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Performance assessment of heat exchanger using intelligent decision making tools

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ABSTRACT

Process and manufacturing industries today are under pressure to deliver high quality outputs at lowest cost. The need for industry is therefore to implement cost savings measures immediately, in order to remain competitive. Organizations are making strenuous efforts to conserve energy and explore alternatives. This paper explores the development of an intelligent system to identify the degradation of heat exchanger system and to improve the energy performance through online monitoring system. The various stages adopted to achieve energy performance assessment are through experimentation, design of experiments and online monitoring system. Experiments are conducted as per full factorial design of experiments and the results are used to develop artificial neural network models. The predictive models are used to predict the overall heat transfer coefficient of clean/design heat exchanger. Fouled/real system value is computed with online measured data. Overall heat transfer coefficient of clean/design system is compared with the fouled/real system and reported. It is found that neural net work model trained with particle swarm optimization technique performs better comparable to other developed neural network models. The developed model is used to assess the performance of heat exchanger with the real/fouled system. The performance degradation is expressed using fouling factor, which is derived from the overall heat transfer coefficient of design system and real system. It supports the system to improve the performance by asset utilization, energy efficient and cost reduction in terms of production loss. This proposed online energy performance system is implemented into the real system and the adoptability is validated.

1. Introduction

Heat exchangers are used to transfer the heat between two fluids across a solid surface that are at different temperatures [18]. Shell and tube heat exchangers are used in refrigeration, power generation, heating, air conditioning, manufacturing and medical applications [20,15]. These heat exchangers consist of a bundle of tubes and enclosed within a cylindrical shell. One type of fluid flows through the tube and second type of fluid flows between shell and tubes. The performance of heat exchanger deteriorates with time due to formation of fouling [5]. It is categorized into particulate, corrosion, biological, crystallization, chemical reaction and freeze. It is exclusively due to single mechanism in many situations. The methodology followed to observe performance of the heat exchangers mainly depends on the adopted practice in the plant, application, type of heat exchanger and experience of the operator. Vijaysai et al. [31] reported that the following key practices have been seen to be most prevalent and include monitoring of heat exchanger from gathering information with experts: (i) outlet temperature of the hot stream (T_{ho}) profile, (ii) approach temperature ($T_{ho} - T_{ci}$) profile, (iii) log mean temperature difference (LMTD) with time, (iv) heat load profile, (v) time series of overall heat transfer coefficient. Although the first four methods are widely used, they are ineffective in terms of isolating the net impact of fouling from process upsets, whereas the overall heat transfer coefficient method requires detailed calculations and knowledge of the geometry of the exchangers. Any deviation from the design heat transfer coefficient will indicate the occurrence of fouling [30,14]. To overcome this, heat exchanger performance should be monitored online with intelligent tools and assess the performance periodically. It needs competent predictive model of a system to assess the heat exchanger performance. Modeling is a representation of physical or chemical process by a set of mathematical relationships that effectively explain the significant process behavior. These models are frequently used for process design; safety system analysis and process control [29]. In experimental studies and engineering applications of thermal science, researchers and engineers are expected to reduce experimental data into one or more simple and compact dimensionless heat transfer correlations [32]. The drawbacks of this method are heat transfer coefficients strongly depend on their definitions and temperature differences, and certainly need iterative method to find correlations when fluid properties are dependent on fluid

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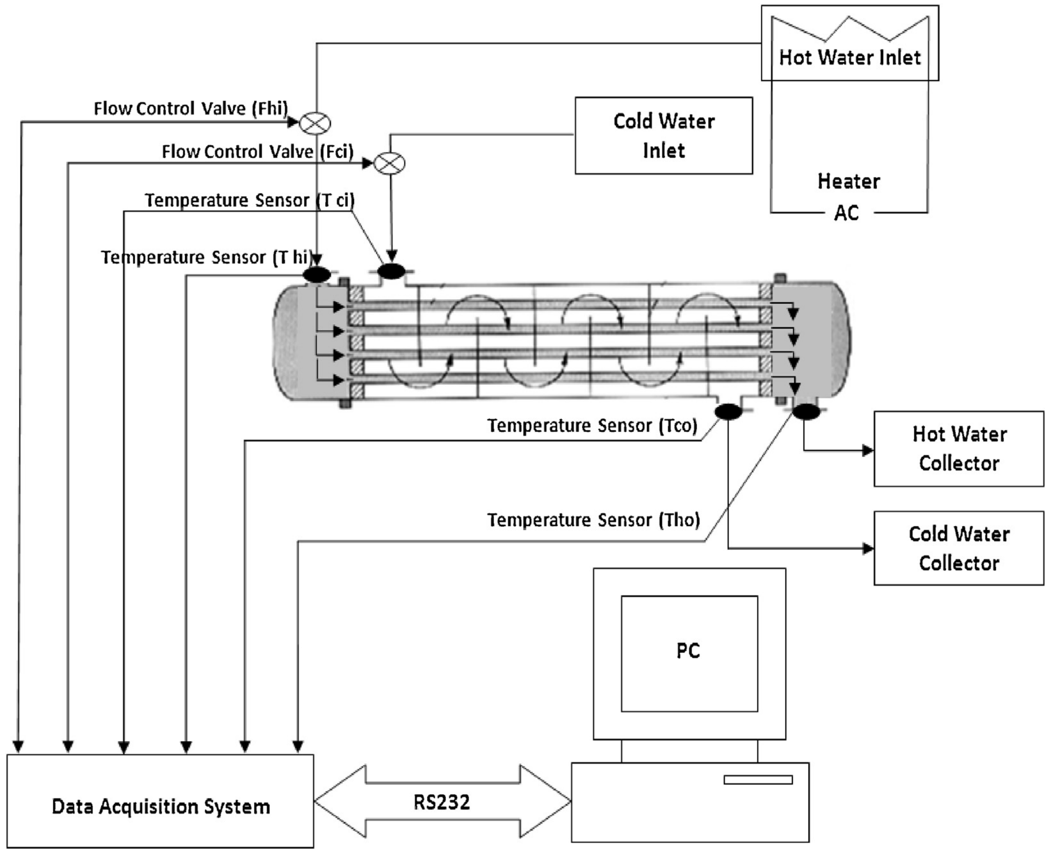

Fig. 1. Schematic diagram of experimental set-up in shell and tube heat exchanger.

temperatures [36]. The limitations of correlation methods are addressed by computational intelligent techniques, such as Artificial Neural Networks, fuzzy logic [24,23] and genetic algorithm [25,8]. Artificial Neural Network (ANN) is one of the most powerful computer modeling techniques, based on statistical approach, currently being used in many fields of engineering for modeling complex relationships which are difficult to describe with physical models. It only needs input/output samples for training the network and learn complex nonlinear relationship [33].

In recent years, Artificial Neural Networks have been used in thermal systems for heat transfer analysis, performance prediction and dynamic control [32]. ANN is applied in heat transfer data analysis [28,26], evaluating heat transfer coefficients from experimental data [13], identifying and controlling heat exchangers [3], simulation of heat exchanger performance using limited experimental data [6], modeling of heat exchanger dynamic characteristics [37], dynamic modeling and controlling of heat exchangers [34], dynamic prediction and neuro controller design for heat exchangers [7], neuro predictive controller design of heat exchangers [17], determining fin-and-tube heat exchangers performance with limited experimental data using soft computing and global regression [21,22], predicting heat transfer rate of a wire-on-tube heat exchanger [11], heat transfer analysis of air flowing in corrugated channels [35,12,2], control of heat exchanger in a closed flow air circuit [16] modeling the thermal performance of compact heat exchanger [27], predict the performance of laminar turbulent fluid flow in heat exchangers [9], performance assessment of heat exchanger [1] and optimization of steam cycle power plant [8]. From the above-mentioned successful applications, ANNs are well suitable for thermal analysis in engineering systems, especially in heat exchangers [10,19]. In this paper, an online monitoring system is developed for a shell and tube heat exchanger using secondary measurements namely the temperatures and flow rates of the hot and cold fluid (water). Experimental system is developed to investigate the performance of heat exchanger. Neural network trained with Back Propagation algorithm (BPNN), Genetic Algorithm (NNGA) and Particle Swarm algorithm (NNPSO) are attempted to model the heat exchanger with experimental data. The input parameters to develop a model for design/clean heat exchanger are inlet temperature and flow rate of shell and tube side fluids and output is overall heat transfer coefficient (U_{Design}). The overall heat transfer coefficient of real/fouled system (U_{Real}) is calculated using online measured values such as inlet temperature, outlet temperature and flow rate of shell and tube side fluids. The heat exchanger performance is assessed by comparing the results of clean/design and fouled/real system. Any deviation from the result of design/clean system indicates that the performance is degraded due to fouling. Its degree is derived from fouling factor (FF) using U_{Design} and U_{Real}.

2. Experimental set-up and conduction

The present work is carried out at the process control lab of Instrumentation and Control Engineering department in National Institute of Technology Tiruchirappalli, India. Experiments are conducted on a 1-1 shell and tube heat exchanger. Fig. 1 shows the schematic diagram of the experimental set-up developed in shell and tube heat exchanger and its photographic view is shown in Fig. 2. Specifications of the fabricated heat exchanger are given in Table 1.

Cold and hot water flow into the shell and tubes respectively is changed using pneumatic control valves. The inlet and outlet temperatures of the shell and tube side fluid are measured using resistant temperature detectors. Hot water inlet temperature is maintained constant with a ±0.5 °C variation using an inbuilt digital proportional–integral–derivative controller. Cold water is supplied at the room temperature (27 °C). The inlet flow of the cold water is varied in the range of 0–350 liter per hour (LPH) and that of hot water between 0 and 250 LPH. The flow rate of cold and hot water are measured using flow transmitter. All the sensors and actuators are interfaced with a 16 bit data acquisition system (Advantech ADAM 5000 series hardware). The module consists of eight analog input and four analog output channels. A personal computer is used to log the data and run the program in MATLAB environment. RS232 cable is used for communication.

In experimental design, three levels of process parameters hot water inlet temperature, cold water flow rate and hot water flow rate are selected and are tabulated in Table 2. Full factorial design of experiments is used and their experimental combinations of process parameters are presented in Table 3. The experiment is carried out in a single phase, both the fluid streams being water and are passed in a co-current fashion. In the overhead tank, water