Contents lists available at ScienceDirect

Education for Chemical Engineers

journal homepage: www.elsevier.com/locate/ece

Transient analysis of shell-and-tube heat exchangers using an educational software

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ABSTRACT

Computer-aided design has become extremely popular and its use in classroom can be very helpful, adding more analysis capabilities to all engineering areas. A free piece of educational software to teach transient analyses of shell-and-tube heat exchanger equipment to undergraduate students is presented. The software was developed to provide unit operation courses with realistic exercises involving dynamic simulation of chemical processes. The use of the program improves the efficiency of the course since it let students practice heat exchanger analysis while relieving them of tedious repetitive calculations.

Keywords: Heat exchanger; Unit operations; Education; Software; Simulation

1. Introduction

Computer-aided design and analysis has leveraged a major shift in the way chemical engineering has been taught in recent years. Any modern and competitive engineering curricula cannot afford the absence of computer/software related courses, just because their students and future engineers would have difficulties to adapt or to match the current professional market demands.

The benefits of using computer-aided tools to improve the learning process of engineering students are broadly recognized. Although the market for process engineering simulators is supplied by a number of vendors, such as Hysys, Pro/II, CHEMCAD, COMSOL, ASPEN Plus, HTRI, HTFS, THERM and CCTherm (Selbaş et al., 2006); such packages are meant for the professional with full understanding of process equipment and are not well suited for didactical purposes when the understanding of the phenomena influencing an equipment functionality is intended.

Shell-and-tube is the most used type of heat exchangers in chemical industries. It consists of a bundle of pipes or tubes enclosed within a cylindrical shell. One fluid flows through the tubes and a second fluid flows within the space between the tubes and the shell. They can operate at high pressures, and their construction facilitates disassembly for periodic maintenance and cleaning (Selbaş et al., 2006; Butterworth, 1987; Cartaxo and Fernandes, 2009; Castier and Amer, 2011). Although the concept is simple, there are a large number of phenomena associated with flow and heat transfer that results in a system that is difficult to master without making in numerous calculations (Dı′az et al., 2001).

Shell-and-tube heat exchangers requires the knowledge and calculation of complicated heat and fluid flow geometries, turbulence in the flow, existence of hydrodynamic and thermal entrance regions, non-uniform local heat transfer rates and fluid temperatures, secondary flow in the tube bends, vortices in the neighborhood of the tube-fin junctions, heat conduction along tube walls, natural convection within the tubes, and temperature dependence of fluid properties. Even steady-state predictions are not easily made from a first principle analysis, therefore dynamic predictions are, of course, harder.

A number of education professionals have found their own pedagogical solutions for teaching heat exchanger design as an analysis. To fill the gap left by third-party packages and commercial vendors, instructors around the world have

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Received 2 August 2013; Received in revised form 27 March 2014; Accepted 6 May 2014
http://dx.doi.org/10.1016/j.ece.2014.05.001
1749-7728/

developed customized computational applications to fulfill their educational needs (Lona et al., 2000; Ali Kara and Güraras, 2004; Fernandes and Rodrigues, 2004; Cartaxo and Fernandes, 2009; Fernandes and Cartaxo, 2010; Martín and Mato, 2008). Most available software were developed aiming mechanical and thermal engineering after the steady-state operation was reached. Additionally, few software aims toward chemical engineering problems.

Dynamic studies are important to study control strategies, study cooling performance and also to program changes in temperature that may be required by chemical reactors. Many studies depicting several scenarios are reported in the literature showing the importance of dynamic studies in the engineer's life. Control problems and scenarios have been reported by Yan et al. (2014). Shen et al. (2014) and Beier (2014) have studied the cooling performance of heat exchangers using dynamic changes. Dynamic studies can also be used to develop control strategies for reducing the energy consumption (Diaz-Mendez et al., 2014; Ibrahim et al., 2014). The importance of developing heat exchange programming for reactors was presented by Fu and Xu (2013) and Henini et al. (2013).

This work presents a non-commercial educational software developed to introduce the transient study of heat exchanger equipments (shell and tube heat exchangers, from 1–1 to 1–4 flows configurations) to undergraduate students. Special care was taken in the design of the software interface to allow the students to concentrate their efforts in learning how to analyze the transient behavior of shell-and-tube heat exchangers and not in learning how to use the program. Several exercises and also stand alone simulations can be performed with the software, so the students can have a permanent tool to be used when needed.

The development of the program started in 2009 and since then the program has been tested in undergrad courses on heat exchangers and simulation of our university. The program has also been available through the Internet during most of this time. The information gathered from this experience has been used to optimize the capabilities and interface of the program. *DHXA* is distributed without charges on the web page www.deq.ufc.br and it can be installed by the students on their personal computers.

2. Learn through doing concept

The philosophy used to develop the software is the "learning through doing", where the exercises are presented in a way to involve the student in the assignment. The software was developed to be complementary to the teaching of the fundamentals and mathematical methods of the technical phenomena. The software is used to stress the engineering practice, not only the textbook design procedure, so that students do not have the wrong idea that an isolated analysis is complete. They need a perspective that the practice is much more than the fundamentals.

Showing some applications examples, the graduate will enter engineering with an awareness of how fundamentals can be connected to practice, and there will be less of a tendency to resort to pure empiricism. Furthermore, this will build an awareness of the complexity and scope of engineering practice, and will combat any impression that the isolated and simplified school day's design is sufficient (Rhinehart, 1991).

Specifically for the case of teaching heat exchangers, the example applications are to be carefully planned. Although, in practical terms, the operation and control of these equipments are relatively simple, their analysis and design is complex due to the large amount of equations that needs to be solved and due to the iterative nature of the solving technique (Cartaxo and Fernandes, 2009). The design of shell-and-tube heat exchangers including thermodynamic and fluid dynamic design, cost estimation and optimization represents a rather complex engineering task involving a variety of design rules, judgment considerations, calculating methods and empirical knowledge of various fields.

Some industrial cases were reviewed and common examples were transformed into exercises to be used with the software (Shreve and Austin, 1984; Kirk et al., 1992). The exercises present the problem that should be solved, where the equipment is placed inside the process and asks for the student to find a solution for that particular problem. The exercises bring several concepts into the student's attention, such as: industrial applications of the heat exchangers, influence of major design parameters, influence of the operating conditions and environmental concerns. The student can feel themselves as an engineer making the course more interesting than the ones in which the student only solves exercises without having an idea about the process they are working with.

The *DHXA* software was built to be a pathway to understand the heat exchanger dynamic behavior. We have focused on the overall comprehension of the cause–effect relation governing the equipment operation. Details about the design method, the numerical solution scheme and other important concepts are considered a prerequisite at this time, and in our university it is ministered in the unit operations course.

3. Software

The software code was implemented in Delphi v7 and is available for PC's running Windows system (XP or higher). The use of Delphi v7 allowed the software to be fully visual and avoided any kind of link with external DLLs that could require installing third party software. A set-up was built for easy installation of the software that can be run in any PC.

The software was divided into modules comprising the typical workflow of analyzing a heat exchanger, i.e., input the project parameters, equipment specification, equipment operation and the transient analysis.

The simulator built in the software implements a solver for the numerical solution of the mathematical model. The mathematical model is comprised essentially by a set of partial differential equations, combined with some constitutive relations for estimation of physical properties, heat transfer coefficients, among others model parameters. Several design options can be assessed and modified by the user, such as the number of passes in the tubes, number of tubes, internal and external tube diameter, shell diameter, tube length, tube pitch, pitch type (squared or triangular), baffle spacing, and allocation of the cold and hot fluids (shell or tube side).

While the software allows the student to quickly run several test cases to gain insight about sensitive parameters in the design process, it does not do the entire job. The student should learn how to read standard tables like IPS or BWG pipe specifications to input the required pipe dimensions into the software (Kern, 2001). This approach enhances the learning