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Suitability of some commonly available software for unconventional condenser analysis

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HIGHLIGHTS

- The goal is to assess suitability of common SW tools for unconventional geometries.
- Review of available methods for calculation of filmwise condensation is provided.
- SW tools are compared via thermal-hydraulic analysis of an industrial condenser.
- Results obtained during simulations are compared to experimental data.
- There is a lack of flexible tools capable of evaluating non-standard geometries.

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ABSTRACT

Computer aided design of heat transfer equipment, i.e., thermal-hydraulic design of process and power apparatuses for heat exchange, is an essential part of industrial practice. There are several world-renowned software tools of which the most-used ones are those developed by Heat Transfer Research, Inc. (HTRI® Xchanger Suite®), Aspen Technology, Inc. (Aspen Exchanger Design & Rating), and Chemstations, Inc. (CHEMCAD™). Advantages of these sophisticated software systems are unquestionable particularly in the field of conventional heat exchanger solutions. This paper, however, aims to compare and discuss features of the above-mentioned packages in case of unconventional equipment via a specific industrial problem in which components having common geometries could not be used.

For this purpose, thermal-hydraulic analyses of an unconventional steam condenser is performed using educational versions of the three packages with operating parameters at the inlet of the apparatus, thermo-physical properties of streams, and geometry of the apparatus being taken from the operator of the condenser. Based on comparison of the obtained results and condenser operating data it can be seen that although some of the available software tools offer relatively large sets of functionalities, there still is opportunity for development of flexible tools – especially those capable of evaluating non-standard geometries.

1. Introduction

Two-phase flow heat exchangers are widespread and important equipment that greatly influence reliability of the process and energy units in which they are used. A large subset of these apparatuses are condensers, i.e., heat exchangers with one of the working fluids being converted – at least partially – from vapor to liquid phase. Condensation occurs in a wide range of applications. Such equipment can be utilized both for condensing of media ("condensers") and heating of process streams by condensing fluids. Also, often the condensing hot stream causes evaporation of the heated cold stream – typically in evaporators or feed-effluent heat exchangers in petrochemical refineries. In all these cases condensation heat transfer coefficient usually controls the heat exchange process. All the mechanisms occurring during condensation therefore significantly influence design of the entire equipment.

Configurations of such apparatuses are quite diverse and must respect types of the condensing and the cooling substances, required degree of condensation, extent of subcooling of the condensate and many other factors. In order to meet all the requirements and with respect to the design considerations related to

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operating conditions, a wide range of configurations has been developed for various process and energy industry applications. Design methods must therefore be as flexible as possible while retaining sufficient accuracy. As for the available commercial software tools, these are primarily intended for design and rating of standardized configurations and hence their wider use is somewhat hindered. In light of these facts one cannot blindly rely on commercial tools without questioning validity of the obtained results.

What is more, designers must often optimize the standardized equipment in order to achieve higher efficiency [1], cut operating cost via reduced fouling [2], or decrease the amount of emissions being produced [3]. This process commonly involves layout customizations or modifications of designs of individual components of the equipment. To do so, equipment manufacturers can either use their own in-house software tools based on generally available [4] or proprietary methodologies or they can employ commercially available software packages. In the latter case, however, the range of available functionalities is limited considering non-standard equipment geometries. Such limitations then inherently lead to simplifications of the respective model geometries and/or substitutions of custom parts by standardized components. Quality of the obtained results may therefore be lower.

Considering the above, suitability of the three often-utilized software packages, namely educational versions of CHEMCAD [5], HTRI Xchanger Suite [6], and Aspen Exchanger Design & Rating [7], for evaluation of unconventional process equipment is investigated. This is done by means of simulation of an industrially used steam condenser in all three tools and comparison of the obtained results to data provided by the operator of the apparatus.

1.1. Available calculation methods

Considering filmwise condensation of pure vapors, it was first described by Nusselt [8]. In his analysis, he assumed – among other things – that the condensation surface was isothermal, heat transport through liquid film was by conduction only, and that liquid and vapor phases were in thermodynamic equilibrium at the interface. His method was later many times modified by other researchers and also by Nusselt himself in order to make it more general (see e.g. Ref. [9]).

As for vapor mixtures, there are two main approaches. The first approach is utilized in equilibrium methods which are based on the equilibrium condensation curve. This was first described by Atkins [10]. The basis for calculation of heat transfer rates via an equilibrium method was devised by Silver [11] and later, independently, extended by Bell and Ghaly [12]. However, the general assumption that the condensation process follows the equilibrium curve may not always be valid and may thus introduce significant errors.

Film theory methods representing the second approach are based on film theory of mass transfer. These methods take into account the rate of diffusion of molecules in the vapor phase. Film theory assumes that mass transfer resistance to diffusion of a condensing mixture is approximated by a thin film placed next to the vapor–liquid interface. Generally, there are different film theory methods for various mixtures. Vapor phase resistance is calculated using the Colburn–Hougen method [13] in case of condensation of a vapor in the presence of a non-condensing gas. Vapor phase resistance of a binary vapor mixture, on the other hand, is utilized in the Colburn–Drew method [14]. In case of a multicomponent mixture, it may consist only of condensing vapors or may contain one or more non-condensing gases. Then the vapor phase resistance is calculated via the Krishna–Standart method [15].

The most common method used to calculate heat transfer rates during condensation is the Bell–Ghaly method. In fact, the majority of available commercial software tools employ condensation models based on this method [[16], pp. 591]. Implementation of the Bell–Ghaly method is rather straightforward and follows the basic principle of equilibrium methods. The starting point here is construction of a condensation curve characterizing the equilibrium (temperature and vapor fraction at the given pressure) between the condensing vapor mixture and the condensate in relation to the amount of heat released along the heat transfer surface. Such condensation curve thus represents an approximation of the actual "condensation path". The entire path is then discretized and in each segment – so called "zone" – thermophysical properties and all other parameters including film heat transfer coefficient are considered to be constant. Discretization is performed with respect to equal enthalpy or temperature increments [5] and allows us to use simplified algebraic equations, that is, equations without differential terms. Once all the zones are evaluated, individual quantities are summed up over the zones which gives us their overall values. Accuracy of the results is predetermined by accuracy of the condensation curve since this curve is the basis for all performed calculations (determination of the sensible and latent heat, temperature of the cold stream, available temperature difference, individual heat transfer coefficients and the overall heat transfer coefficient, etc.).

Nonetheless, in order to produce an accurate-enough condensation curve in one of the commercially available software tools, proper selection of the utilized thermodynamic model is crucial [17]. In other words, our selection of phase equilibrium calculation method will significantly influence the resulting condensation curve and hence also the accuracy of the obtained results.

Considering the three discussed software tools, HTRI Xchanger Suite offers the Resistance Proration Method (RPM) which is an enhanced equilibrium method and the Composition Profile Method (CPM) which is a method based on film theory of mass transfer.

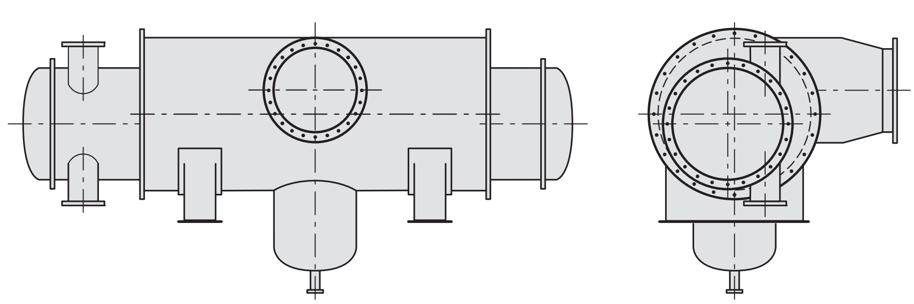

Fig. 1. Schematic of the investigated condenser.