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Optimization investigation on configuration parameters of serrated fin in plate-fin heat exchanger using genetic algorithm

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A B S T R A C T

In this paper the configuration of serrated fin in plate-fin heat exchange is optimized with genetic algorithm combined with Kriging response surface method. The fin height *h*, fin thickness *t*, fin space *s* and interrupted length *l* of serrated fins are considered as four optimization parameters, while the *j* factor, *f* factor and *JF* factor are considered as three single objective functions for a specified Reynolds. Meanwhile, maximum of *j* factor and minimum of *f* factor are optimized as two conflicting objective functions, in which a set of optimal solutions are obtained. The comparison between the optimal design and the common design for a specified mass flow rate under given space restriction is performed to demonstrate the effectiveness of optimization configuration. The results show that the heat transfer rate of the optimal heat exchanger increases by 145 W, while the power consumption decreases by 48.5%. In addition, compared with conventional genetic algorithm, a genetic algorithm combined with Kriging response surface method overcomes the dependence on empirical correlations. The optimizing method of this paper can be used to optimize various complex problems of engineering applications.

1. Introduction

Heat exchangers are used to transfer thermal energy between two or more media and be known as one of the most essential equipment in almost every industrial plants, including power engineering, aerospace, electronics, automobile, petroleum refineries, cryogenic and chemical industries, etc. Plate-fin heat exchanges (PFHEs) are widely used for their high compactness (up to 1000–2500 m^2/m^3 [1]) and relatively good heat transfer efficiency that help save material and space. A PFHE is assembled from a series of flat sheets, called parting sheets and layers of fins in a sandwich construction. Depending on the diverse application, there are many types of fins such as corrugated, louver, perforated, serrated strip and pin fins [2]. While among the many enhanced fin constructions, rectangular serrated fin is widely used. This type of fin is characterized by a high degree of surface compactness, high reliability and substantial heat transfer enhancement due to the boundary layer re-starting at the uninterrupted channels formed by the fins. However, there is, on the other hand, an associated increase in a large pressure drop for the interrupted arrays. Many researches have been performed in serrated fins. Kays and London [3] have provided comprehensive experimental data for surface properties of serrated fins. Manson [4], Joshi and Webb [5], Wieting [6], Mochizuki et al. [7], Dubrowsky [8], Manglik and Bergles [9] and Yujie Yang and Yanzhong Li [10] have provided different empirical correlations for plate-fin heat exchanges with serrated fins based on experimental data. In addition, Kim and Lee [11] proposed the new correlations based on numerically investigated. These correlations were divided by blockage ratio for their deemed the previous correlations cannot be used for fins with a larger blockage ratio. In general, the secondary heat transfer surface of PFHEs, which is established by the fins, is regarded as the most important heat transfer component in PFHEs. Since the secondary heat transfer surface can expand the heat transfer area, improve the heat transfer efficiency, enhance the compactness, and upgrade intensity and bearing capacity of PFHEs. In addition, the secondary heat transfer surface is closely related to the heat transfer characteristics and pressure losses of PFHEs. Therefore, optimizing the fin parameters of serrated fins are effective and important for energy saving and cost reduction.

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Configuration optimization of PFHEs is indeed needed by industries, which has attracted lots of interests [12–14]. However, the conventional design of PFHEs is mainly based on empirical chosen, checking computations with trial-and-error and the results obtained by predecessors. Once satisfied the heat transfer performance and resistance requirements, this type of heat exchanger and fin constructions can be used as candidates. Although various commercial programs are available to design and evaluate PFHEs at present, they do not compose any optimization strategy. Thus these obtained results cannot be guaranteed as the best solution. Indeed, the conventional methods are difficult to optimize the configuration of serrated fin, owing to the complexity of PFHEs, including lots of design parameters, nonlinear equations and so on. Genetic algorithm (GA) or hybrids GA have been successfully applied for the optimal design of PFHEs. Sahin et al. [15] optimized the configuration parameters of a heat exchanger with rectangular fins by Taguchi experimental-design method. Peng [16] and Wang [17,18] used the GA to achieve minimum total weight or total annual cost of PFHE with given constrained condition. Mishra et al. [1] considered the minimize number of entropy generation units as objectives and performed GA to find the optimum design parameters of cross flow PFHEs with the specified heat duty under given space. Hang [19] optimized a PFHE through a GA, in which a total entropy production unit is optimized by single objective optimization. Rao and Patel [20] optimized a plate-fin heat exchanger by minimization of total number of entropy generation units for specific heat duty requirement under given space restrictions, minimization of total volume and minimization of total annual cost, respectively. Furthermore, optimization of PFHEs may face with more than one objective function and some of them are conflicting, so a trade-off must be considered. Multi-Objective optimization with GA is also successfully used for optimizing these difficult problems. Najafi et al. [21,22] successfully utilized multi-objective optimization with GA to optimize the plate-fin heat exchangers with serrated fins by considering maximum the total rate of heat transfer and minimum the total annual cost as two objective functions. Lee and Kim [23] used a multi-objective genetic algorithm with surrogate modeling technique to maximize heat transfer and minimize pressure drop in a heat exchanger. Foli et al. [24] estimated the optimum geometric parameters of micro-channels in micro-heat exchangers by maximizing the heat transfer rate and minimizing the pressure drop as two objective functions. Gholap and Khan [25] studied the PFHEs by minimizing the energy consumption and material cost as two conflicting objective functions. Liu and Cheng [26] optimized a recuperator for the maximum heat transfer effectiveness as well as minimum exchanger weight or pressure loss. Hilbert et al. [27] considered both of heat exchange and pressure loss as objectives. And they performed multi-objective optimization to find the optimum geometry that can satisfy the objectives in an acceptable level. However, majority of the previous optimizations were calculated using empirical correlations, which may result in big errors for the deviation of empirical correlations. In addition, there is a lack of empirical correlations for some complex engineering problems. The response surfaces are functions of different natures where the output parameters are described in terms of the input parameters. Therefore, an approximation of the output values can be provided from the response surfaces to replace the conventional empirical correlations. The Kriging response surface method combined with hybrid genetic algorithm, in particular, is effective in the optimization of engineering fields.

In this paper, a new method using hybrid genetic algorithm based on the Kriging response surface for optimization of a plate-fin heat exchanger with serrated fins is proposed. Firstly, numerical simulation is studied, in which fin height h, fin space s, interrupted length l and fin thickness t of serrated fins are considered as optimization parameters, in order to calculate the j factor, f factor and JF factor of PFHEs. Secondly, based on Kriging model fit, a sensitivity analysis of four optimization parameters on the objective functions is carried out. Thirdly, a genetic algorithm with the Kriging response surface is studied by maximum the j factor, JF factor and minimum f factor as three single objective functions. In addition, a multi-objective optimization with genetic algorithm is utilized by trade-off j factor and f factor as two conflicting objective functions. Lastly, a comparison between common design and optimal design is also carried out to demonstrate the effectiveness of the optimization results.

2. Calculation model and numerical method

2.1. Physical model

The schematic diagram of a typical serrated fin is shown as in Fig. 1. The optimization design parameters include fin height h, fin thickness t, fin space s, and interrupted length l. In order to cover the design range of majority of serrated fin, the fin height h is selected from 4.7 mm to 9.5 mm, fin thickness t is 0.1 mm–0.5 mm, fin space s is 1.4 mm–3 mm and interrupted length l is 3 mm–9 mm. Meanwhile, to better understand the thermal hydraulic behavior of serrated fin, the hydraulic diameter for serrated fin is studied. As shown in Fig. 2. The fin end for serrated fin geometry consists of primary and secondary fin end. The area of the fin end in a periodic unit cell is calculated by

$$A_{end} = 2t(h-t) + t(s-2t) \quad (1)$$

Therefore, the hydraulic diameter for serrated fin is defined as follows:

$$D = \frac{4lA_c}{A} = \frac{4l(s-t)(h-t)}{2(l(h-t)+l(s-t)+t(s-t))+t(s-2t)} \quad (2)$$

Fig. 3 shows the schematic diagram of a 3D computational domain. The entrance part and exit part are considered here in order to make the simulation process close to the actual experimental test. In addition, it should be noted that the entrance area is vary with structural parameters of serrated fins in order to

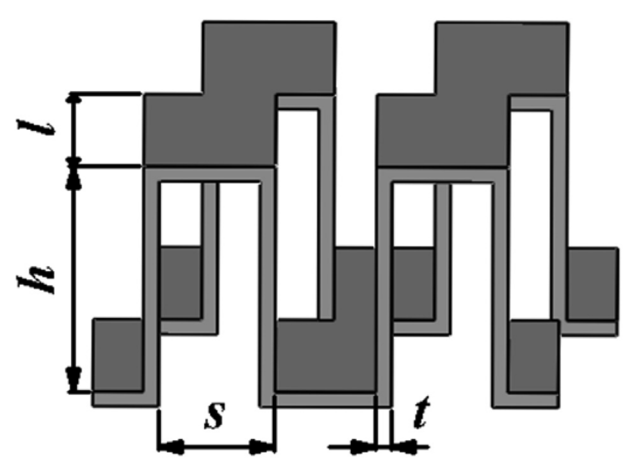

Fig. 1. The schematic diagram of serrated fins.