A transient regime for transforming thermal convection: Cloaking, concentrating, and rotating creeping flow and heat flux

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I. Introduction

Heat can generally transfer via thermal conduction, radiation, and convection. All the existing theories of transformation thermotics and optics can treat thermal conduction and thermal radiation, respectively. Here, by introducing porous media, we develop a general theory of transient transformation thermal convection by considering the convection-diffusion equation (1), the Darcy's law (2) and the continuity equation (3) simultaneous. As model applications, the theory helps to show the effects of thermal cloaking, concentrating and rotating.

II. Method

To apply the transformation theory in transient thermal convection, we consider the incompressible flow in porous media, in which the progress of heat and mass transfer is determined by a set of equations with form-invariance under coordinate transformation $\{x_i\} \rightarrow \{y_i\}$:

$$\tau \frac{\partial \vec{v}}{\partial t} + \vec{v} = -\frac{\beta}{\eta} \nabla p, \tag{1}$$

$$\frac{\partial (\phi \rho_f)}{\partial t} + \nabla \cdot (\rho_f \vec{v}) = 0, \tag{2}$$

$$\frac{\partial (\rho C)_m T}{\partial t} + \nabla \cdot \left(\rho_f C_f \vec{v} T \right) = \nabla \cdot (\kappa_m \nabla T), \tag{3}$$

Also the density of fluid is temperature-dependent, written as

$$\rho = \rho_0 [1 - \gamma (T - T_0)]. \tag{4}$$

We should transform the conductivity, permeability, porosity and the product of density and specific heat.

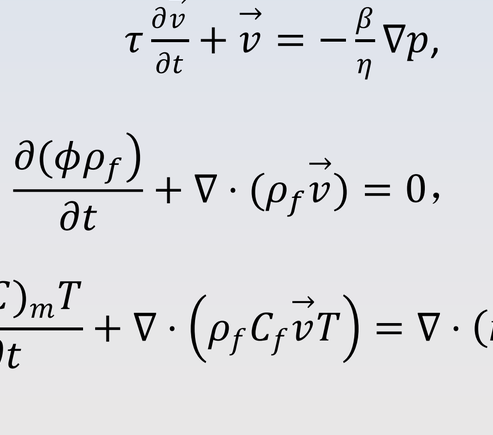

Fig. 1 Schematic design

III. Simulation Results

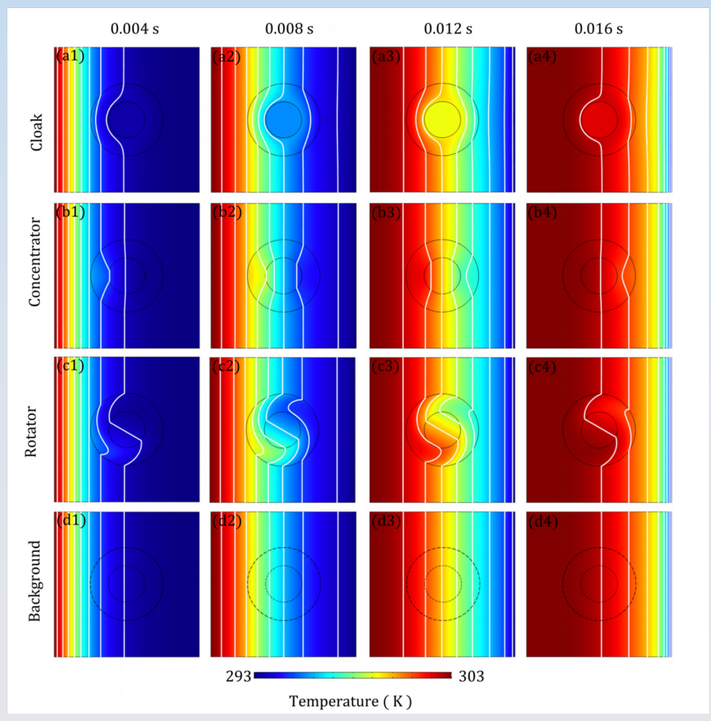

Fig. 2 Temperature dostribution of thermal cloak, concentrator and rotator.

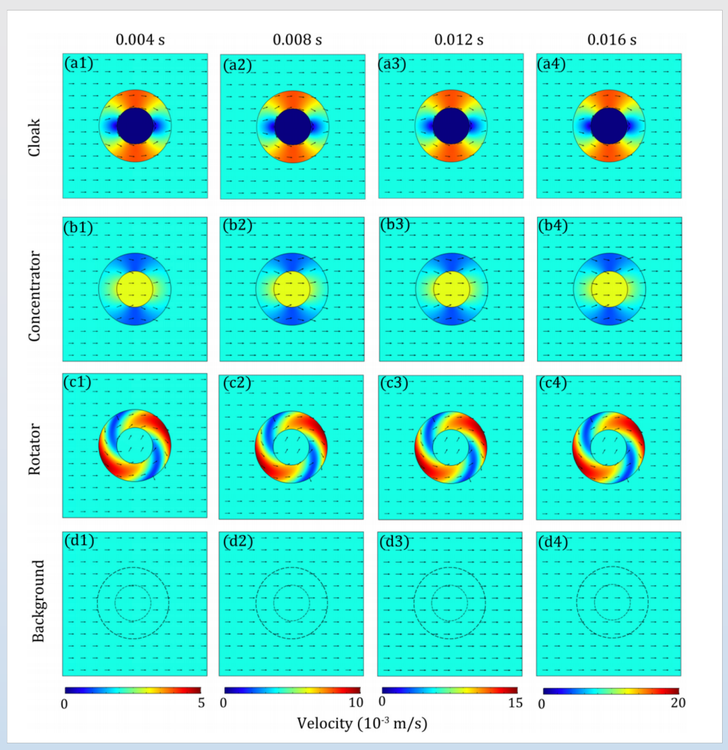

Fig. 3 Velocity distribution of thermal cloak, concentrator and rotator.

V. Conclusion

To sum up, our work offers a transformation theory for transient thermal convection. It not only provides different hints on how to control heat transfer by combining thermal conduction, thermal convection, and thermal radiation, but also benefits mass diffusion and other related fields that contain a set of equations and need to transform velocities at the same time.

Reference

[1] G. L. Dai and J. P. Huang, J. Appl. Phys. **124**, 235103 (2018)