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Performance monitoring of heat exchangers via adaptive observers

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Abstract

In this paper, a method for monitoring the performance degradation in a heat exchanger is presented. This method is based on the use of an adaptive observer which estimates the overall heat transfer coefficient U. The monitoring of this parameter can be useful to decide when the heat exchanger needs preventive or corrective maintenance. A simplified mathematical model of the heat exchanger is used to synthesize the adaptive observer. The effectiveness of the proposed method is demonstrated via numerical simulations and through experimental results.

Keywords: Performance monitoring; Heat exchanger; Adaptive observer

1. Introduction

Heat exchangers are present in a wide variety of engineering processes. They are generally used to achieve efficient heat transfer from one fluid to another. Examples of such useful devices are intercoolers, preheaters, boilers and condensers in power plants, just to mention some.

There are several types of heat exchangers:

- *recuperative type:* the fluids exchange heat on either side of a dividing wall;
- *regenerative type:* hot and cold fluids occupy the same space containing a matrix of material that works alternatively as a sink or source for heat flow;
- *evaporative type, such as cooling towers:* a liquid is cooled evaporatively in the same space as coolant.

In this work, the recuperative type of heat exchanger, which is the most common in practice, is considered.

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Nomenclature

T_{ci}, T_{hi}	inlet temperatures in the cold and hot side, respectively, K
T_{co}, T_{ho}	outlet temperatures in the cold and the hot side, respectively, K
U	heat transfer coefficient, J/(m^2 K s)
A	heat transfer surface area, m^2
c_{pc}	specific heat in the cold side, J/(kg K)
c_{ph}	specific heat in the hot side, J/(kg K)
ρ_c	density of the cold fluid, kg/m^3
ρ_h	density of the hot fluid, kg/m^3
V_c	volume in the cold side, m^3
V_h	volume in the hot side, m^3
v_c	flow rate in the cold side, m^3/s
v_h	flow rate in the hot side, m^3/s

One of the main problems of heat exchangers is the deterioration of the heat transfer surface due to the accumulation of a fouling film. For instance, fouling causes decay in the heat transfer effectiveness. This most often leads to increased energy consumption. In general, fouling is accepted as an unavoidable problem but many efforts are made to try to detect, mitigate and/or correct its occurrence [1–3]. This work is devoted to propose a way to detect performance degradation in a heat exchanger by means of an adaptive observer. Observers, generally referred to as *software sensors*, are useful to cope with the problems associated to the lack of relevant on-line sensors. They are used to estimate unknown parameters or unmeasured state variables from on-line and/or off-line measurements, see e.g. [4–7]. Much of the work done in the area of observer design has been based in the application of Kalman filters or extended Kalman filters (EKF) [8,9]. A different category of state estimators has been developed by other authors and implies the use of Luenberger observers or some extensions of them [10,11]. All these observers are used only for state estimation. Nevertheless, it is often the case that some parameter values of the processes are physically unavailable for measurement or they are time varying. When such is the case, provided that some assumptions are satisfied, it is possible to use adaptive observers for their estimation. An adaptive observer is basically one in which both the parameters and state variables of the system are estimated simultaneously. In the case of linear systems, they have been studied since the 1970s [12]. Recent works of adaptive observers are often based on variable changes transforming the original system into some canonical form in which the presence of the unknown parameters is simplified to some extent [13,14]. Recently, a simple constant-gain observer has been proposed in [15]. This approach involves two tuning parameters whatever the number of considered differential equations of the model is. Furthermore, the proposed observer is proved not only to be stable but also to yield the estimation error to zero.

Adaptive observers have been applied successfully to a wide variety of dynamical systems, for example, for the estimation of: the sprung mass in automotive suspensions [16], the partial pressure of hydrogen in the anode channel of fuel cells [17], the reaction kinetics in polymerization reactors [4] or bioreactors [7]. This work is devoted to propose a method based on an adaptive observer that can be used to track the overall heat transfer coefficient $U(t)$ of a counter-current heat exchanger. A periodic estimation (this periodicity depending on the use of the heat exchanger) of this coefficient can be useful to determine when the equipment needs a preventive or corrective maintenance. This is possible if the estimation on U of two different periods, performed under the same operation conditions of the equipment, gives considerably different results. The observer performance is evaluated first via numerical simulations and then using real process data.

This paper is organized as follows. Section 2 presents a simplified model of reasonable accuracy for counter-current heat exchangers. In Section 3, the problem of estimating the state for a class of nonlinear systems is considered. The observer synthesis for the heat exchanger is based on the mathematical model described in Section 2. Finally, concluding remarks are given in Section 4.

2. Simplified model of a heat exchanger

The recuperative type of heat exchanger may be designed according to one of the following types:

- parallel-flow (fluids flow in the same direction);
- counter-flow (fluids flow in the opposite direction);