Enhanced heat transfer performance of cylindrical surface by piezoelectric fan under forced convection conditions

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Many electronic components have a cylinder form. However, when force convection is applied to a cylindrical tube, a low heat transfer performance occurs in the wake area behind the tube. Accordingly, in the present study, a piezoelectric fan is used to enhance the heat transfer performance. The flow fields around the fan tip and cylindrical surface are examined using a flow visualization technique. Furthermore, three-dimensional numerical simulations are performed to examine the detailed characteristics of the heat and fluid flow fields generated by the vibrating fan. The numerical and experimental results show that the vibrating fan blade produces a jet-like flow, which mixes the free stream and the fluid in the wake region and prompts an improved heat transfer performance as a result. It is shown that the vibrating fan enhances the overall heat transfer ratio as much as 132%, and the local heat transfer ratio up to 214%. However, given a large fan tip amplitude, a large fan tip-to-heated surface clearance distance and a Reynolds number greater than Re = 2200, the jet flow induced by the vibrating blade reduces the heat transfer from the cylindrical surface.

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1. Introduction

Heat transfer in electrical devices is generally limited due to space constraints and the need to minimize noise. Consequently, heat transfer is generally dominated by the effects of natural convection. However, natural convection has a relatively poor cooling efficiency, and thus for many electrical devices, external fans are required to prevent component damage. Many electronic components have a cylindrical form (e.g., capacitors, solenoids, inductors, transistors, and so on). As air flows over a cylindrical surface, part of the fluid coheres at the so-called stagnation point, resulting in an increase in the static pressure. However, as the air flows further along the surface, the pressure reduces due to viscous effects, and a boundary layer is formed under the effects of the favorable pressure gradient. Having passed the point of minimum pressure, the pressure gradually increases with an increasing flow distance; thereby creating an adverse pressure gradient. In other words, the fluid velocity within the boundary layer transits from a positive direction to a negative direction, and a zero velocity gradient occurs at the flow separation point [1]. Behind this separation point, vortex and wake structures are formed in the downstream region; resulting in a significant reduction in the heat transfer performance.

Many methods have been proposed for improving the heat transfer coefficient in the wake region of a cylindrical surface under forced convection conditions. For example, Fiebig et al. [2] and Biswas et al. [3] used delta wings, rectangular wings, delta winglets, and rectangular winglets as vortex generators to produce longitudinal vortexes to enhance the heat transfer coefficient in the wake region of fin-and-tube heat exchangers. In later studies [4,5], several other types of vortex generator were proposed for enhancing the heat transfer performance around heated fin-tubes. Existing proposals for enhancing the heat transfer performance can be broadly classified as either passive (e.g. vortex generators such as those proposed in [2–5]) or active. Of the various active devices available, piezoelectric fans have attracted particular attention due to their operational simplicity, small size, minimal noise and low power consumption. Toda [6] performed a theoretical and experimental investigation into the air flow induced by a vibrating PVF2 bimorph fan. The results showed that the cooling efficiency of the fan was dominated by the vibration amplitude and the wing tip velocity. Açikalin et al. [7] investigated the thermal performance of a piezoelectric fan, and showed that the heat transfer performance was increased by more than 100% compared to that achieved under natural convection conditions. Kimber et al. [8] used an infrared thermal camera to visualize the temperature field around a piezoelectric fan given vibration amplitudes ranging from 6.35 to 10 mm. The results showed that the two-dimensional contours of the local heat transfer coefficient changed from a lobed-shape to a circular shape, and finally to an elliptical shape, as the distance between the fan tip and the heat source was increased from 0.01 to 2.0 times the vibration amplitude. Kimber et al. [9] showed that...