Energy, Thermal fluid device, Complex flow

A challenging study on the upper limit of convective heat transfer

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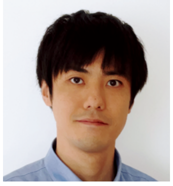

Abstract

Understanding, predicting, and controlling heat transfer phenomena through fluids is of significant importance for solving major challenges in geophysics and astrophysics, such as atmospheric circulation on planets, mantle and core movements, and energy transport in stars. It also directly relates to the development of heat transfer technologies in various engineering equipment and thus is critically important from the perspective of efficient energy use. It is generally well known that turbulent flows can enhance heat transfer. On the other hand, we have recently discovered theoretically that specific flows can achieve heat transfer far exceeding turbulent heat transfer. This research aims to realize the upper limit of convective heat transfer by using porous media or electromagnetic forces.

Background & Results

In recent years, there has been a strong demand for further improvements of thermal and flow control technologies, which aim to enhance heat transfer in applications such as air conditioners, automotive radiators, CPU/GPU cooling devices, and heat exchangers in power plants. Against this backdrop, understanding, predicting, and controlling heat transfer phenomena through fluids is of paramount importance for effective energy use in a sustainable society. It is well known that heat transfer is significantly enhanced when flow spontaneously or forcibly becomes turbulent. Then, can heat transfer be further increased beyond that of turbulence? This research addresses the naive question in thermo-fluid engineering.

We have found velocity fields to achieve optimal heat transfer in the fluid layer between parallel walls held at a constant temperature difference. The maximal heat transfer rate is quite close to the rigorous, mathematical upper bound. It represents the so-called ultimate heat transfer, where the wall heat flux is independent of the fluid's viscosity and thermal conductivity. To practically achieve the `upper limit of convective heat transfer', we have focused on the wall composed of porous media and conducted direct numerical simulations of turbulent thermal convection between permeable walls. The results revealed that wall permeability (wall porosity) generates large-scale thermal plume structures in turbulence, leading to the ultimate heat transfer. Furthermore, similar control strategies have been applied to turbulent shear flow, demonstrating the emergence of large-scale spanwise vortex structures and achieving the ultimate heat transfer.

Significance of the research and Future perspective

This research has found that the introduction of porous media or electromagnetic forces into turbulent flow generates large-scale, strong convective motion, resulting in a significant enhancement of heat transfer. The flow states exhibit the ultimate heat transfer, where the wall heat flux is independent of the fluid's viscosity and thermal conductivity. In the future, we aim to understand the complex thermo-fluid phenomena and generate new insights in fields such as geophysics and astrophysics. Furthermore, we will implement the control technology identified in this research and contribute to the realization of a sustainable society.

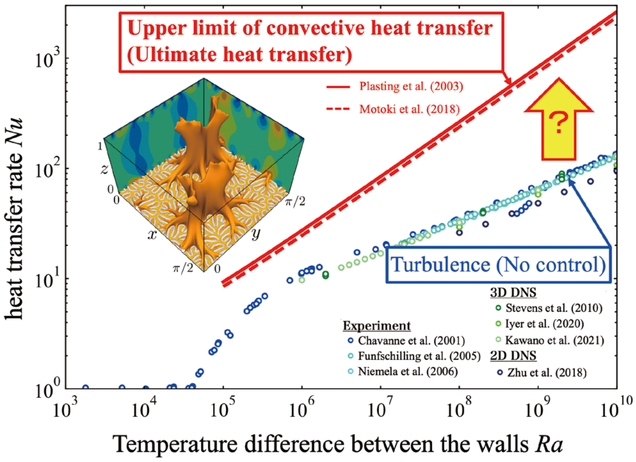

Fig.1 Heat transfer rate vs temperature difference between the walls in thermal convection.

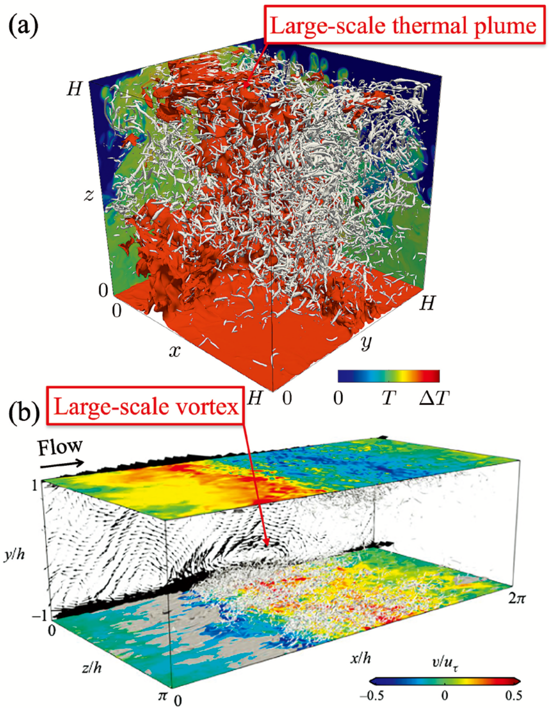

Fig.2 Ultimate heat transfer states between permeable walls. (a) thermal convection (b) wall shear flow.

Patent	
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URL	https://sites.google.com/view/wwwkawaharalaben
Keyword	thermal and fluid control, energy efficiency technology, ultimate heat transfer, turbulence, nonlinear optimization