International Communications in Heat and Mass Transfer 39 (2012) 258–263

Contents lists available at SciVerse ScienceDirect

International Communications in Heat and Mass Transfer

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

Optimal design of plate-fin heat exchangers by a hybrid evolutionary algorithm☆

M. Yousefi [a,*], R. Enayatifar [b], A.N. Darus [a]

[a] Department of thermo-fluids, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
[b] Faculty of computer science, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia

ARTICLE INFO

Available online 9 December 2011

Keywords:
Plate-fin heat exchanger
Particle Swarm Optimization
Genetic Algorithm
Hybrid algorithm
Optimization

ABSTRACT

This study explores the first application of a Genetic Algorithm hybrid with Particle Swarm Optimization (GAHPSO) for design optimization of a plate-fin heat exchanger. A total number of seven design parameters are considered as the optimization variables and the constraints are handled by penalty function method. The effectiveness and accuracy of the proposed algorithm is demonstrated through an illustrative example. Comparing the results with the corresponding results using GA and PSO reveals that the GAHPSO can converge to optimum solution with higher accuracy.

1. Introduction

Because of their adaptability to a wide range of applications, high compactness and relatively good heat transfer efficiency, plate fin heat exchangers (PFHEs) are widely used in different aspects of industry such as automobile, chemical and petrochemical processes, cryogenics and aerospace. The design of a PFHE is a complex task based on trial-and-error process in which geometrical and operational parameters are selected to satisfy specified requirements such as outlet temperature, heat duty and pressure drop. Moreover, optimization based on the desired objective should always be taken into consideration. According to the literature, the common objectives in heat exchanger design are associated with minimizing capital cost and original cost. Practically, a higher velocity yields to higher heat transfer coefficient which consequently leads to smaller heat transfer area and lower capital cost. It should be noticed that, however, higher velocity results in higher pressure drop and power consumption, too. Therefore, before the optimal design is performing, the objective function should be considered based on the requirements. In most cases a compromise between the capital cost and power cost should be achieved by the design parameters. Many works have been devoted to the optimization of heat exchangers using traditional mathematical methods[1–5], In addition, recently, GAs, as stochastic global search algorithms, have been widely implemented in design and optimization of compact heat exchangers[6–17] since they have been proved to be very effective tools in finding near optimal solutions without having information of the derivatives. Particle Swarm Optimization (PSO), a new evolutionary based technique, has been recently introduced by Kennedy and Eberhart [18] and has shown its effectiveness in design of CHEs [19,20]. Similar to GAs, PSO starts with an initial population of the possible solutions. Each solution is called a 'Chromosome' in GA and a 'Particle' in PSO where on the contrary to the former new solutions are not created from the parents within the evolution process. In PSO, any individual just tries to evolve its social behavior and move towards destination. Since PSO and GA are both working with a random initial population of solutions, Lu and Juang [21] combined their searching abilities of these two methods and proposed a new search method called, hybrid GA with PSO (HGAPSO). They successfully applied HGAPSO in design of a fuzzy controller. In this work, it is desired to see the feasibility of this newly introduced metaheuristic algorithm in optimization of plate fin heat exchangers.

2. Thermal modeling

A schematic of a typical cross-flow plate fin heat exchanger with offset strip fin can be seen in Fig. 1. In the analysis, for the sake of simplicity, the variation of physical property of fluids with temperature is neglected where both fluids are considered to be ideal gases. Other assumptions are as follows.

1– Number of fin layers for the cold side (N_b) is assumed to be one more than the hot side (N_a). It is a conventional way in design of heat exchangers in order to avoid heat waste to the ambient.
2– Heat exchanger is working under steady state condition.
3– Heat transfer coefficient and the area distribution are assumed to be uniform and constant.
4– The thermal resistance of walls is neglected.
5– Since the influence of fouling is negligibly small for a gas-to-gas heat exchanger, it is neglected.

☆ Communicated by W.J. Minkowycz.

* Corresponding author.
E-mail address: yousefi.moslem@gmail.com (M. Yousefi).

0735-1933/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.icheatmasstransfer.2011.11.011

Nomenclature

A, A_{HT}	heat exchanger surface area (m^2)
A_{ff}	free flow area (m^2)
C	heat capacity rate (W/K)
Cr	C_{min}/C_{max}
C_1	Cognition factor
C_2	social collaboration factor
D_h	hydraulic diameter (m)
f	friction factor
f(X)	objective function
g(X)	constraint function
G	mass flow velocity (kg/m^2s)
h	convective heat transfer coefficient(W/m^2K)
H	height of fin (m)
j	Colburn factor
l	lance length of the fin (m)
L	heat exchanger length (m)
m	mass flow rate (kg/s)
n	fin frequency (fins per meter)
N_a, N_b	number of fin layers for fluid a and b
NTU	number of transfer units
Pi	Particle's best position
Pg	best particle in the current generation
pm	mutation probability
Pr	Prandtl number
Q	rate of heat transfer (W)
rand( )	Random function
Rand( )	Random function
Re	Reynolds number
R1	penalty parameter
t	fin thickness (m)
T	temperature °C
U	overall heat transfer coefficient
V	Particle velocity
X	Particle position

Greek symbols

ε	effectiveness
μ	viscosity (N/m2s)
ρ	density (kg/m3)
( )	penalty function
ΔP	Pressure drop (N/m2)
ω	Inertia weight

Subscripts

a,b	fluid a and b
i,j	variable number
max	maximum
min	minimum

In the present work, since the outlet temperature of the fluids is not specified the *ε-NTU* method is used for rating performance of the heat exchanger in the optimization process. The effectiveness of cross-flow heat exchanger, for both fluids unmixed is proposed as [22].

$$\varepsilon = 1 - \exp\left[\left(\frac{1}{Cr}\right)\mathrm{NTU}^{0.22}\left\{\exp\left[-\mathrm{Cr.NTU}^{0.78}\right]-1\right\}\right] \tag{1}$$

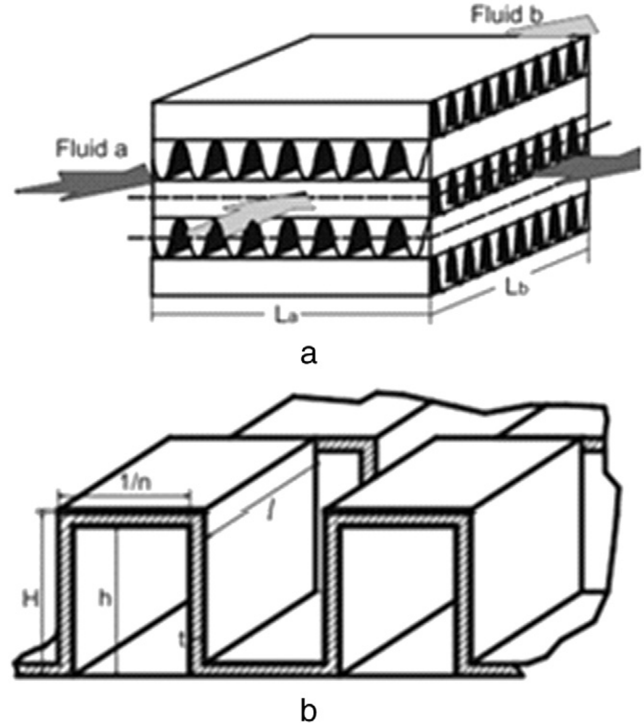

Fig. 1. (a) Schematic representation of cross-flow plate-fin heat exchanger, and (b) detailed view of offset-strip fin.

In the mentioned equation, $Cr = C_{min}/C_{max}$. Neglecting the thermal resistance of the walls and fouling factors, NTU is calculated as follows.

$$\frac{1}{UA} = \frac{1}{(hA)_a} + \frac{1}{(hA)_b} \tag{2}$$

$$\mathrm{NTU} = \frac{UA}{C_{min}} \tag{3}$$

Heat transfer coefficient is calculated from j Colburn factor.

$$h = j.G.Cp.Pr^{-\frac{2}{3}}. \tag{3}$$

In this formula, $G = \frac{m}{Aff}$, where A_{ff} is free flow cross-sectional area which is calculated considering the geometrical details in Fig. 2.

$$Aff_a = (H_a - t_a)(1 - n_a t_a)L_b N_a \tag{5}$$

$$Aff_b = (H_b - t_b)(1 - n_b t_b)L_a N_b \tag{6}$$

Heat transfer area for both sides can be calculated similarly.

$$Aa = L_a L_b N_a[1 + 2n_a(Ha - t_a)] \tag{7}$$

$$A_b = L_a L_b N_a[1 + 2n_b(H_b - t_b)] \tag{8}$$

Then, total heat transfer area is given by:

$$A_{HT} = A_a + A_b. \tag{9}$$

Heat transfer rate is calculated as follows.

$$Q = \varepsilon\ C_{min}\left(T_{a,1} - T_{b,1}\right) \tag{10}$$

Frictional pressure drop in both sides is given by:

$$\Delta P_a = \frac{2 f_a L_a G_a^2}{\rho_a D_{h,a}} \tag{11}$$