Development of direct numerical simulation database for supercritical carbon dioxide

Supercritical CO_2 Power Cycles Symposium

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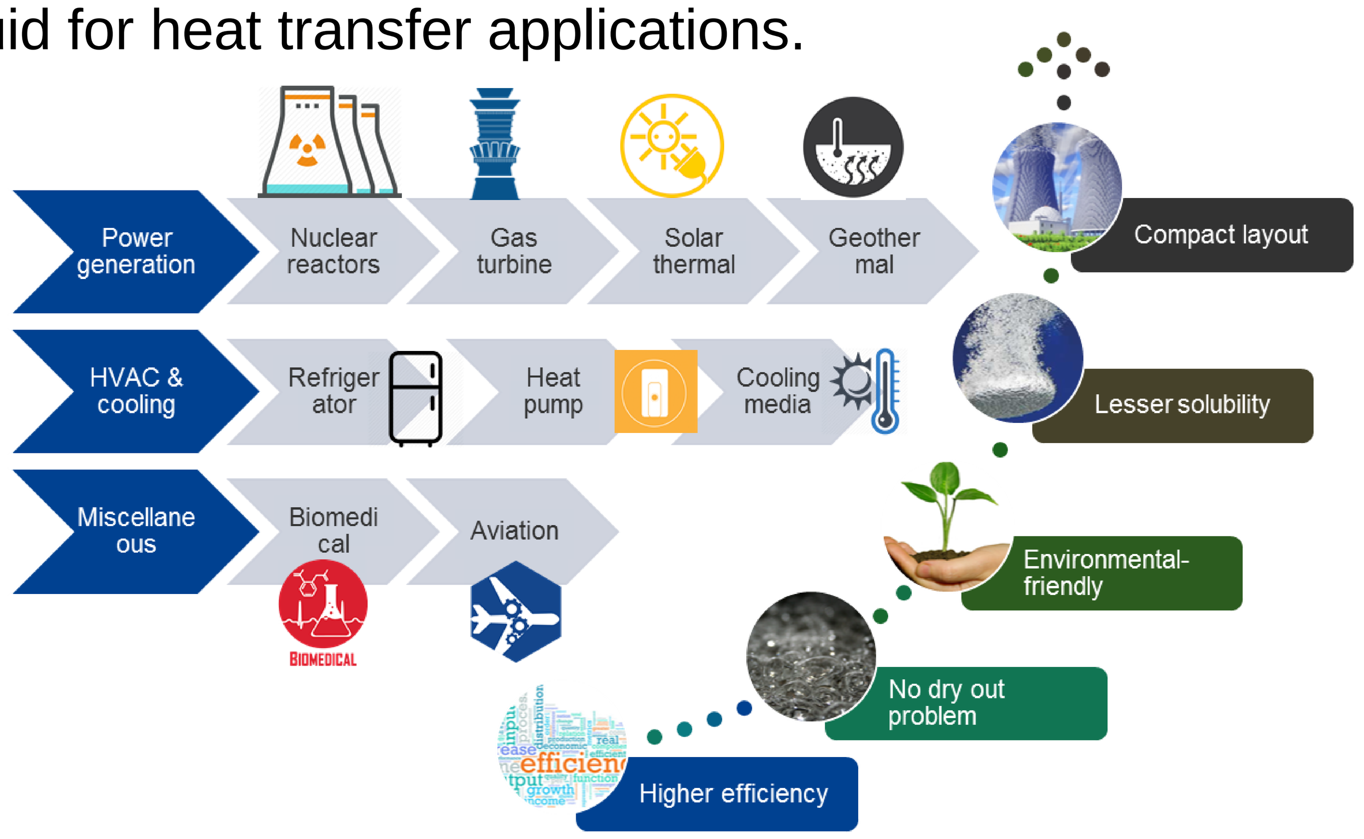
Motivation and Aim

- Supercritical carbon dioxide (sCO_2) is a promising working fluid for heat transfer applications.



- Heat transfer peculiarity creates a problem in prior prediction, therefore a database of mean statistics is delivered, which is generated by direct numerical simulations.

Numerical and computational details

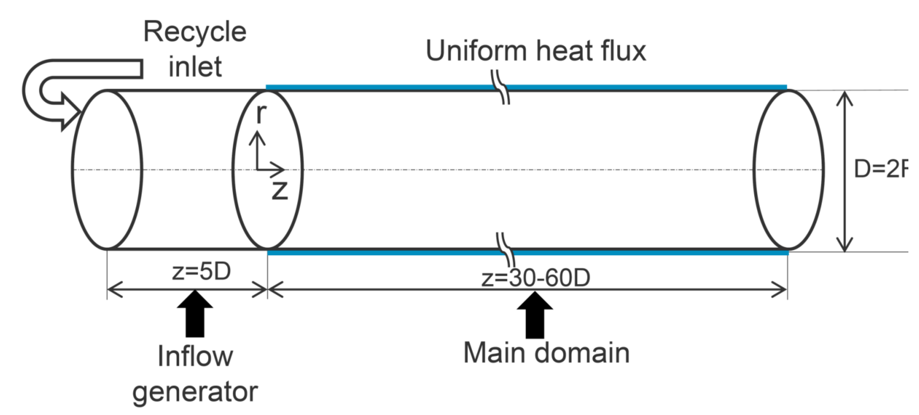
- Low-Mach Navier-Stokes equations are used instead of the fully compressible N-S equations and finite volume based solver was employed for the DNS.

$$\frac{\partial \rho}{\partial t} + \frac{\partial (\rho U_j)}{\partial x_j} = 0 \qquad (1)$$

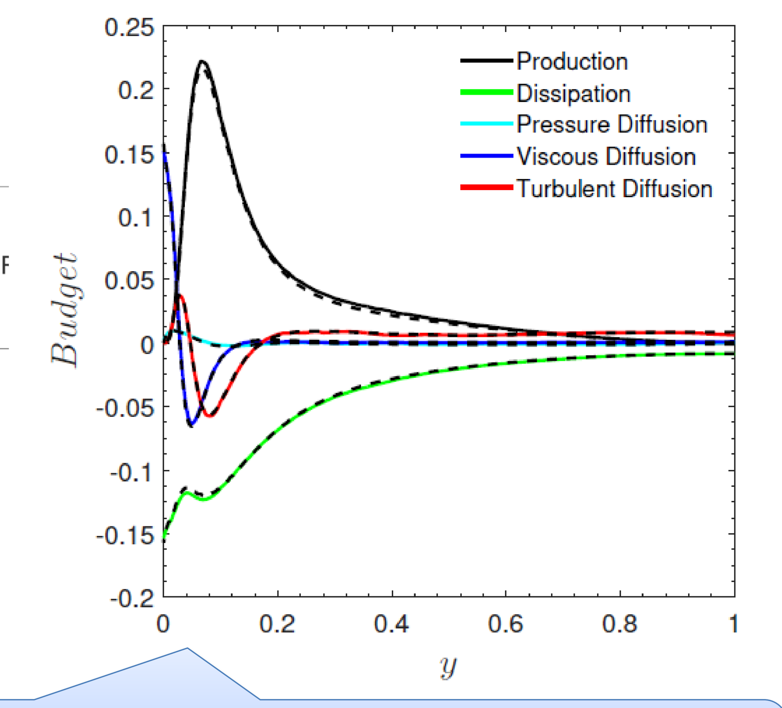
$$\frac{\partial \rho U_i}{\partial t} + \frac{\partial (\rho U_i U_j)}{\partial x_j} = -\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\mu\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)\right) \mp \rho g \delta_{i1} \qquad (2)$$

$$\frac{\partial \rho h}{\partial t} + \frac{\partial (\rho U_j h)}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\kappa \frac{\partial T}{\partial x_j}\right) \qquad (3)$$

- The simulation domain consists of a tube with a total length of 35-65 diameters. Tube diameter ranges from 2-10 mm.



Geometry of the tube



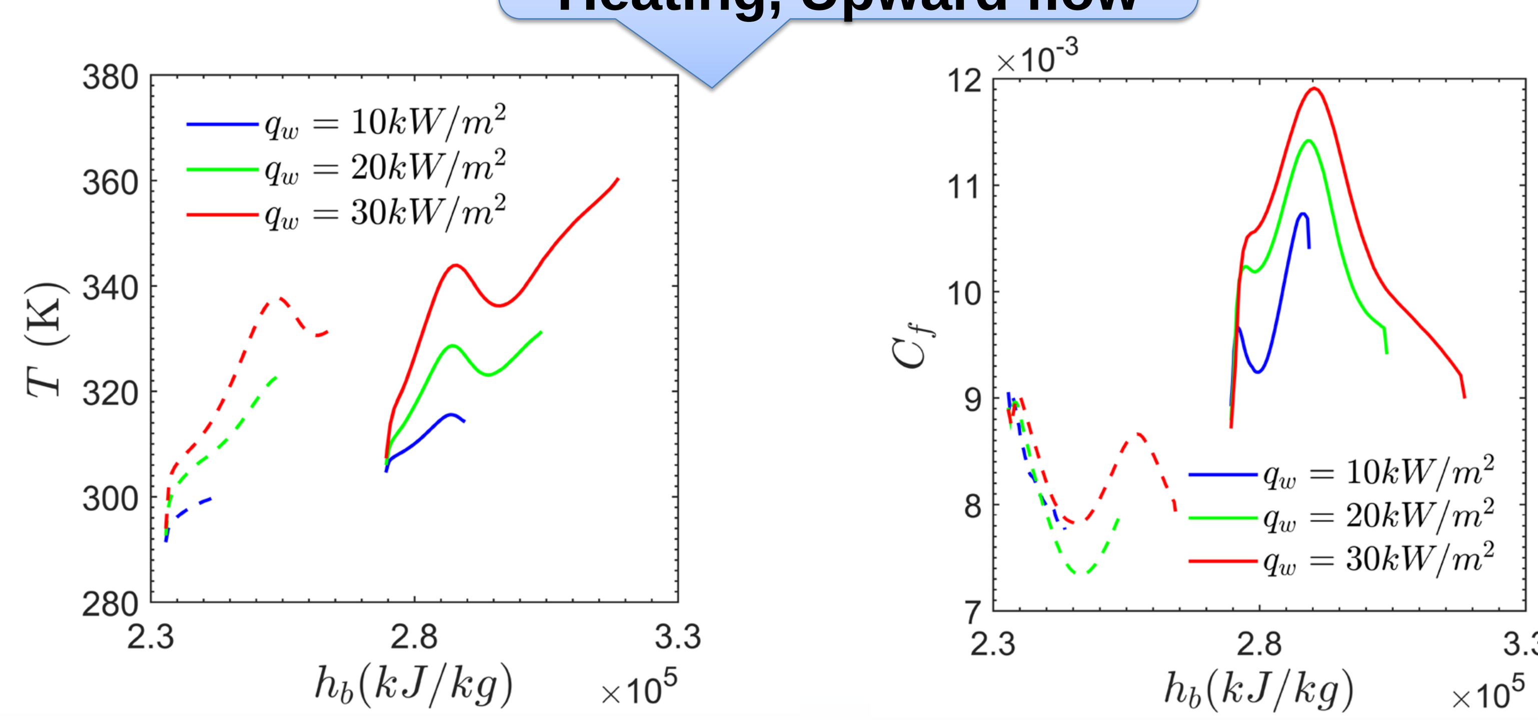
Validation of inflow turbulence with 'KTH FLOW' database

- Total 47 cases were simulated by means of DNS. This includes heating and cooling in the vertical orientation of tube. For heating, we conducted DNS only for upward flow with combinations of inlet temperature, pressure, diameter, and heat flux. For cooling, all three possibilities (upward, downward and forced) were simulated for 2 mm diameter.

Results

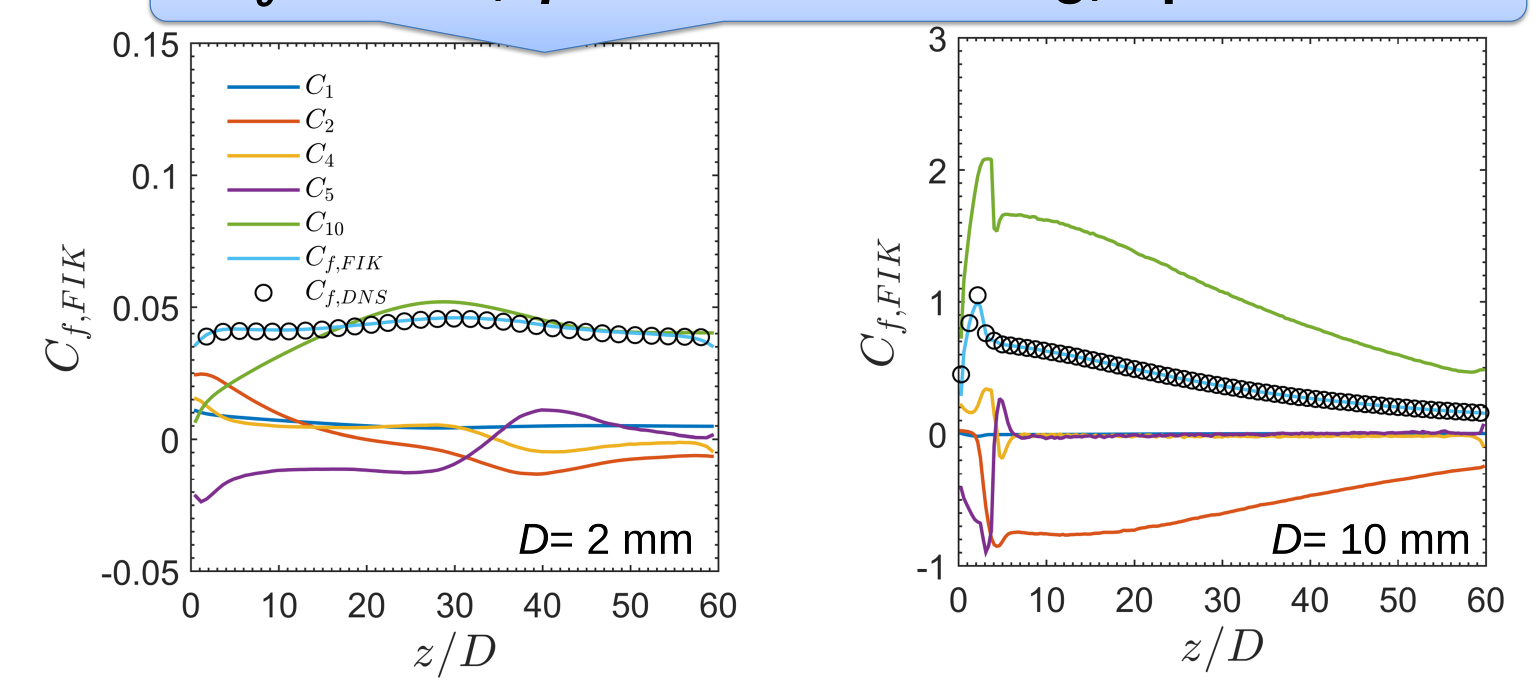
- During heating, a local peak in temperature can be seen in upward flow, which is a characteristic of heat transfer deterioration.

D= 2 mm, P_0= 8 MPa, Heating, Upward flow

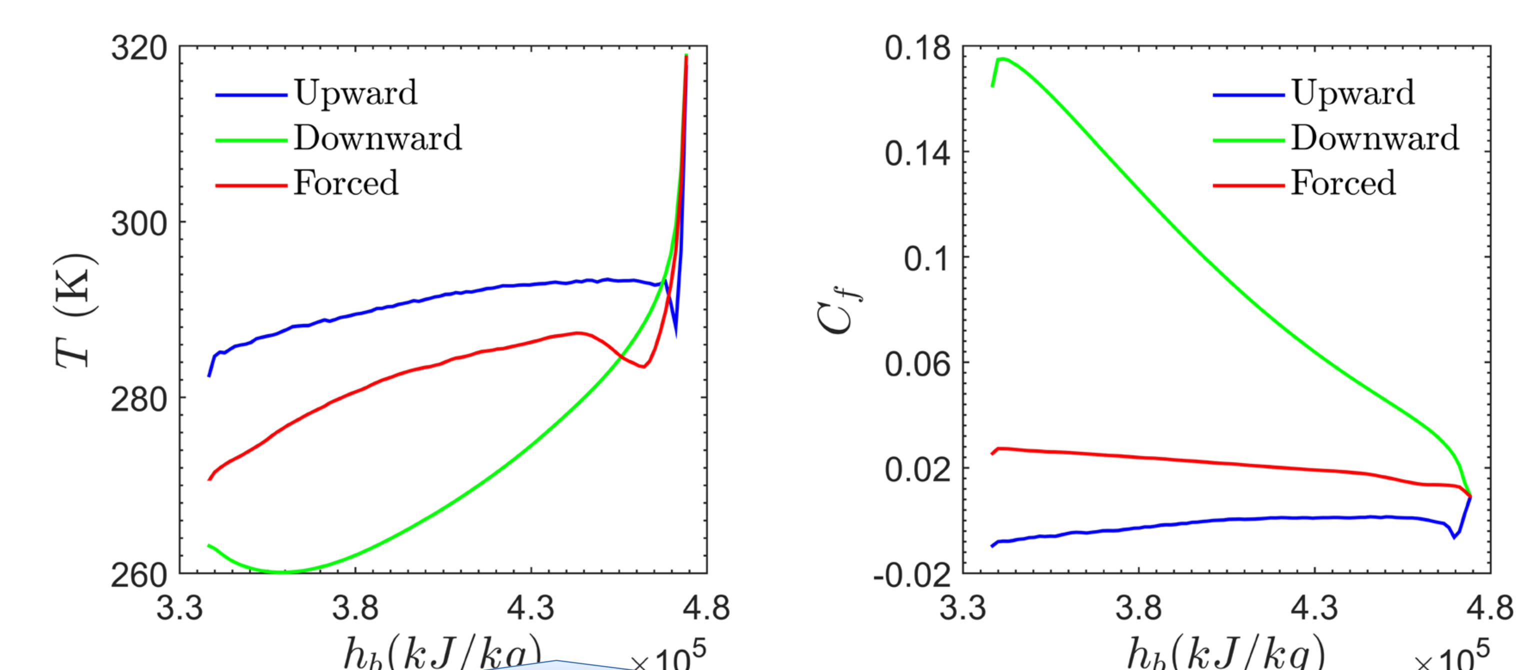


- The decomposition of skin friction coefficient (FIK identity) shows that C_{10}, which is buoyancy contribution to skin friction, has the largest contribution.

P_0= 8 MPa, q= 20 kW/m^2 Heating, Upward flow



- During cooling, downward flow case suffers from the heat transfer deterioration. The ejection and sweep events reduced in the downward flow case which attenuate the turbulence, thereby, the heat transfer.



D= 2 mm, P_0 = 8 MPa, q= -61.74 kW/m^2, Cooling

- Streak stretching in the downward flow (in cooling) leads to impaired heat transfer.

Upward flow

Downward flow

- This database can be used in benchmarking of turbulence models, empirical fitting of the coefficient in correlations, and training of machine learning algorithm.

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Scan code to download data