Abstract

Meshless methods discretize the partial differential equations over scattered points instead of grids. Radial basis functions (RBFs) have been popularly used as high-accuracy interpolants of function values at scattered locations. In this work, we have used polyharmonic splines (PHS) as the radial basis function (RBF), augmented with polynomial. A detailed investigation into the order of accuracy and convergence of the method reveals that, for a given number of points, the discretization error rapidly decreases as the degree of the appended polynomial increases. The order of convergence is found to be at least $p-1$ for a polynomial degree of p for both steady and transient heat conduction cases. The algorithm is extended to simulate domains with interfaces. There is an abrupt change in properties across the interface leading to discontinuous coefficients at or near the interfaces. For a multi-domain scenario, the clouds of interpolation points are restricted to be within individual subdomains. It is shown that the imposition of the flux balance condition at the interface points (and not satisfying the governing equation) does not degrade the expected high accuracy of the overall algorithm. Compared with previously proposed meshless algorithms with domain decomposition, the cloud-based interpolations are numerically better conditioned, and achieve higher accuracy through the appended polynomial. The accuracy of the algorithm is demonstrated in several two and three-dimensional problems using manufactured solutions with sharp discontinuity in thermal conductivity. We demonstrate the applicability of the algorithm to solve heat conduction in complex domains with different boundary conditions and internal heat generation. Systematic computations with varying conductivity ratios, interpoint spacing and polynomial degree are performed to investigate the accuracy of the algorithm. Furthermore, we investigate the temperature distribution in a battery pack and evaluate the efficacy of hybrid cooling techniques. Several discharge rates, spanning from low to high (1C-5C), coolant inlet velocity, PCM thickness are parametrically studied. By combining PCM and air cooling, low velocity air circulation can be used to control the battery pack temperature, leading to low power requirements. As the inlet velocity is increased from $u_{in} = 0.086$ to 0.258 m/, there is a corresponding decrease in the temperature of Li-ion cells due to high convective heat transfer. However, with the increase of PCM layer thickness from 2-4 mm, this effect significantly reduces due to presence of secondary recirculating regions resulting in local hotspots. Temperature is lowest in the first column of the battery pack with the highest temperatures observed in the last column. The temperature distribution around the cells located in the first column is not axisymmetric. We also provide an extensive validation for benchmark problems involving natural and mixed convective flows. An in-depth examination of the effect of Richardson number (Ri), Reynolds number (Re), location and direction of rotation of the circular cylinders on fluid flow and heat transfer mechanisms in a cavity with four rotating cylinders is conducted.

Keywords: Meshless method, Polyharmonic splines, Multiple domains, Fluid flow, Heat transfer