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Toward modeling of supercritical CO_2 flow using the one-dimensional turbulence model

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Within the CCS (Carbon Capture and Storage) technology the transport of captured CO_2 is increasingly regarded as the missing link in research. For industrial applications it is essential to transport CO_2 from power plants to geological sites through pipelines and well bores. The effectiveness of such a transport could be increased by keeping CO_2 in a supercritical state. This however requires a temperature of at least 31Celsius and a pressure above 73.8 bar. If these conditions are not maintained throughout the whole pipeline, which is challenging and expensive under non-laboratory conditions, density and phase changes and pressure fluctuations may result in harmful vibrations of the pipelines.

Typically, simulations of pipeline flow are based on large-eddy simulations (LES) or the Reynolds averaged Navier-Stokes (RANS) equations which both do not resolve the smallest turbulent scales or even phase boundaries. Due to the effect that on pipe diameter scales the flow statistically changes predominantly in the wall normal direction one might consider 1D modeling approaches.

The work presented here is part of the GeoEn II activities funded by the Federal Ministry of Education and Research (BMBF) to better understand risks and benefits of CCS technology. Our project goal is to better understand the small scale physics in turbulent CO_2 flows and to improve subgrid-scale models used in LES codes.

To achieve this we use ODT (One-Dimensional Turbulence), a statistical turbulence modeling strategy, where turbulent flow evolution along a notional 1D line of sight is emulated by applying instantaneous maps to represent the effect of individual turbulent eddies on property profiles along the line. The occurrence of an eddy itself is affected by the property profiles, resulting in a self-contained flow evolution that obeys the applicable conservation laws. Using a 1D ansatz permits a higher resolution of boundary and single phase density gradients which is key to understand the local CO_2 pipe flow.

Additionally, a level set technique can be used to track phase boundaries along the line of sight through a multi phase flow. Thus, artificial numerical smearing of the phase boundaries can be avoided. The ODT process can then move, create, and annihilate such interfaces.

On the poster we illustrate some milestones to be reached to contribute to a better understanding of the small scale CO_2 pipe flow problem. First ODT is validated and calibrated against a turbulent channel flow DNS at $Re_\tau = 590$ from Moser [1]. Second the evolution of turbulence statistics from a liquid jet experiment [2] is compared to ODT results. Concerning the single supercritical phase we give illustrative examples on how expectable temperature (density) changes in the pipe influence the turbulence [3].

Note that the numerical frame work presented here is not restricted to CO_2 flows. The milestones and test cases already indicate other technical applications.

References

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