Project FORTE - Nuclear Thermal Hydraulics R&D for BEIS

Meshless Methods for Nuclear Thermal Hydraulics

THE CHALLENGE

The design of Nuclear Power Plants involves complex geometry, such as fuel grid spacers and wire wrapped fuel assemblies. The detailed CFD modelling techniques that are currently used to resolve the flow, turbulence and heat transfer in these areas require very large meshes that take a significant amount of time to generate and solve.

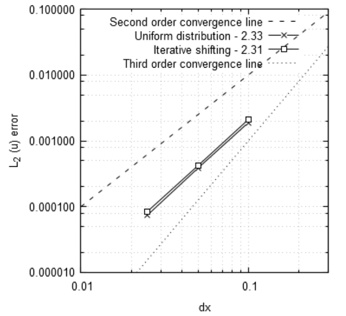
Smoothed Particle Hydrodynamics (SPH) is a novel meshless discretisation scheme capable of modelling highly non-linear deformations and multiphase flows with complex geometries. The traditional advantage of SPH is its Lagrangian nature and the absence of an interconnected mesh, which simplifies the discretisation of the domain as required in mesh based methods. However, SPH and more specifically Incompressible SPH (ISPH) has yet to be applied in nuclear thermal hydraulics modelling.

OUR SOLUTION

Recent advances of ISPH in an Eulerian framework (ESPH) demonstrated near ideal convergence characteristics with second and higher order convergence rates. Although Eulerian, the meshless particle distribution remains an advantage for complex domains. Development and implementation of the ESPH models is done using a 3D parallel solver suitable for large scale 3-D simulations developed in collaboration with STFC. To date, the following models have been developed and implemented in the ISPH solver:

- Eulerian 3-D ISPH accurate to 2^{nd} and higher order.
- Accurate wall and inflow/outflow boundary conditions to 2^{nd} and 4^{th} order.
- Accurate spatial discretisation of arbitrary geometries.
- Turbulence modelling using RANS models (k-ε).
- Heat transfer.

The ISPH solver will be applied to single phase natural convection. In addition, future advances on phase change and two-phase flows are suited to the meshless and Lagrangian (or semi-Lagrangian) nature of SPH.

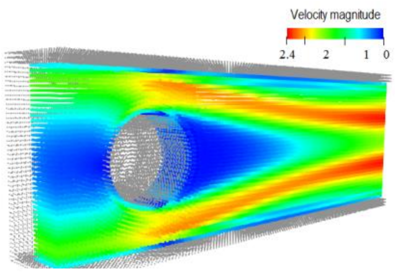


Convergence characteristics of iterative shifting

OUR INNOVATION

The 3-D ESPH scheme has been implemented and validated in the ISPH 3D parallel solver overcoming the long lasting drawback of SPH to accurately represent the wall boundaries. This restriction has been lifted with the development and implementation of near second order wall boundary conditions and recently high order wall boundaries up to 4th order.

The Cartesian particle distribution also posed a restriction for geometries including curves and sharp corners. We have developed a methodology which will attain the second and high-order characteristics of Eulerian ISPH for any arbitrary 3-D geometry. The method utilises diffusion-based particle shifting in an iterative manner, as pre-processing, to regularize the particle distribution to a near isotropic spacing. Further, the parallel 3-D ISPH solver has been extended for turbulence in ESPH using RANS models. Currently the RANS model (k-ε) has been validated and is being applied to a single phase rod bundle sub-channel test case. In addition, the implementation of heat transfer in the solver will be used for single phase natural convection test cases, such as natural convection loops.



Flow around a cylinder

THE BENEFITS

These innovative developments are unique within the SPH scheme, which was traditionally considered to be a low order method. Mesh-based methods (Finite Element/Volume) have dominated nuclear thermal hydraulics to-date. However, these recent developments in SPH in terms of accuracy, convergence rates and general geometries mean that this meshless method could be applied to nuclear thermal hydraulics in realistic geometries.

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