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Application of firefly algorithm for design optimization of a shell and tube heat exchanger from economic point of view

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ABSTRACT

In the present work, a shell and tube heat exchanger optimization design approach is developed with respect to the total annual cost by application of Firefly algorithm. The total annual cost including the investment cost and the operating cost is considered to be the objective function of the optimization process. The developed algorithm is applied to two case studies and the results show that the operating cost can be reduced by 77% while the total cost can be reduced by 29% as compared to the original design. Further the outcome of the Firefly algorithm is compared with various design optimization algorithms and the results show a much better solution to the problem of economic optimization for the design of a shell and tube heat exchanger. Simultaneously, the present method shows a marginal development in increase of overall heat transfer coefficient and decrease of heat exchanger area corresponding to same heat duty as compared to other optimization methods.

1. Introduction

A heat exchanger is a device in which two fluid streams, one hot and one cold, are brought into thermal contact with each other in order to transfer heat from the hot fluid stream to the cold one. It provides a relatively large surface area of heat transfer for given volume of the equipment. The specific applications of heat exchangers are most frequently found in chemical process industries as well as power production, waste heat recovery, cryogenic, air conditioning and petrochemical industries. Among the various types of heat exchangers, the shell and tube type heat exchangers are the most widely used heat exchangers which contribute approximately more than 65% of the exchangers in chemical process industries [1]. This is due to the fact that they provide area density greater than 700 m^2/m^3 for gases and greater than 300 m^2/m^3 for liquids. Besides higher efficiency, reduced volume, weight and cost for specific heat duty justify shell and tube heat exchangers to be the best among all other kinds of heat exchange equipments. This exchanger is generally built of a bundle of round tubes mounted in a cylindrical shell with the tube axis parallel to that of the shell. The major components of this exchanger are tubes, shell, front end head, rear end head, baffles and tube sheet. The selection criteria for a proper combination of these components depend upon the operation pressures, temperatures, thermal stress, corrosion characteristics of fluids, fouling, cleanability and cost. Fig. 1 shows the schematic diagram of a typical single pass heat exchanger [2].

The design of shell-and-tube heat exchangers involves a large number of geometric and operating variables as part of the search for an exchanger geometry that meets the heat duty requirement and a given set of design constraints. Efforts have been made by various researchers to develop systematic design approaches for seeking the best possible heat exchanger that provides the optimum heat duty while meeting a set of specified constraints. In the pursuit of improved designs, much research has been carried out with objective functions aimed at decreasing total cost and heat transfer area. Over the past few years, genetic algorithms (GAs) have been used by many researchers as an optimization method in shell and tube heat exchanger design [3–12]. Selbas et al. provided an optimal design for a shell and tube heat exchanger by using genetic algorithm for finding the global minimum heat transfer area and economic cost [3]. Guo et al. developed a new shell-and-tube heat exchanger optimization design approach wherein the dimensionless entropy generation rate obtained by scaling the entropy generation on the ratio of the heat transfer rate to the inlet temperature of cold fluid was employed as the objective function and the genetic algorithm was applied to solve the associated optimization problem [4]. Sanaye and Hajabdollahi developed an optimum design for a STHE in order to obtain the maximum

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Abbreviations

A	heat transfer surface based on outside tube area (m^2)
B	baffle spacing (mm)
C_e	energy cost (€/kWh)
C_i	capital investment (€)
C_o	annual operating cost (€/yr)
C_{od}	total discounted operating cost (€)
c_p	specific heat (kJ/kg K)
C_{tot}	total cost (€)
I_0	intensity of light at source
k_w	thermal conductivity of tube wall (W/m K)
n	number of tube passes
n_1	numerical constant
N_b	number of baffles
n_y	equipment life (yr)
P	pumping power (W)
r	distance between two fireflies
R_{fs}	shell-side fouling factor (m^2 K/W)
R_{ft}	tube side fouling factor (m^2K/W)
u	light absorption coefficient
U	overall heat-transfer coefficient (W/m^2 K)
ΔP_s	shell side pressure drop (Pa)
ΔP_t	Tube side pressure drop (Pa)

Greek letters

β	attractiveness of a firefly
μ	dynamic viscosity (Pa s)
ρ	density (kg/m^3)
η	overall pumping efficiency

effectiveness and minimum total cost based on multi-objective functions [13]. Fettaka et al. [6] presented the multiobjective optimization for a shell and tube heat exchanger based on heat transfer area and pumping power. This provided a design with multiple Pareto-Optimal solutions which was able to capture the trade-off between the two objectives. Sadeghzadeh et al. [12]. used a combination of genetic and particle swarm algorithms for the design of techno-economically optimum shell and tube heat exchangers. This design considered cost of the heat exchanger based on surface area and power consumption to overcome pressure drops as the objective function.

Several researchers have introduced different optimization methods in recent years that outperform genetic algorithm in terms of optimization results. Yang et al. [14]. proposed a general optimization design method for heat exchangers motivated by constructal theory. In this method, a global heat exchanger was divided into several sub-heat exchangers in series-and-parallel arrangement and the Tubular Exchanger Manufacturers Association (TEMA) standards were rigorously followed for all design parameters. The objective was to minimize the total cost of the shell-and-tube heat exchanger including the investment cost for initial manufacture and the operational cost involving the power consumption to overcome the frictional pressure loss. Asadi et al. [15]. used the cuckoo search algorithm to develop an optimal design of a shell and tube heat exchanger with respect to total annual cost. This optimization process was based on the minimization of the total annual cost including the capital investment and operating expenses. The case studies show that the operating costs can be reduced by 77% and 48% compared to the results obtained from Particle Swarm Optimization and Genetic Algorithm. Hadidi and Nazari [16] developed an improved optimization design approach for shell and tube heat exchangers based on biogeography based optimization (BBO) algorithm. The BBO algorithm has some improved features in reaching to the global minimum as compared to other evolutionary algorithms. In this study, the BBO technique was applied to minimize the total cost of the equipment by varying various design variables such as tube length, tube outer diameter, pitch size, baffle spacing, etc. The obtained results indicated that the BBO algorithm can be successfully applied for optimal design of shell and tube heat exchangers in comparison to other optimization algorithms such as Genetic Algorithm or Particle Swarm Optimization. Sahin et al. [17]. applied the Artificial Bee Colony (ABC) to minimize the total cost of the equipment including capital investment and the sum of discounted annual energy expenditures related to pumping of shell and tube heat exchanger by varying various design variables. The Artificial Bee Colony (ABC) method was found to be the most accurate and quick according to other traditional methods. Patel and Rao [18] used a non-traditional particle swarm optimization technique for design optimization of shell-and-tube heat exchangers from economic view point. Three design variables such as shell internal diameter, outer tube diameter and baffle spacing were considered for minimization of the total annual cost. A new shell and tube heat exchanger optimization design approach was developed by Hadidi et al. [19]. based on

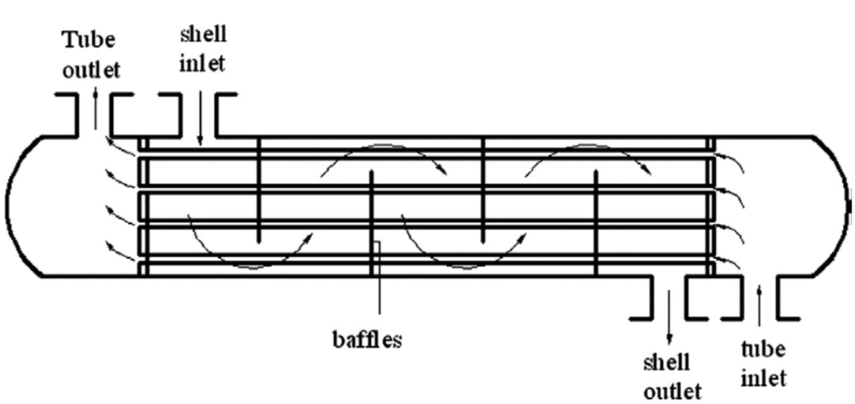

Fig. 1. Shell and tube heat exchanger.