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Research paper

Experimental and numerical investigation of the heat transfer augmentation and pressure drop in simple, dimpled and perforated dimpled louver fin banks with an in-line or staggered arrangement

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HIGHLIGHTS

- An inclined louvered fin bank has been investigated experimentally and numerically.
- Effect of dimples and perforations in different arrangements has been investigated.
- Temperature distribution through louvers and pressure drop has been evaluated.
- The maximum *j* and *f* factor occurs in staggered perforated dimple arrangement.
- Staggered perforated dimple louver shows the best thermal hydraulic performance.

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ABSTRACT

Numerical and experimental models have been developed to investigate the effect of adding an in-line and staggered arrangement of dimples and perforated dimples to multilouvered fins on the heat transfer augmentation and the pressure drop of the air flow through a multilouvered fin bank. Three-dimensional simulations of single row of louvers were conducted for the given geometries. Simulations were performed for different Reynolds numbers. The simulations revealed that the heat transfer and temperature augmentations occur due to the existence of a circulation region that is created by the dimple. Additionally, continuous temperature gradients have been observed over the louver surface with the highest temperature at the base of the louver and the lowest temperature at the middle of the louver. Additionally, the difference between these two points is more obvious with greater Reynolds numbers. Fin efficiency and fin effectiveness were calculated to assess louver performance. The air-side performance of the heat exchanger is evaluated by calculating the Colburn *j* factor and the Fanning friction *f* factor. The results demonstrate that adding dimples on the louver surface increases the *j* factor and the *f* factor. Likewise, adding perforation to the dimples results in the same increase. The present results indicate that compared with the in-line arrangement, the staggered arrangement could effectively enhance the heat transfer performance.

1. Introduction

Compact heat exchangers have many industrial uses, such as in refrigeration, air conditioning, and automotive applications, and many attempts have been made to improve their performance. The commonly applicable way to improve the overall performance of the compact heat exchanger is to use interrupted surfaces on the fin side. The implementation of dimples, louvers, and perforation on fins has been shown to achieve the best enhancement of compact heat exchanger performance. Many numerical and experimental attempts have been performed to improve the heat transfer of compact heat exchangers using dimples and multi-louvered fins. Kays and London [1] published the first reliable data on louvered fin surfaces. Beauvias [2] performed flow visualization experiments on a louvered fin array as the first study in this area. This work showed that louvers actually redirect the flow between the fins.

Davenport [3] demonstrated two asymptotic flow regimes: duct directed flow and louver directed flow. Smoke trace studies were

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also performed on a scale model, which was ten times smaller, of a non-standard variant of a corrugated louvered fin geometry. Finally, he developed the heat transfer and friction correlations for corrugated louvered fin geometry. Chang and Wang [4] tested 27 samples of louvered fin heat exchangers with different geometrical parameters in an induced-draft, open wind tunnel and carried out extensive experiments on the heat transfer and the pressure drop characteristics of brazed aluminum heat exchangers. Rugh et al. [5] experimentally studied the use of a high fin density louvered surface in automobiles.

Some other attempts have been made to develop two-dimensional models of louvered fin surfaces. Achaichia and Cowell [6] modeled only one louver in a fully developed flow region by assuming cyclic boundary conditions. Suga et al. [7] performed a finite difference analysis on the two-dimensional flow and the heat transfer characteristics of louvered fins. Achaichia et al. [8] used a novel mesh structure with mesh lines running parallel to the louvers and extending over several fins. Dong et al. [9] studied the air-side heat transfer and pressure drop characteristics for 20 types of multi-louvered fin and flat tube heat exchangers. Hsieh and Jang [10] carried out a 3-D numerical analysis on the heat and fluid flow by increasing or decreasing the louver angle patterns.

The use of dimpled surfaces, as a type of enhanced surface, has received attention in the past decades due to their good heat transfer characteristics and low pressure drop penalties. Afansayev et al. [11] studied the effects of shallow dimples on flat plates on the overall heat transfer capacity and pressure drop. These authors reported a significant heat transfer enhancement (30–40%) at a low pressure drop cost. Ligrani et al. [12] experimentally investigated the flow structure in dimpled surfaces and demonstrated the existence of a flow recirculation zone in the upstream half of the dimple. Zhengyi et al. [13] observed a symmetric 3-D horseshow vortex inside a single dimple using laminar flow simulations. Additionally, the flow structure and the heat transfer in dimpled channels with fully turbulent regimes have been studied in the literatures [14]. Elyyan and Tafti [15] investigated the flow and heat transfer characteristics of dimpled multi-louvered fins. These authors reported not only significant heat transfer augmentation but also a considerable amount of friction loss augmentation through dimpled louvers. Additionally, their work showed that perforations on dimples have a sharp impact on heat transfer augmentation. In another numerical study [16], these same researchers introduced a novel geometry that was the result of altering the dimple shape. Greater heat transfer and fiction loss values were reported for this geometry. These researchers have also reported that the turbulence level increases due to the shear layer induced by their new geometry's split dimples.

Elyyan et al. [17] investigated the effect of the existence of dimpled fins in compact heat exchangers for heat transfer enhancement. These researcher conducted direct and large-eddy simulations in a fin bank with dimples and protrusions over encompassing laminar, transitional and fully turbulent regimes. Shokuhmand and Sangtarash [18] conducted experimental and numerical studies on the heat transfer and flow efficiency of multilouvered fins. These authors reported that implementing simple and perforated dimples on the louvers enhance the heat transfer and flow efficiency significantly. In previous studies [19,20], the j factor and f factor have been utilized to characterize the heat transfer and pressure drop of simple louver fin banks.

The present study experimentally and numerically investigates the effect of fin geometry, which includes the simple louver, the in-line and staggered dimpled louver, and the in-line and staggered dimple-perforated louver, on the heat transfer in multilouvered heat exchangers. To the best of our knowledge, no similar attempts have been carried out using the temperature distribution of fin surface to calculate the heat transfer. The temperature distribution over the louver surface is simulated for five independent geometries. The computational results are compared with data obtained from experiments. The fin efficiency and fin effectiveness are introduced to evaluate the performance of the fin geometry on heat transfer. Finally, the j factor and f factor are computed to investigate the variation of heat transfer and pressure drop as function of the Reynolds number for different fin geometries.

2. Experimental

A low turbulence wind tunnel, Model No. TE.44/D Manufactured by PLINT and PARTNERS ENGINEERS LTD, was used in this research. The cross section of the measurement section is 460 $\times$ 460 mm and the length of the test section is 600 mm. The non-uniformity of the velocity distribution is negligible. The turbulence intensity is less than 0.2 for the largest Reynolds numbers in our test domain. The experiment apparatus is shown in Fig. 1.

The fin array geometry used in these calculations consists of an entrance and exit louver with four louvers on either side of the redirection louver. A scaled-up (ratio of 10) inclined louvered fin model of an automobile radiator was used as simple model without dimples and perforations. Additionally, four samples, including an in-line and staggered arrangement with dimples and perforated dimples, were constructed to have the same size. The five geometries that were studied in this research are listed in Table 1.

DeJong and Jacobi [19] presented a computational method to determine the minimum required rows of fins for flow visualization studies without losing periodic flow. This method is used in this research. Fig. 2 shows the schematic structure of the three types of experimental apparatus with their geometrical parameters. For all the calculations in this article, the louver thickness is fixed at 1 mm. Further geometrical details are listed in Table 2.

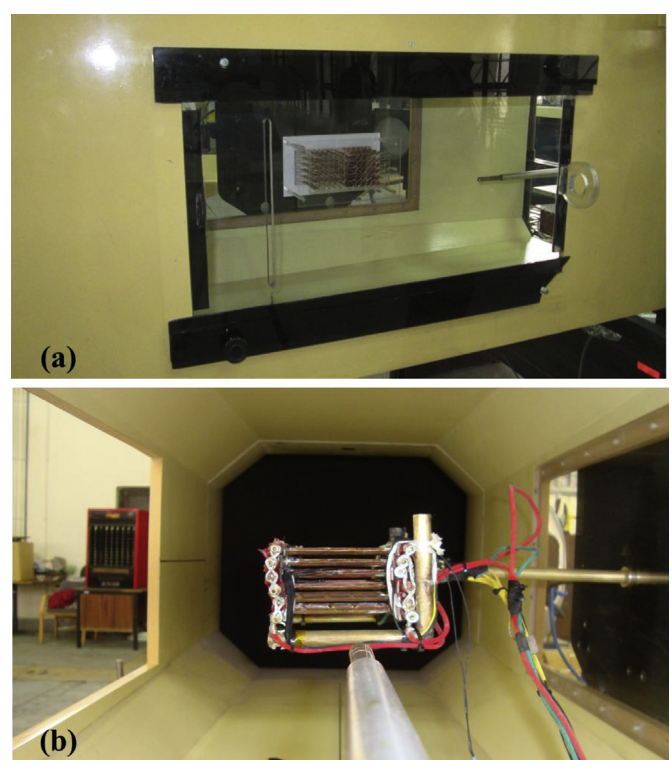

Fig. 1. Experimental apparatus (a) external view, (b) internal view.