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Dynamic characteristics of natural convection from horizontal rectangular fin arrays

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ABSTRACT

This work numerically analyzes the dynamic behavior of natural convection from horizontal rectangular fin arrays. Unsteady simulations are conducted for different fin lengths of $L = 56$–500 mm with fin heights of $H = 6.4$ and 38 mm and a fixed fin spacing of 6.4 mm. With a decreasing H/L ratio, the flow pattern evolves from a steady single-chimney to an oscillating sliding-chimney flow in which cold air is drawn downward from the upper ambience. For both fin heights, the average convection heat transfer coefficient decreases with increasing fin length. It first drops steeply and then decreases mildly beyond a certain length when the sliding-chimney flow occurs. The effect of the downward flow on heat transfer is weaker for high fins because the penetration depths are limited by the thicker boundary layers developed in the high channels. The predicted average Nusselt numbers agree well with the experimental data in the literature. For an intense sliding-chimney flow pattern from long and low fin arrays, an unsteady simulation yields higher average convection heat transfer coefficients than those using a steady-state simulation.

1. Introduction

Natural convection from horizontal rectangular fin arrays finds important application in the heat dissipation of LED lamps in recent years. To cope with high lamp powers, large fin dimensions are needed due to the low convection heat transfer coefficients associated with natural convection. For example, Luo et al. [1] dissipated the heat of a 112 W LED street lamp with a horizontal rectangular fin array having a base area of 530 mm × 350 mm and a fin height of 17 mm. Since 60 s, experiments on this topic [2–8] began with flow visualization and measurement of the heat transfer coefficients for natural convection. Starner and McManus [2] experimented on the horizontal rectangular fin arrays with a fin length of $L = 254$ mm and four fin heights ($H = 6.4$, 13, 25, and 38 mm). The fin spacing was $S = 8$ mm for $H = 25$ mm, while $S = 6.4$ mm for the other three heights. The convection heat transfer coefficients for the two larger fin heights are lower than those for the two smaller fin heights. With the array's ends closed, h decreases by about 50% for large Hs but remains unaffected for small Hs. These different features result from the different flow patterns for different Hs. For a large H, a considerable amount of fresh air is drawn from the array's end, while the most of fresh air is drawn from the upper ambience for a small H. Harahap and McManus [3] continued on the horizontal rectangular fin arrays with two fin lengths ($L = 127$ and 254 mm). The other fin geometries were the same as those in Ref. [2]. They not only measured the time-averaged overall convection heat transfer coefficients ($\bar{h}$) but visualized the plume patterns using the Schlieren shadowgraph technique. They observed stable single-chimney plumes, as shown in Fig. 1a, for the short L (127 mm) with large Hs (25 and 38 mm). In contrast, sliding-chimney plumes (Fig. 1b [2]), sliding back and forth along the longitudinal direction, appear for the long L (254 mm) with small Hs (6.4 and 13 mm). The $\bar{h}$ values for the long-fin sliding-chimney condition are lower than those for the short-fin single-chimney condition. An empirical correlation for Nusselt numbers (Nu) was proposed to account for the variations of L, H and S. Jones and Smith [4] applied the Zehnder–Mach interferometer for $\bar{h}$ measurement for the natural convection from horizontal rectangular fin arrays with length $L = 254$ mm. The interferometric technique provides radiation-free $\bar{h}$ measurements. Their experimental results show that fin spacing exerts a strong effect but fin

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[2] It is noted that the simplified sketch of Fig. 1b, depicted by Harahap and McManus [3] for the sliding-chimney plume, could not reflect the complex oscillatory behavior. In addition, the vertically downward cold-air flow in Fig. 1b is unrealistic, as will be shown by the present numerical results.

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