Proceedings of the Canadian Society for Mechanical Engineering International Congress
32nd Annual Conference of the Computational Fluid Dynamics Society of Canada
Canadian Society of Rheology Symposium
CSME-CFDSC-CSR 2025
May 25–28, 2025, Montréal, Québec, Canada

Numerical analysis of carbon capture technology using supersonic flow

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ABSTRACT

Greenhouse gas emissions have caused various environmental and societal challenges and various technologies for carbon capture have been developed with the goal of achieving a net-zero CO_2 emission society. However, current carbon capture technologies face issues in scaling up and limitations in operational conditions.

The utilization of supersonic flow for carbon capture has been proposed by several groups. By expanding gas containing CO_2 to a low temperature and pressure supersonic state in a converging-diverging nozzle, CO_2 can be condensed into a solid and separated from the gaseous flow. Our laboratory suggests using a particle-seeded gas to improve CO_2 condensation and separation. A reliable CFD model is essential for optimizing this carbon capture technology.

The objective of this study is to propose a CFD model for the carbon capture using supersonic flow. The flow is modeled as a multiphase flow of gas with suspended inertial particles using the Eulerian-Eulerian approach, and part of the gas undergoes condensation. For the gas phase, the compressible Navier-Stokes equation is used. For the seeding particle cloud, the pressure is assumed to be zero, and conservation of mass, momentum, and energy is considered. These phases are mutually coupled via drag force and heat transfer using source terms. To consider the heterogeneous condensation of CO_2 onto particle surface, the mass and heat transfers from gas-phase to particle phase are implemented. The condensation is activated by an onset criterion as a function of saturation ratio of CO_2. These equations are discretized using a cell-centered finite volume method. The second-order sequential operator method is used for time marching. The second-order spatial reconstruction is performed before calculating numerical flux at cell boundaries. To solve particle reflection on a wall, the wall reflection model using multi particle families is employed, combining a constant coefficient of restitution.

Condensation and separation parts of the supersonic carbon capture technology were investigated using the proposed CFD model and compared with laboratory experiments. For the CO_2 condensation in a supersonic nozzle (designed Mach number is around 5.5 for a dry flow), static pressure showed agreements between CFD and experiment. In particle separation, the CFD model showed similar particle dynamics to experiment. The effects of particle material and size were investigated to pursue better performance of CO_2 condensation and separation.