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# Plate-fin array cooling using a finger-like piezoelectric fan

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## HIGHLIGHTS

- Heat transfer of a piezoelectric fan-cooled plate-fin array was investigated.
- Effects of fan position, fan height and fan material on heat transfer were examined.
- Similar heat transfer enhancement range was shown for both fin array orientations.
- Fin heat transfer with a running Al fan at $x = 0$ was higher than that at $x = 0.25L$.
- Besides fan Reynolds number, the area ratio also determined *Nu* of the fin array.

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## ABSTRACT

In this study, the heat transfer of a plate-fin array cooled by a vibrating finger-like piezoelectric fan comprising four flexible rectangular blades was investigated. The results indicated that the heat transfer enhancement of the fin array cooled by a vibrating piezoelectric fan at $x/L = 0.5$ and $H = 5$ mm ranged between 1.5 and 3.3, regardless of the fin array orientation. However, the heat transfer enhancement caused by a fan being placed at either edge of the fin array yielded a dissimilar result between both of the fin array orientations because of the superimposed effects of the boundary layer development and the air flow induced by the fan. This dissimilarity was especially noticeable when the piezoelectric fan was composed of aluminum blades to accommodate the moderate Reynolds number. In addition to the Reynolds number, the ratio of the fan blade vibration envelope to the source area determined the *Nu* number of the piezoelectric fan-cooled fin array. This design enhanced the fin array heat transfer and reduced cooler volume by embedding multiple vibrating beams into the fin array.



## 1. Introduction

The thermal management of modern portable electronic products is a vital concern because an increasing amount of power is being generated within narrow enclosures. Although attaching heat sinks to hot chips without using fans is the most simple and inexpensive method for dissipating the heat, using an air-cooled heat sink under natural convection is not highly efficient. Piezoelectric fans, constructed using a flexible cantilever beam bonded with a piezoelectric material, have received much attention over the past few years because these fans possess several advantages. Since Toda's work [1,2] was conducted, numerous experimental and numerical studies have been conducted to investigate the air flow induced by a running piezoelectric fan and the cooling characteristics demonstrated by using various arrangements of the fan for cooling a flat surface [3–7]. Kimber et al. used infrared thermal imaging [8–10] to investigate the heat transfer of a constant-heat-flux flat surface when employing arrays of piezoelectric fans operating in the first resonant mode. The results of this previous study indicated that the area-averaged thermal performance of the fan array was superior to that of a single fan and that the pitch of the fan array strongly affected the convection pattern.

Petroski et al. [11] proposed a flow-optimized heat sink concept using a 3-D flow-shaping design to substantially enhance the cooling capability of a heat sink-piezofan assembly. They reported that a heat sink and piezoelectric fan system had a COP*v* 5 times higher than that of a typical natural-convection solution.

Abdullah et al. [12] tested a finned heat sink with a multi-piezofan (three piezoelectric fans) placed at various tip gaps and orientation angles to maximize the heat removal. They determined that the optimal tip gap and orientation of the multi-piezofan were $\delta = 0.17$ and 90°, respectively. Compared with natural convection, an enhancement in the convective heat transfer coefficient exceeding 88% was achieved under this condition.

Ma et al. [13] analyzed the effects of operating frequency, fan amplitude, fan arrangement, on the dimensionless thermal performance, *Ri*, and power consumption of a cooling system

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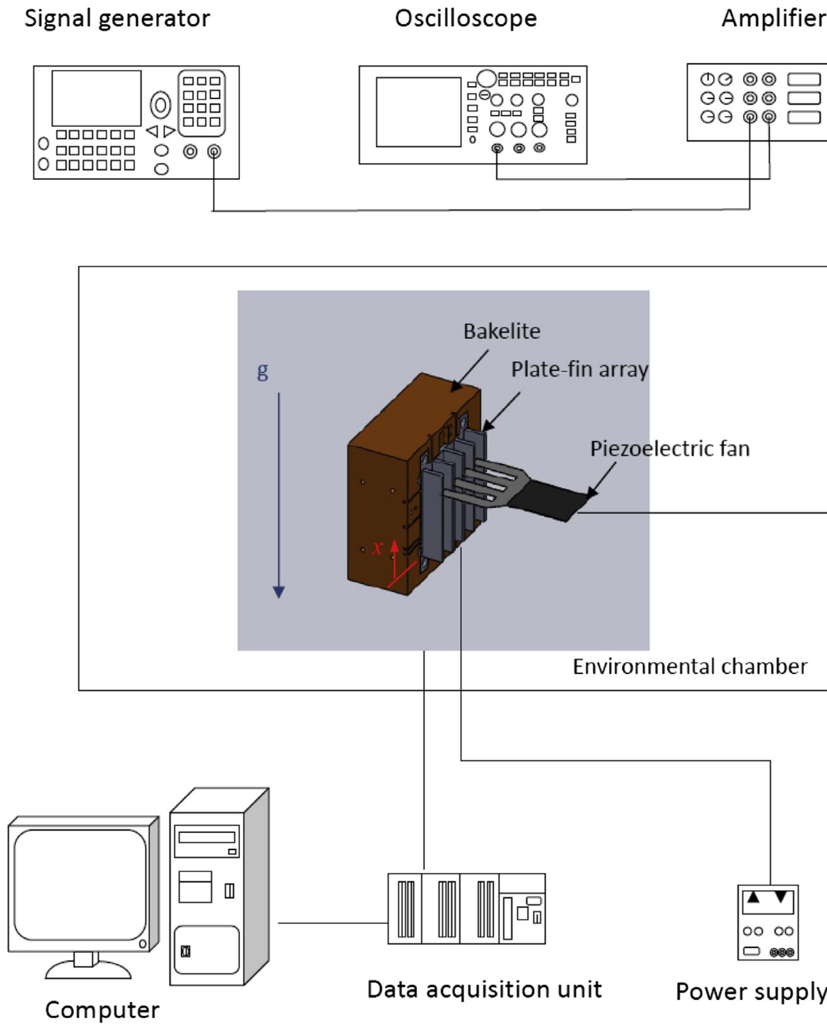


**Fig. 1.** Schematic of the experimental setup containing a vertical plate-fin array.

comprising an aluminum heat sink and a piezoelectric fan to create an optimal design. Afterward, Ma et al. [14] proposed an innovative multiple vibrating-fan cooling system containing a PZT actuated fan and four other plastic fans driven by magnetic force.

Li et al. [15] conducted experiments to study various effects, including piezoelectric fan configuration, piezoelectric fan location, and the heat sink dimensions on the thermal resistance of plate-fin heat sinks. The results indicated that a vertical piezoelectric fan produced the optimal thermal performance when the fan tip was at the heat sink center, whereas a horizontal piezoelectric fan produced the optimal thermal performance when the fan tip was at the front edge of the heat sink.

Based on this literature survey, cooling a heat sink by using multiple piezoelectric fans [8,9,12,14] was determined to be more effective than cooling using a single piezoelectric fan. However, actuating multiple independent piezoelectric fans in an air-cooling system is likely to be a complex task because doing so requires either multiple independent signal source inputs for each individual fan, or a signal source input distributed to multiple fans using a complex circuit design. In addition, because the heat transfer of the heat sink is optimal when the piezoelectric fans are oriented at an angle of 90°, the present study proposes using a finger-like piezoelectric fan that contains four flexible blades oriented at an angle of 90° to perform plate-fin heat sink cooling. Thus, the present piezoelectric fan vibrates in a manner similar to that of four piezoelectric fans, but only a single signal source is necessary to actuate it. Furthermore, this design can possibly yield a high cooling performance and reduce the volume of the fan-heat sink assembly because the finger-like design allows the piezoelectric fan to intrude into the fin array. This is especially crucial when the cooler is used in electronic equipment within a slim housing. The heat transfer and thermal resistance of a plate-fin array were measured using a vibrating piezoelectric fan characterized by various sizes and materials at two specific fan tip gaps.

## 2. Experiment setup

The experimental setup, consisting of a signal generator, an amplifier, an oscilloscope, a test fin array, a piezoelectric fan, and a data acquisition system, is illustrated in Fig. 1. All of the piezoelectric fans were self-fabricated by bonding a commercially available piezoelectric patch (PSI–5H4E/T107-H4E-602, Piezo Systems, USA) to a finger-like flexible blade using epoxy for testing. Before the piezoelectric patch was bonded to a blade, a raw square piezoelectric sheet of 72.4 mm in length was diced into several rectangular sheets with a length of 30 mm and a width of 24 mm, respectively, using a diamond saw. A signal generator (Picotest G5100A) was used to provide a sine wave of a specified frequency for the amplifier (Piezomechanik Gmbh SVR500-3) to generate a 55-V voltage for powering both the oscilloscope (Tektronix TDS10001B) and the piezoelectric fan.