International Communications in Heat and Mass Transfer 38 (2011) 951–957

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

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

Transient behavior simulation of fin-and-tube heat exchangers for the variation of the inlet temperatures of both fluids ☆

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ARTICLE INFO

Available online 20 April 2011

Keywords:
Heat exchanger
Transient
Time constant
Fin-and-tube

ABSTRACT

In this article, a transient behavior simulation of fin-and-tube heat exchangers has been studied. Energy equation for fluid flow and tube wall is derived and solved numerically. The variation of the temperatures of both fluids with time and position are obtained for a step-change in the inlet temperatures of the water and air fluids. The results show that in step-change of inlet water-side temperature, outlet water-side temperature will get steady faster than air-side, while in step-change of inlet air-side temperature, outlet air-side temperature will become steady state faster than water-side. Also, the time constant (the time interval that the flow will reach steady state) of the system is not influenced by the step-change amplitude of inlet air and water temperatures. The inlet water temperature expands along the tube and after a time interval, it reaches the outlet section of the tube. But, the inlet air temperature reaches the outlet section without time delay.

1. Introduction and aim of the work

Fin-and-tube heat exchangers have been employed in industrial application such as car radiator, air conditioning, refrigeration, cryogenics, heat recovery, marine and boiler economizer, as well as in many products available in the marketplace. One of the main problems of heat exchangers is the prediction of the transient behavior which occurs during start up and shut down or during non-stationary function. The control of systems incorporating heat exchangers is necessary to understand the response of the latter to the variations of flow rates and entering fluid temperatures. The analysis is mainly about the response characterization as well as the design of the necessary controls to the safe operation of heat exchangers under steady and transient conditions. Over the years, several articles and books on the design of fin-plate heat exchangers have appeared in the literatures, including Kays and London [1], Kern and Kraus [2] and Shah et al. [3]. A study on transient response of the fin-and-tube heat exchangers was first attempted by Shah [4]. In this study, a transient response analysis including problem formulation, exchanger variables and specific solutions, for the responses to the step-changes in inlet temperatures and/or flow rates have been presented. The importance of the transient behavior of heat exchangers because of its effect on overall performance of the system has been studied by Gogus and Ataer [5]. They discussed the general formulation of the problem, some simple solutions, recent novel approaches and various techniques. In another article, Ataer et al. [6,7] developed three successive numerical approaches for the step-change in the inlet temperature of the hot fluid. Energy equations for the hot and cold fluid, tube wall and the fins are derived for each of these approaches and solved numerically using a finite-difference method. Roetzel and Xuan [8] investigated the transient behavior of multi pass shell and tube heat exchangers. They used the Laplace transformation to obtain the transient temperature distribution of the core wall and both fluids. Pierson and Padet [9] considered a physical model in which the response of double-pipe heat exchangers to step-changes in the inlet temperature of one fluid was studied completely. Hadidi and Padet [10] extended this model to simulate step-changes in inlet temperatures. To use the full capacity of the heat exchanger, the general method is to control the exit temperature of the cold fluid. It has been shown that this method is advantageous in air conditioning in comparison to controlling steam pressure or water flow rate. More recently, Yin and Jensen [11] presented an integral method of approximation of transient behavior of the heat exchanger. In this work, authors assumed that the single-phase fluid temperature distribution could be expressed by a combination of the initial and final temperature distributions and a time function. The solution method employed provided good predictions for transient performance when one of the fluids keeps a constant temperature along the whole process. Srihari et al. [12] studied the dynamic behavior of the single pass plate heat exchangers, considering flow maldistribution from port to channel. In addition to maldistribution the fluid axial dispersion was used to characterize the back mixing and other deviations from plug flow. They presented the effects of flow maldistribution and conventional heat exchanger parameters on the temperature transients of both U-type and Z-type configurations. Lenic et al. [13] presented numerical and experimental analyses of

☆ Communicated by: J. Taine and A. Soufiani.
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0735-1933/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.icheatmasstransfer.2011.04.016