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Local heat transfer enhancement induced by a piezoelectric fan in a channel with axial flow

Key words:
piezoelectric fan; local heat transfer enhancement; forced convection; longitudinal vortex; pressure drop

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Research background

- Nowadays, the rapid growth of heat flux in electronic systems has made thermal management very important. However, the effectiveness of conventional natural and forced convection cooling methods is in general limited by space and noise constraints.
- Piezoelectric fan is an innovative design which consists of a piezoelectric layer and a flexible blade. When an alternating voltage is applied to the piezoelectric layer, the piezoelectric layer expands and contracts periodically, which causes vibration of the flexible blade. It has attracted extensive attention owing to its high reliability, low noise, low power consumption, and low space requirement.
- The existing research shows that a vertical-oriented piezoelectric fan interacting with cross flow can remarkably enhance the heat transfer performance of heated surfaces, but the vertical arrangement method also requires a extra space for installation, which obviously limits the application scope of piezoelectric fan.
- This work proposes a horizontal arrangement for installing a piezoelectric fan interacting with cross flow in a channel. The horizontal arrangement not only has an excellent heat transfer performance, but also does not need extra installation space, which makes it a better choice in space restricted forced convection heat transfer applications, such as cold plate.

Experimental setup

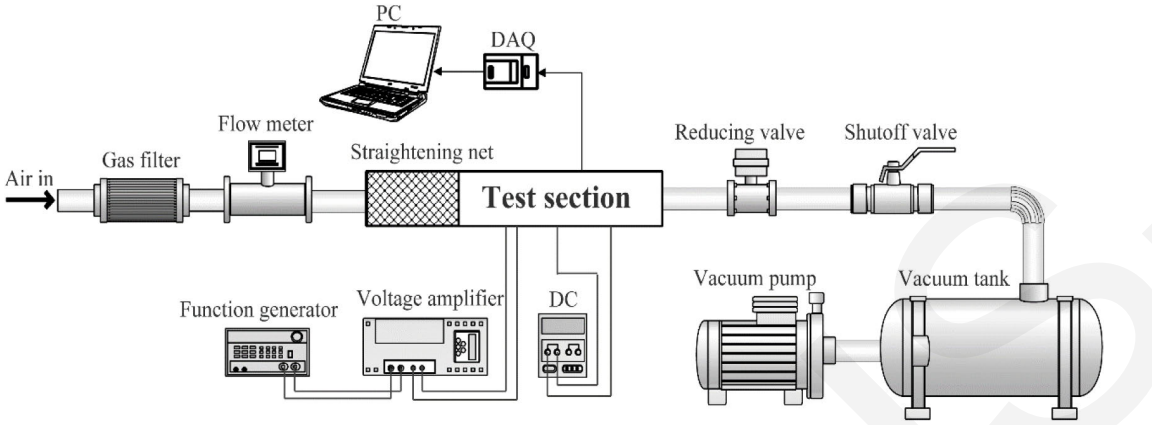


Fig. 1 Schematic diagram of the experimental setup

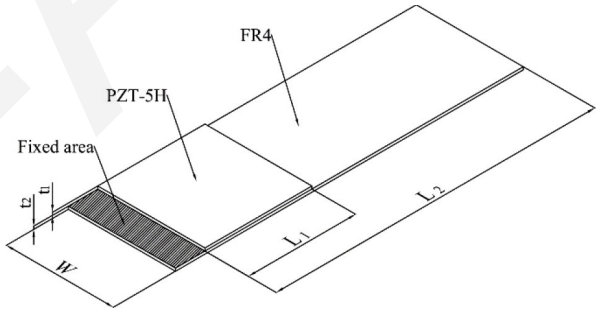


Fig. 3 Schematic diagram of the piezoelectric fan

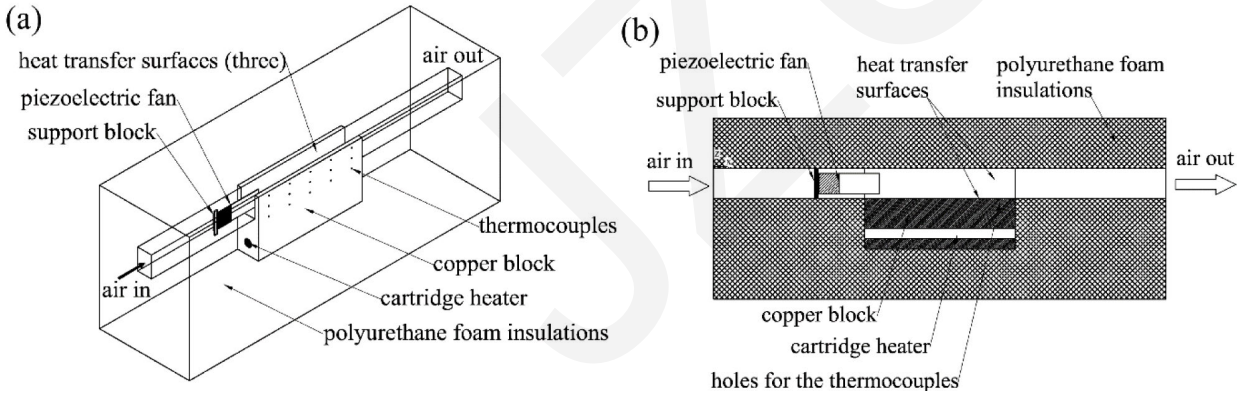


Fig. 2 Schematic diagram of the test section

Table 1 Dimensions of the PE fan

Parameter	Value
Thickness of PZT-5H	0.2 mm
Thickness of FR4	0.2 mm
Width of the fan	20 mm
Length of PZT-5H	20 mm
Length of the fan	60 mm
First resonant frequency	41.2 Hz

Numerical simulations

➢ Governing equations

$$\frac{\partial(\rho\phi)}{\partial t}+\frac{\partial(\rho(u_i-\hat{u}_i)\phi)}{\partial x_i}=\frac{\partial}{\partial x_i}\left(\Gamma_\phi\frac{\partial\phi}{\partial x_i}\right)+S_\phi$$

➢ Computational domain

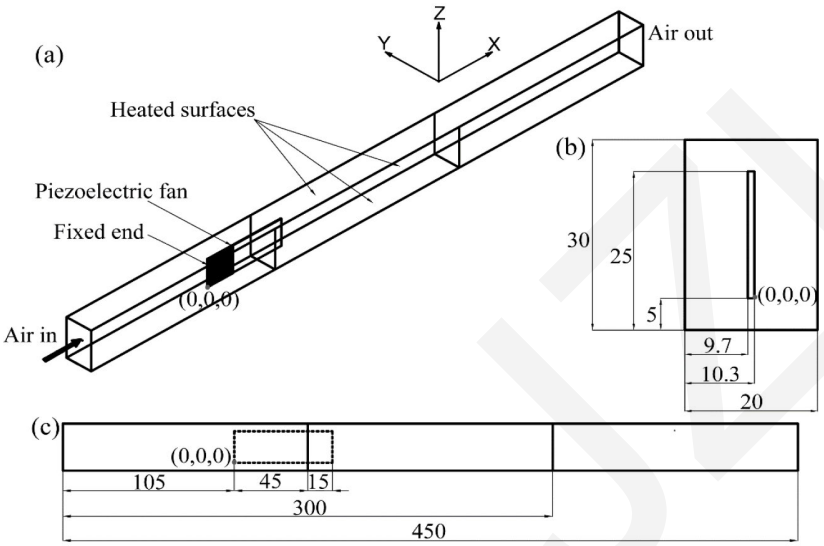


Fig. 5 (a) Schematic of the computational domain; (b) side view; (c) front view. (units: mm)

➢ Boundary conditions

$$y(x)=\frac{A_{pp}}{2}\cdot y_n(x)\cdot sin(2\pi ft)$$

$$y_n(x)=-1.8865e^{-7}\times x^4+2.1833e^{-5}\times x^3-$$
$$4.0447e^{-4}\times x^2+3.0414e^{-3}\times x-7.4908e^{-4}$$

➢ Mesh generation and independence validation

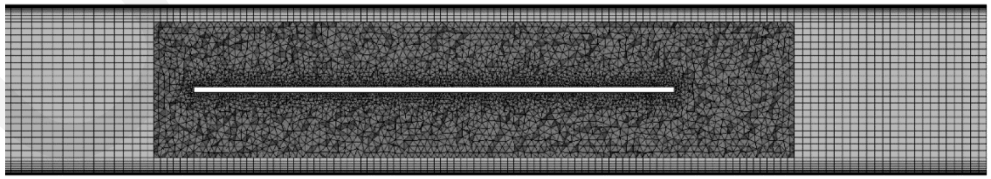


Fig. 7 Computational mesh using hybrid mesh

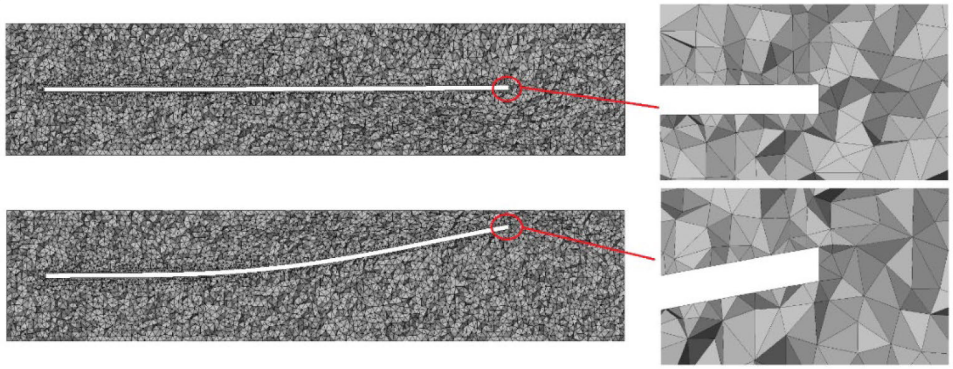


Fig. 8 Computational mesh before and after deformation

Results and discussions

➢ Experimental results

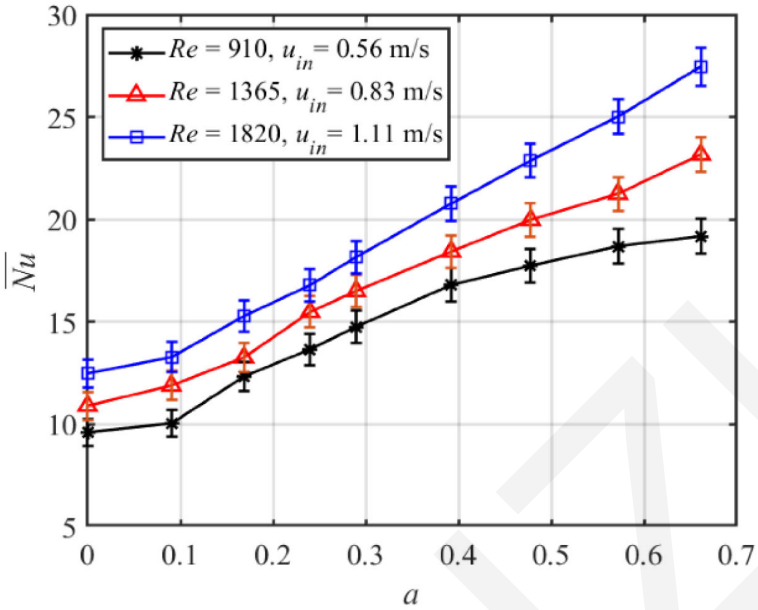


Fig. 4 Variations of the time-averaged mean Nusselt number with the dimensionless amplitude (*a*) for different *Re*

➢ Validation of the numerical simulations

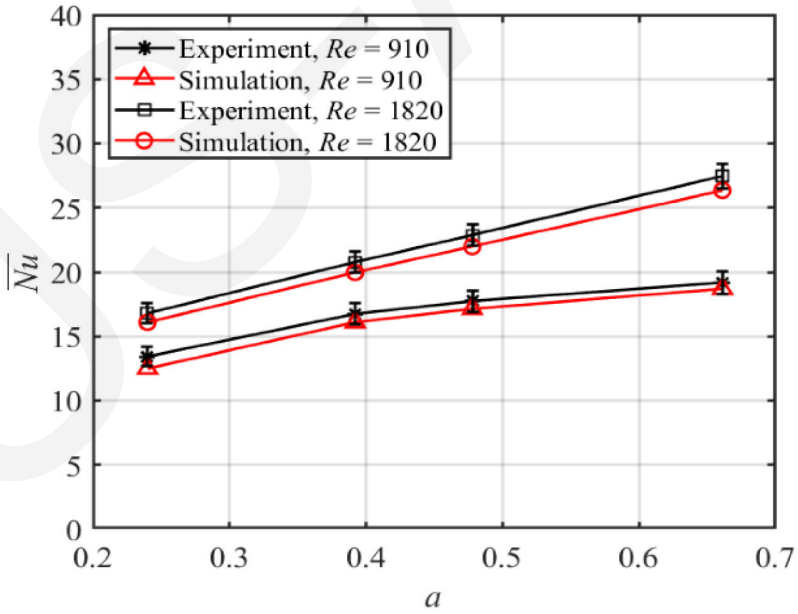


Fig. 10 Comparisons of the computed time-averaged mean Nusselt number with the experimental results

Results and discussions

➢ Flow structure

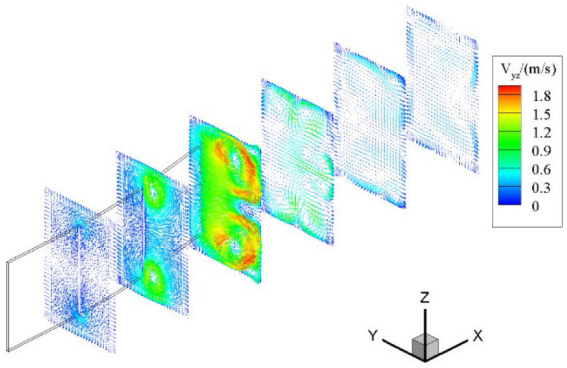


Fig. 11 Lateral velocity vectors in the cross sections of x = 20, 40, 60, 80, 100, and 120 mm.

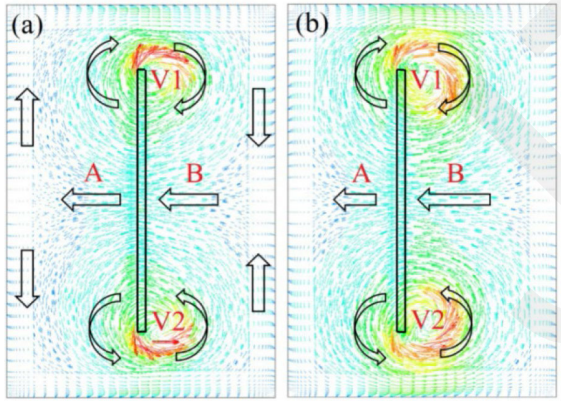


Fig. 12 Lateral velocity vectors in the cross sections of x = 40 mm.

➢ Heat transfer

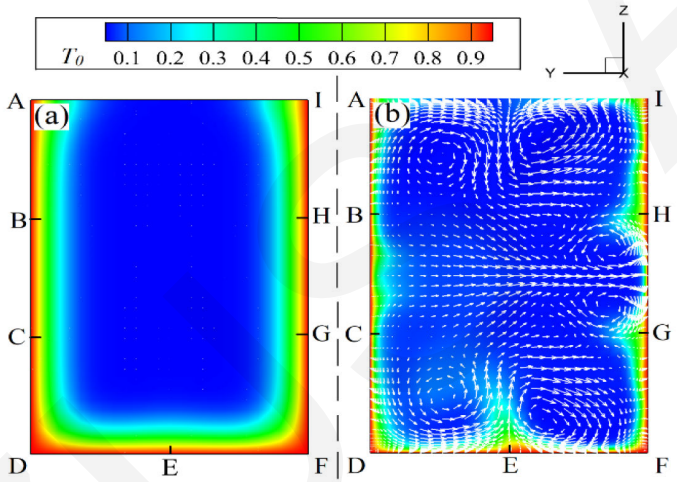


Fig. 13 Temperature contours and velocity vectors in the cross sections of x = 80 mm.

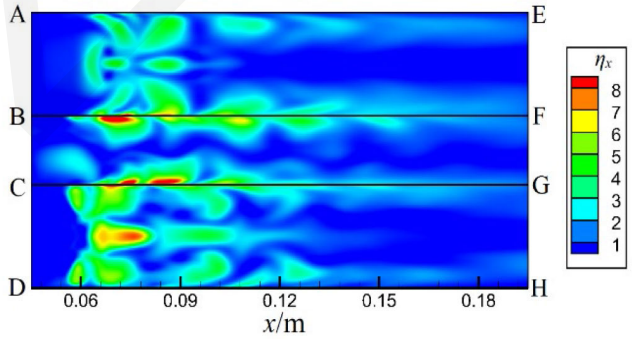


Fig. 15 Distribution of the instantaneous local boundary heat flux ratio.

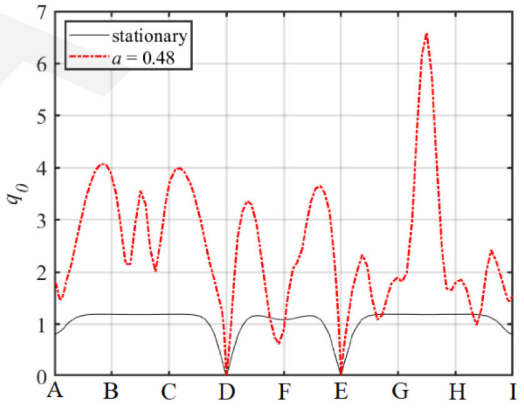


Fig. 14 Distributions of the local boundary heat flux at x = 80 mm.

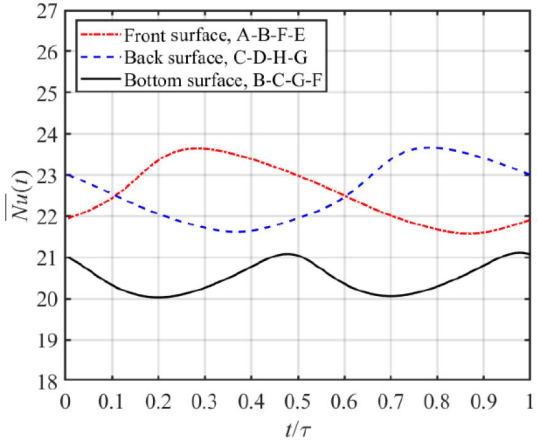


Fig. 16 Variations of the mean Nusselt number in one period.

Conclusion and prospect

- **Conclusion 1:** A vibrating piezoelectric fan can substantially improve the local cooling performance of the channel. Compared with the stationary case, the piezoelectric fan operated at a = 0.66 and Re = 1820 enhances the time-averaged mean Nusselt number ($\overline{Nu}$) by as much as 119.9%.
- **Conclusion 2:** The heat transfer enhancement mainly comes from the longitudinal vortex pairs generated by the piezoelectric fan, which greatly promote the heat exchange between the hot fluid near the heated walls and the cold fluid in the main flow.
- **Conclusion 3:** The piezoelectric fan's vibration has less effect on the pressure drop of the channel. In the case of a = 0.48 and Re = 1820, the pressure drop is only increased by 12.5%.
- **Prospect:** Piezoelectric fan has a good prospect in the field of local heat transfer enhancement. It allows the cooling circuit to be operated at lower mass flow rate while keeping the hot-spot area working safely. Future studies further investigate the interaction between the mainstream and the piezoelectric fan by presenting more visualization works. Moreover, more parametric investigations should be conducted to figure out the main parameters and develop mathematical models.