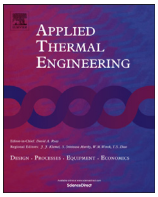
Applied Thermal Engineering xxx (2015) 1–8

Contents lists available at ScienceDirect

Applied Thermal Engineering

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



Research paper

Control of a heat exchanger using neural network predictive controller combined with auxiliary fuzzy controller

Anna Vasičkaninová*, Monika Bakošová

Slovak University of Technology in Bratislava, Faculty of Chemical and Food Technology, Institute of Information Engineering, Automation, and Mathematics, Radlinského 9, 812 37 Bratislava, Slovak Republic

HIGHLIGHTS

- The heat exchanger is a system with interval parametric uncertainty.
- The neural network predictive control is combined with the fuzzy control.
- PID, fuzzy and neural network predictive controllers are also implemented.
- The control structure with two controllers assures the control objectives.

ARTICLE INFO

Article history:
Received 18 December 2014
Received in revised form
20 February 2015
Accepted 23 February 2015
Available online xxx

Keywords:
Heat exchanger
Neural network predictive control
ANFIS
Takagi–Sugeno fuzzy controller
PID control

ABSTRACT

The paper presents an advanced control strategy that uses the neural network predictive controller and the fuzzy controller in the complex control structure with an auxiliary manipulated variable. The controlled tubular heat exchanger is used for pre-heating of petroleum by hot water. The heat exchanger is modelled as a nonlinear system with the interval parametric uncertainty. The set point tracking and the disturbance rejection using intelligent control strategies are investigated. The control objective is to keep the outlet temperature of the pre-heated petroleum at a reference value. Simulations of control of the tubular heat exchanger are done in the Matlab/Simulink environment. The complex control structure with two controllers is compared with the conventional PID control, fuzzy control and NNPC. Simulation results confirm the effectiveness and superiority of the complex control structure combining the NNPC with the auxiliary fuzzy controller.

1. Introduction

Heat exchangers play an important role in the process industry. A review of the methods used in the thermal analysis of heat exchangers and alternate approaches for providing fouling allowance in heat exchanger design are discussed in Ref. [1]. The objective of work [2] is to explore an efficient simultaneous synthesis method for heat exchanger network to provide satisfactory network designs with acceptable computational effort. As energy costs are permanently increasing, energy saving is becoming very important in industrial processes, and it is necessary to optimize the heat exchanger utilization [3]. The paper [4] presents a cost derivative method for finding the optimal area allocation for a defined heat exchanger network structure and stream data to achieve minimum total cost.

Predictive control is recently the most widely implemented advanced process control strategy in industrial applications. The novel approach of a fuzzy model-based multivariable predictive functional control of a heating ventilating and air conditioning system is presented in Ref. [5]. A novel supervision strategy is proposed in Ref. [6], reporting innovative techniques and main results of an application tool to diagnose the heat transfer efficiency of a heat exchanger of a pilot plant using neural network based models and parity space approaches associated to a rule based decision making strategy. In Ref. [7] is showed how to predict the heat transfer and pressure drop for in-line flat tube configuration in a crossflow, using an adaptive neuro-fuzzy inference system (ANFIS). The study demonstrates that the integrated system model is capable predicting the system's seasonal performance with a high degree of accuracy and minimum time demand, and can

---

* Corresponding author.
E-mail address: anna.vasickaninova@stuba.sk (A. Vasičkaninová).

http://dx.doi.org/10.1016/j.applthermaleng.2015.02.063
1359-4311/

Please cite this article in press as: A. Vasičkaninová, M. Bakošová, Control of a heat exchanger using neural network predictive controller combined with auxiliary fuzzy controller, Applied Thermal Engineering (2015), http://dx.doi.org/10.1016/j.applthermaleng.2015.02.063

effectively replace the costly and time consuming real-life experiments and trails. The inverse neural network is applied to optimization of operating conditions or parameters in energy processes in Ref. [8].

Fuzzy logic control (FLC) is nowadays successful control approach to complex nonlinear systems or even nonanalytic ones. Fuzzy controllers have the advantages over the conventional controllers: they are cheaper to develop, they cover a wider range of operating conditions, and they are more readily customizable in natural language terms. FLC has been suggested as an alternative approach to conventional control techniques in many situations. A survey on recent developments of analysis and design of FC systems focused on industrial applications reported after 2000 is presented in Ref. [9]. The paper [10] is the second in the series of three addressing the problem of how to deal with uncertainties in the modelling of engineering problems using only available data. The problem of the heat exchanger was selected as the example because it is sufficiently complex. In Ref. [11], a modified form of fuzzy finite element method is presented. The design of the controller based on the use of a finite-dimensional approximate model of high order, derived by spatially lumping the infinite-dimensional model of the heat exchanger is described in Ref. [12]. Fuzzy logic controllers have been implemented successfully in a variety of applications. Wakabayashi describes procedures related to the application of PI fuzzy control in a semi-batch reactor [13]. Hayward and Davidson illustrate the power of fuzzy logic through a simple control example [14]. In Ref. [15], a FLC of the motion of differential drive mobile robots has been presented. In Ref. [16], a new method for automatic extracting all fuzzy parameters of a fuzzy logic controller in order to control nonlinear industrial processes is proposed. A major contribution of fuzzy logic is its capability of representing vague data [17]. A novel artificial neural network aided fuzzy logic controller for simultaneous control of indoor air temperature and humidity was developed and is reported in the paper [18]. A multi-level, multi-factor and non-structural fuzzy optimum decision model is used in the optimal selection of compact heat exchangers in Ref. [19]. The neural network and fuzzy logic were used as modelling tools in Ref. [20].

Our paper presents an advanced control strategy that uses the neural network predictive controller and the fuzzy controller in the complex control structure with an auxiliary manipulated variable. The tubular heat exchanger was chosed as a controlled process because of its sufficient complexity.

2. Controlled process description

The heat exchanger is a device that is used to modify and control the temperature distribution of one medium by the other one when they are in direct or indirect contacts with each other. Consider a co-current tubular heat exchanger [21], where petroleum is heated by hot water through a copper tube (Fig. 1).

Among the input variables, the hot water flow rate $q_3(t)$ is selected as the control variable. The controlled variable is the outlet petroleum temperature T_{1out}. The mathematical model of the heat exchanger is derived under some simplifying assumptions. Parameters and steady-state inputs of the heat exchanger are given in Ref. [22].

For the identification, the step changes ±10%, ±20%, ±30% of the inlet volumetric flow-rate of the heating water were generated (Fig. 2).

According to the step changes, the heat exchanger is a time-delay nonlinear system with asymmetric dynamics. The model was identified using the Strejc method [23] from the step responses in the form of the nth order plus time delay transfer function in (1).

$$G = \frac{K}{(\tau s + 1)^n} e^{-Ds} \tag{1}$$

As several step responses were identified, intervals were obtained for the gain K, the time constant τ, the time delay D, and the heat exchanger was represented as the 3rd order system with interval parametric uncertainty. The nominal values of the parameters are the mean values $\tau_{mean} = 19.5$ s, $D_{mean} = 1.5$ s and $K_{mean} = 5.35 \times 10^4$ °C m^{-3} s [22].

3. Control of the heat exchanger

3.1. Neural network predictive control with auxiliary fuzzy controller

Predictive control is a model-based strategy used to calculate the optimal control action, by solving an optimization problem at each sampling interval, in order to maintain the output of the controlled plant close to the reference [24].

The appropriate predictive model is a key question in nonlinear model predictive control. The neural network-based model predictive controller (NNMPC) uses a neural network model of a plant to predict future plant performance. The predictions are used by a

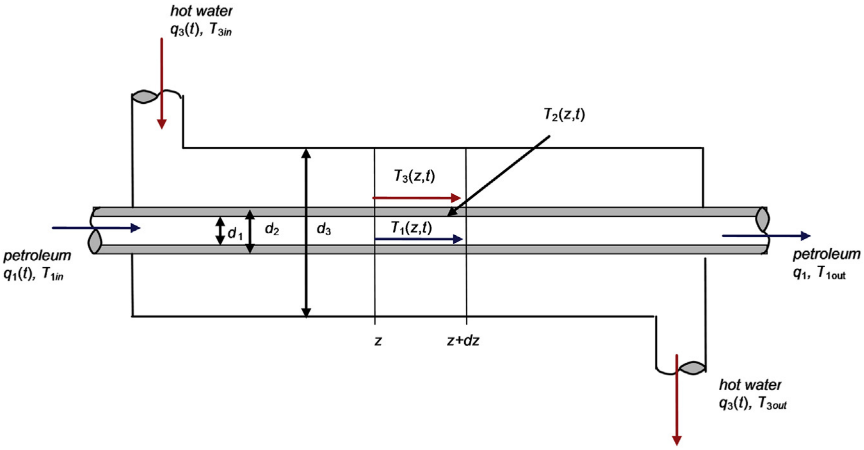


Fig. 1. Scheme of the co-current tubular heat exchanger.

Please cite this article in press as: A. Vasičkaninová, M. Bakošová, Control of a heat exchanger using neural network predictive controller combined with auxiliary fuzzy controller, Applied Thermal Engineering (2015), http://dx.doi.org/10.1016/j.applthermaleng.2015.02.063