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A robust approach for optimal design of plate fin heat exchangers using biogeography based optimization (BBO) algorithm

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HIGHLIGHTS

- The first use of a BBO algorithm for optimization of plate-fin heat exchangers.
- Total cost, pressure drop and the heat transfer area of exchanger minimized by BBO.
- A quick method proposed to optimal design of heat exchangers with low run time.
- All of available and possible constraints and restriction is handled.

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ABSTRACT

Design of plate-fin heat exchangers is a very complex task generally based on trial and error process. Traditional designing methods are very time consuming and do not guarantee the archive of an optimal solution; therefore heuristic based computation methods are used, usually. So, in present paper a new design method proposed for optimization of plate fin heat exchangers using biogeography-based optimization (BBO) algorithm. The BBO algorithm has some advantages in detecting the global minimum compared with other heuristic algorithms. In present research the BBO scheme has been employed for optimal design of the plate fin heat exchanger by minimization of the total annual cost, heat transfer area and total pressure drops of the equipment considering main structural and geometrical parameters of the exchanger as design variables. Based on proposed approach, a full computer code was developed and three various case studies are investigated by it to illustrate the effectiveness and accuracy of the proposed method. Comparison of the results with those obtained by previous methods reveals that the BBO algorithm can be successfully employed for optimization of plate fin heat exchangers. Finally, parametric analysis carried out to evaluate the sensitivity of the proposed method to the cost and structural parameters.

1. Introduction

One of the most important types of compact heat exchangers is a plate fin heat exchanger which has widespread engineering applications [1,2]. In a plate fin heat exchanger, hot and cold fluids flow through plates of the exchanger known as parting sheets and fins. A plate fin exchanger is shown in Fig. 1, schematically [3].

Designing procedure of plate fin exchangers comprises of thermodynamic and fluid dynamic design, geometry and structure design, cost calculation and optimization. This procedure reveals a complex process. In practice, the design of the exchanger is a complex and heavy trial and error procedure; hence, there is always the possibility that the designed results are not the optimum. Consequently, researchers attempt to optimize thermal equipment and systems using heuristic based optimization algorithms. Accordingly, many interesting studies have been conducted using artificial intelligence methods, recently. Zhou et al. [4] used a multi-level, multi-factor and non-structural fuzzy optimum decision model in the optimal selection of compact heat exchangers. They considered the performance of two different plate fin heat exchangers made of stainless steel and PTFE composite. They concluded that the plate-fin heat exchanger made of PTFE composite is feasible and optimal to be used as an acid solution cooler. Other studies have been conducted on optimization of compact or other types of heat exchangers as a part of other industrial equipment [4–16]. Lee et al. [5] have developed a novel heat exchanger with new geometries for application in the low temperature lift heat pump (LTLHP). Their main design strategy were regulating the flow area ratio and offsetting plates in order to balance the heat transfer

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Nomenclature

A, A_{HT}	heat transfer area (m^2)
A_f	annual coefficient factor
A_{ff}	free flow area (m^2)
C	heat capacity (W/K)
C_A	cost per unit area (\$/m^2)
C_{in}	investment cost (\$/year)
C_{op}	operating cost (\$/year)
C_r	C_{min}/C_{max}
D_h	hydraulic diameter (m)
f	friction factor
$f(x)$	objective function (pressure loss)
G	mass flow velocity (kg/m^2 s)
h	convective heat transfer coefficient (W/m^2 K)
H	height of fin (m)
j	Colburn factor
k_{el}	electricity price (\$/MW h)
l_f	fin offset length (m)
L	heat exchanger length (m)
m	mass flow rate (kg/s)
n	fin frequency (fins per meter)
n_1	numerical constant
N_a, N_b	fin layers number for fluid a and b
NTU	number of transfer units
P	pressure
Pr	Prandtl number
Q	heat transfer rate (W)
r	interest rate
Re	Reynolds number
t	thickness of fin (m)
T	temperature (°C)
TAC	total annual cost (\$/year)
U	overall heat transfer coefficient (W/m^2 K)
y	depreciation time

Greek symbols

ε	effectiveness
η	efficiency of the pump or fan
μ	dynamic viscosity (Pa s)
ρ	density (kg/m^3)
τ	hours of operation
ΔP	pressure drop (Pa)

Subscripts

a, b	fluid a and b
max	maximum
min	minimum

and pressure drop of the heat exchanger. Nagarajan et al. [12] proposed a fin named rip saw fin and applied it to a high temperature ceramic plate-fin heat exchanger. They optimized the new designed exchanger using CFD analysis. They showed in their research that application of the designed fins in the heat exchanger enhances the performance of the heat exchanger. Bayer et al. [13] have used a mathematical optimization approach for optimal design of borehole heat exchangers. They concluded that the benefit from mathematical optimization increases with heat extraction/injection imbalance. Varun and Siddhartha [14] have optimized a flat plate solar air heater using a genetic algorithm. They considered the thermal performance of the exchanger and optimized the exchanger considering the different system and operating parameters to obtain maximum thermal performance. Bellis and Catalano [15] have used a CFD approach and two evolutionary algorithms for optimization of an immersed particle heat exchanger. They considered geometric parameters of the heat exchanger such as diameters, angles of inlet and outlet pipes and particle injection mode as optimization variables. The objective of their research was to maximize the heat exchanger efficiency by maximizing the dispersion of the particles falling in countercurrent within the flow. They demonstrated that this type of the exchangers has been proposed recently and further attempts are needed to optimal design of these exchangers. There is a need for use stronger optimization algorithms for optimal design of this type of exchangers. Luo et al. [16] considered design and optimization of cross flow fin-tube type internally-cooled dehumidifiers. They considered the geometry parameters and operating conditions of the dehumidifier as optimization variables. They calculated optimum length of the air flow direction. They have not used an intelligence based method for optimization of the exchanger so their optimization procedure involved only with one design parameter; where by using intelligence based optimization algorithms, various and numerous parameters of the exchanger can be used as optimization variables and consequently reach to the global optimal design.

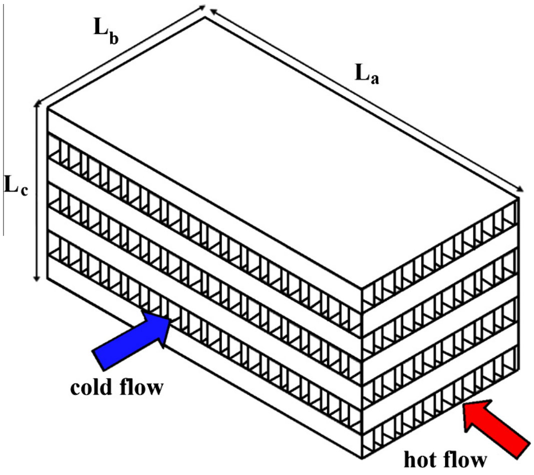

Fig. 1. Diagram of a typical plate fin heat exchanger [3].

Several studies have been conducted on optimization of the plate fin exchanger using genetic algorithms (GA) [3,17–20]. The research of Mishra et al. [17] is an example of application of GA for optimization of PFHEs. They optimized plate fin heat exchangers using a genetic algorithm considering the given heat duty and flow restrictions as optimization constraints. Zhao and Le [21] proposed an effective layer pattern optimization model for multi-stream plate-fin heat exchanger using a genetic algorithm. These researchers indicated that multi-stream flow and heat transfer in one plate fin heat exchanger are used in petroleum, chemical, air separation and other industrial systems; so optimization of this type of plate fin exchangers considered in their research. Also Yujie and Yanzhong [22] studied the heat transfer behavior and optimization of multi-stream plate-fin heat exchangers. Zhe and Yanzhong [23] conducted an experimental investigation on the thermal performance of multi-stream plate-fin heat exchanger based on genetic algorithm layer pattern design. They presented few layer pattern criterion models to determine an optimal stacking pattern. They developed mentioned model by employing a genetic algorithm with binary chromosome ring representing alternatively placed hot and cold layer fluid streams. These