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Design and economic investigation of shell and tube heat exchangers using Improved Intelligent Tuned Harmony Search algorithm

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Abstract This study explores the thermal design of shell and tube heat exchangers by using Improved Intelligent Tuned Harmony Search (I-ITHS) algorithm. Intelligent Tuned Harmony Search (ITHS) is an upgraded version of harmony search algorithm which has an advantage of deciding intensification and diversification processes by applying proper pitch adjusting strategy. In this study, we aim to improve the search capacity of ITHS algorithm by utilizing chaotic sequences instead of uniformly distributed random numbers and applying alternative search strategies inspired by Artificial Bee Colony algorithm and Opposition Based Learning on promising areas (best solutions). Design variables including baffle spacing, shell diameter, tube outer diameter and number of tube passes are used to minimize total cost of heat exchanger that incorporates capital investment and the sum of discounted annual energy expenditures related to pumping and heat exchanger area. Results show that I-ITHS can be utilized in optimizing shell and tube heat exchangers.

1. Introduction

Heat exchangers are the manufactures used for transferring heat to one section to another. Shell and tube heat exchangers are the most common type which is almost utilized in every part of energy applications. Chemical and process industries, power generation, air conditioning and medical applications can be an example of their utilization [1,4]. As application of the other type of heat exchanger is increasing, shell and tube heat exchangers continue its popularity because of its versatility [2]. In shell and tube heat exchangers while one fluid flows across the tube banks, other runs through the tubes. Heat transfer takes place between the shell and the tube side fluids.

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Shell and tube heat exchangers consist of tubes, baffles, shell, front head, rear head, tube sheets and nozzles. Fig. 1 describes the main components of shell and tube heat exchanger. They can operate at high temperatures and pressures. They are easy to assemble as they need maintenance and cleaning [2]. Design of simple shell and tube heat exchanger (STHE) is a very tedious process as there are plenty of design variables that should meet for a given heat duty requirement and set of design constraints. Design process starts with deciding reference geometric configuration of a heat exchanger and assigning an allowable pressure drop for hot and cold medium. After that, design variables are defined with respect to design specification and physical properties of STHE so as to obtain a reliable heat transfer coefficient which helps to acquire satisfactory heat transfer surface. The choice of suitable design variable is a time consuming and tiresome process since there may be many trial and error solutions to meet the design requirements. To overcome this challenging issue, many researchers developed efficient methods.

Fettaka et al. [5] performed non dominated sorting genetic algorithm (NSGA-II) for optimizing shell and tube heat exchangers. Nine decision variables were considered as tube layout pattern, number of tube passes, baffle spacing, baffle cut, tube-to-baffle diameter clearance, shell-to-baffle diametrical clearance, tube length, tube outer diameter, and tube wall thickness. Multiple Pareto optimal solutions which were trade-off between the two objectives are introduced for designers. NSGA-II exposed better performance than the literature studies. Cost minimization of shell and tube heat exchanger is maintained by imperialist competitive algorithm (ICA) [6] by Hadidi et al. [7]. Obtained results showed that ICA can be applicable to shell and tube heat exchanger design problems. Chaudhuri et al. [8] used simulated annealing algorithm to optimize heat exchanger area to have a better heat transfer characteristics. Mizutani et al. [9] used mixed integer programming approach to optimize STHE as there are many discrete design variables like number of tubes and shell passes. Caputo et al. [10] used genetic algorithm to investigate the economic design of the shell and tube heat exchangers. And also there are many attempts to minimize the total cost of STHE's by genetic algorithm [3,11–16]. Differential Evolution (DE) strategies [17], Particle Swarm Optimization (PSO) [18], Artificial Bee Colony [19], Chaotic Quantum behaved Particle Swarm Optimization [20], and Biogeography-Based Optimization algorithm (BBO) [21] were also conducted to minimize total cost of shell and tube heat exchangers.

In this study, total cost of shell and tube heat exchanger is minimized by Improved Intelligent Tuned Harmony Search (I-ITHS) which is an upgraded version of Intelligent Tuned Harmony Search algorithm [22]. To the best of author's knowledge, ITHS has been never used in optimizing shell and tube heat exchangers. ITHS is an upgraded version of harmony search algorithm which is established on a musician who tries to find a pleasing harmony determined by an esthetic criterion. This study uses chaotic sequences generated by Henon map [23] substituted for Gaussian distributed random numbers and intensify on promising areas by local search strategies borrowed from Artificial Bee Colony [24] algorithm and Opposition Based Learning [25] method to upgrade the probing capability of ITHS algorithm. Literature survey exposes that designing shell and tube heat exchangers by using traditional approaches is not a convenient way to obtain satisfying results. Metaheuristic techniques can be an alternative approach of conventional methods as they are derivative free and they find global optimum by applying stochastic searches. I-ITHS technique is proposed for practitioners who aim to design shell and tube heat exchanger in an efficient way. The objectives of this study are (i) to introduce Intelligent Tuned Harmony Search algorithm, (ii) to upgrade ITHS algorithm by proposed methodologies (iii) to optimize heat exchanger in economic point of view, (iv) to compare the results of I-ITHS with other evolutionary algorithms. Rest of the paper is organized as follows, Section 2 gives the details of intelligent tuned harmony search algorithm, Section 3 describes the improvements made on ITHS algorithm, Section 4 details mathematical model and design formulations of shell and tube heat exchangers, Section 5 proposes the results of the current algorithm and comparison of findings with the other algorithms, and finally conclusion is maintained with Section 6.

2. Intelligent Tuned Harmony Search algorithm

2.1. Harmony search

Harmony search is a new emerged metaheuristic algorithm developed by Geem et al. [26]. It works with concept of seeking the best harmonies within possible pitches. As a musician is eager to find perfect state of harmony determined by aesthetic

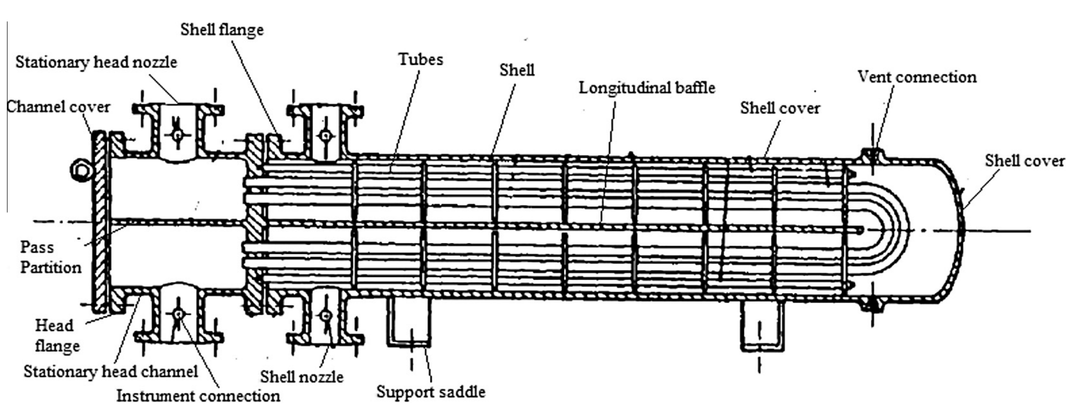

Figure 1 Representation of TEMA U-tube heat exchanger [2].