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DNS of Turbulent Heat Transfer in Supercritical CO_2 Channel Flow

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Summary

The supercritical fluid (SCF) has both gas-like and liquid-like properties, and it is frequently used in many industrial applications such as chemical process, food production and heat transfer. Supercritical CO_2 is widely used because of its cost and nonpolluting nature. In many cases, the supercritical flows are in turbulent or transitional state and the fluid flow is rather complicated. However, the research works on turbulent (or transitional) supercritical flow are very rare until now, and the research on turbulent supercritical flow is very useful to improve the industrial applications of SCF. In this research, direct numerical simulations (DNS) of supercritical CO_2 turbulent channel flow have been performed to investigate the turbulent heat transfer mechanism of SCF.

The channel is assumed to be full with supercritical CO_2 at 8MPa. Full compressible Navier-Stokes equations and energy conservation equation are solved to take into account temperature dependence of thermal and transport properties of SCF. Since the pressure fluctuation is very small, the thermal and transport properties such as viscosity (ν), specific heat (c_p) and thermal conductivity (k) are assumed to be only the function of temperature, and partition parabolic interpolation equations are introduced to calculate these properties. The Peng-Robinson type equation of state [1] is used to estimate pressure from density and temperature. To approximate the convective terms in momentum and energy equations, 7th-order upwind finite difference scheme is used, and 8th-order central finite difference scheme is used for other terms. Time advancement is implemented by 3rd-order TVD type Runge-Kutta scheme [2]. Reynolds number defined by the mean bulk velocity and mean viscosity is $Re_m = 2800$. The length of computational domain in the streamwise direction is selected to be $48\pi\delta$, where δ denotes channel half width. Wall temperature is set to be $T_{w\max}$ in $4\pi\delta < x < 20\pi\delta$ and $T_{w\min}$ in $28\pi\delta < x < 44\pi\delta$ to realize periodical heating and cooling the supercritical CO_2. DNS are conducted for two cases; case 1: $T_{w\min}$ =309.15K, $T_{w\max}$ =319.15K; case 2: $T_{w\min}$ =311.15K, $T_{w\max}$ =321.15K.

Due to the effects of the mean density variation in wall normal direction, mean

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velocity in the cooling region becomes high compared with that in the heating region, whereas the Van Direst velocities at two regions agree very well. These results suggest that mean velocity is affected by density variation, but not by acoustic effects or intrinsic compressibility effects. The r.m.s. of velocity fluctuations in the cooling region are much higher than that in the heating region, which means that turbulent motion is enhanced in the cooling region and is depressed in the heating region. The mean width between high- and low-speed streaks near the wall decreases in the cooling region. Local high Reynolds number effects increases number of coherent fine scale eddies near the wall and enhances turbulence intensity, and local high Prandtl number effects increases temperature fluctuation near the wall. Therefore, in the cooling region, Nusselt number becomes large due modifications of turbulence structure and temperature transport mechanism. Coherent fine scale eddies and high local turbulent heat flux region are visualized to investigate these modifications. The visualizations show that high local heat flux exists near the coherent fine scale eddies, which results in enhancement of local heat transfer.

References

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