for Engineering Technology students.

References

1. Cheng, H., and Luyben, W. (1985). Heat-Integrated Distillation Columns for Ternary Separations. *Ind. Eng. Chem. Process Des. Dev*. 24. pp 707-713.