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Optimization design of slotted fin by numerical simulation coupled with genetic algorithm

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ABSTRACT

Using a novel method that couples genetic algorithm (GA) with numerical simulation, the geometric configuration for a two-dimensional slotted fin has been optimized in this paper. The objective of optimization is to maximize the heat transfer capacity of slotted fin, and minimize the pressure drop penalty of fluid flow through the fin. The key of this method is the fitness function of GA, which were $(j/j_0)/(f/f_0)$ and j/j_0. In this complex multiparameter problem, the numerical simulation is a crucial step to calculate the Colburn factor j and friction factor f. The results showed that for two-dimensional slotted fin considered, the j factor is increased by 229.22%, the f factor is increased by 196.30%, and the j/f ratio was increased by 11.11% at $Re = 500$ based on optimal integrated performance $(j/j_0)/(f/f_0)$; the j factor is increased by 479.08% at $Re = 500$ based on optimal heat exchange capacity j/j_0. The feasibility of optimal designs was verified by the field synergy principle.

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1. Introduction

Fin-and-tube heat exchangers are widely used in various engineering fields such as chemical process, air-conditioning, refrigeration, electronics cooling, and process industry. In order to reduce the energy consumption and benefit the economy, high-performance heat transfer components for thermodynamic process are becoming more and more popular for many applications [1]. The total thermal resistance for such kind of heat exchangers is comprised of three parts: the air-side convective resistance, the wall conductive resistance, and the liquid-side convective resistance. The heat transfer coefficient on the air-side is typically low due to the thermal conductivity of the air and relatively low frontal velocity. The use of enhanced fin surface is the most effective way to improve the overall performance of the fin-and-tube heat exchanger [2,3].

Owing to the requirement of smaller volume, low cost, quiet, and high efficiency in operation, different new types of enhanced fins, such as the wavy fin, the louvered fin and the slit fin, were developed. Experimental studies for these different types of fin have been extensively performed. Large number of investigations shows that slotted fin with protruding strips which are parallel to the base sheet has better performance than the wavy fin and the louvered fin [4,5]. This type of fin geometry was first studied by Nakayama and Xu [6], who reported that its heat transfer coefficient can be 78% higher than that of the plain fin at an air velocity of 3 m/s. Hiroaki et al. [7] indicated that the heat exchanger with slotted fins can reduce the volume by 1/3 compared to that with plain fin. Recently, Wang et al. [8–10] conducted comprehensive experimental investigations for two types of slit fins with different protruding directions, and the experimental correlations of the heat transfer and flow friction were also proposed.

Besides the studies on the heat transfer and flow characteristics of the entire fins, there are some investigations focused on the strips of the slit fin. Yun and Lee [11] analyzed the effects of various design parameters of the strip on the heat transfer and pressure drop characteristics of the slit fin heat exchangers, and presented the optimum value for each parameter. Kang and Kim [12] experimentally studied the effect of strip location on the heat transfer and pressure drop, and found that the slit fin with all the strips mainly positioned in the rear part has the better performance than that of the slit fin with all the strips in the front part. Qu et al. [13] numerically validated this finding and explained it from the viewpoint of field synergy principle, which was first proposed by Guo et al. [14,15] for parabolic fluid flow and heat transfer. Later, Tao et al. [16,17] extended this idea from parabolic flow to elliptic flow. Based on field synergy principle, Cheng et al. [18] proposed a new slotted fin with strips on the fin surface abiding by the rule of "front coarse and rear dense" along the flow direction. The numerical results show that the j factor of the new fin is about 9% higher than the fin with all the same number of strips in the front part.

In recent years, a few academics had applied the genetic algorithm to heat transfer fields. The heat recovery steam generator

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Nomenclature

a	thermal diffusivity, $m^2\ s^{-1}$
A	heat transfer surface area, m^2
A_c	minimum flow area, m^2
c_p	fluid specific heat, $J\ kg^{-1}\ K^{-1}$
D_h	hydraulic diameter, m
f	friction factor
F	fitness function
h	heat transfer coefficient, $W\ m^{-2}\ K^{-1}$
H_i	strip height, mm
j	Colburn factor
L	flow length, mm
L_i	strip width, mm
N	population quantity
Nu	Nusselt number
p	pressure, Pa
Δp	pressure drop, Pa
P	fin pitch, mm
P_c	the crossover probability
P_m	the mutation probability
Pr	Prandtl number
Q	heat transfer rate, W
Re	Reynolds number
St	Stanton number
T	temperature, K
ΔT	logarithmic mean temperature difference, K
u, v	x, y velocity components, ms^{-1}
x, y	Cartesian coordinates

Greek symbols

δ	fin thickness, mm
θ	the local intersection angle, deg
λ	thermal conductivity, $W\ m^{-1}\ K^{-1}$
μ	dynamic viscosity, Pa s
v	kinematic viscosity, $m^2\ s^{-1}$
ρ	fluid density, $kg\ m^{-3}$

Subscripts

b	based on bulk temperature
in	tube inlet
m	mean or average value
out	tube outlet
w	will

[19], the refrigerant circuit [20] were designed to optimize by genetic algorithm. But these optimization designs by genetic algorithm method cannot used to design new heat exchanger because they were typically based on empirical formula. In addition, genetic algorithm is often used to fit correlations based on experimental study results [21].

As previously mentioned, most of the optimization problem of slotted fin was solved by experimental method as yet. The aim of this study is to obtain the optimized design of slotted fin base on different performance evaluations by genetic algorithm coupled with numerical simulation. It is believed that this study not only could be used to optimize the slotted fin, but also provide a new method to design multifarious heat transfer components.

2. Genetic algorithm model design

Two targets of the slotted fin heat exchanger optimization design are considered: one is to obtain the minimum pressure drop penalty, and the other is to obtain the maximum heat exchange capacity. Strip height is the structural parameters that have an important influence on heat transfer and fluid flow characteristics of the heat exchanger. Therefore, the heights of each strip were chosen as the parameters of the optimization problems. As the strips are positioned symmetrically alone the flow direction, there are seven independent parameters. Since each height can be changed continuously, this optimization problem has very tremendous parameter domain, which could be perfectly solved by the genetic algorithm.

The genetic algorithm (GA) uses a population of several individuals to perform the optimization by simulating the genetic and evolution mechanism of biology [22]. It generally contains six steps: coding/decoding, population initialization, evaluation, selection (or reproduction), crossover, and mutation. The individuals are represented with strings in a binary format, and the initial individuals are randomly generated from the search space. Each individual is evaluated and assigned with a fitness value determined by the fitness function. The higher fitness value individual has the higher chance to survive to the next generation during the selection process. Some individuals in the new generation are generated from individuals selected at a given probability by using crossover and mutation operations. Crossover operation generates new individuals by exchanging the data between two randomly chosen individuals, and mutation operation generates new individuals by randomly changing data of one randomly chosen individual. The individuals in the new generation are evaluated and the process is repeated until the given maximum number of generations is reached or convergence is reached. The program flow chart of overall process is shown in Fig. 1.

The height of each strip was chosen as the chromosomes and encoded in the regions form -7.0×10^{-4} to 7.0×10^{-4}. The num-

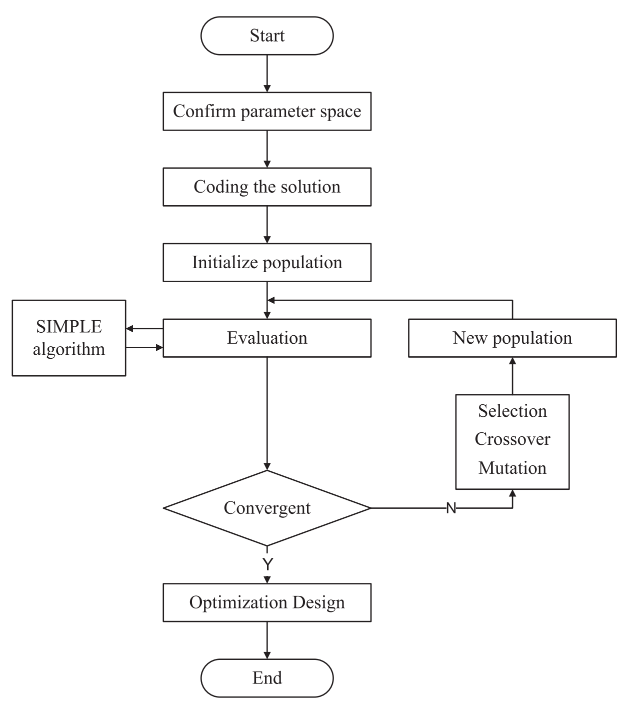

Fig. 1. Flow chart of genetic coupled with SIMPLE algorithm.

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