SOLUTION OF THERMAL CONDUCTIVITY EQUATION BY A MESHLESS METHOD OF SMOOTHED PARTICLE HYDRODYNAMICS

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Abstract: A meshless numerical method of smoothed particle hydrodynamics (SPH) is implemented for solving the thermal conductivity equation in bodies of complex three-dimensional (3D) geometry. The obtained numerical solutions of test problems are compared with analytical and numerical solutions based on the control volume method. The meshless SPH method is used for calculating the evolution of temperature in a 3D model of the cooled cap of a cylinder block of internal combustion engine. The results of calculations based on the meshless SPH method and the control volume method are shown to be in good agreement with each other. The meshless SPH method is intended for the solution of conjagate heat transfer problems for confined reactive flows.

Keywords: 3D thermal conductivity equation; meshless numerical method; smoothed particle hydrodynamics; temperature distribution

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Figure Captions

Figure 1 Smoothing function and domain of influence for the ith particle

Figure 2 Computational domain for test problems

Figure 3 Comparison of the calculated temperature distributions obtained by the SPH method (points) with analytical and numerical solutions (curves) for three test problems: (*a*) problem 1; (*b*) problem 2; (*c*) problem 3: *1* — $N_V = 20\,000$; *2* — 10 000; and *3* — $N_V = 5000$

Figure 4 Schematic of (*a*) full computational domain and (*b*) computational domain with a cut. The "cold" surface is shown in gray, and the "hot" surface is shown in black

Figure 5 Comparison of temperature fields for two time moments predicted by the SPH method with equidistantly spaced particles (left column), distribution of particles like the nodes of the computational mesh (middle column), and control-volume-based method (right column) at $t = 0.1$ (*a*) and 5.0 s (*b*)

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References

1. Lucy, L. B. 1977. A numerical approach to the testing of the fission hypothesis. *Astron. J.* 82:1013–1024.
2. Gingold, R. A., and J. J. Monaghan. 1977. Smoothed particle hydrodynamics: Theory and application to non-spherical stars. *Mon. Not. R. Astron. Soc.* 181(3):375–389.
3. Libersky, L., and A. G. Petschek. 1991. Smooth particle hydrodynamics with strength of materials. *Advances in the free-Lagrange method including contributions on adaptive gridding and the smooth particle hydrodynamics method*. Eds. H. E. Trease, M. F. Fritts, and W. P. Crowley. Lecture notes in physics book ser. Springer. 395:248–257.
4. Takeda, H., S. M. Miyama, and M. Sekiya. 1994. M. Numerical simulation of viscous flow by smoothed particle hydrodynamics. *Prog. Theor. Phys.* 92(5):939–960.
5. Morris, J. P., P. J. Fox, and Y. Zhu. 1997. Modeling low Reynolds number incompressible flows using SPH. *J. Comput. Phys.* 136(1):214–226.
6. Brookshaw, L. 1985. A method of calculating radiative heat diffusion in particle simulations. *P. Astron. Soc. Aust.* 6:207–210.
7. Cleary, P. W., and J. J. Monaghan. 1999. Conduction modelling using smoothed particle hydrodynamics. *J. Comput. Phys.* 148(1):227–264.
8. Parshikov, A. N., and S. A. Medin. 2002. Smoothed particle hydrodynamics using interparticle contact algorithms. *J. Comput. Phys.* 180(1):358–382.
9. Sikarudi, M. A. E., and A. H. Nikseresht. 2016. Neumann and Robin boundary conditions for heat conduction modeling using smoothed particle hydrodynamics. *Comput. Phys. Commun.* 198:1–11.
10. *Liu, M. B., and G. R. Liu.* 2010. Smoothed particle hydrodynamics (SPH): An overview and recent developments. *Arch. Comput. Method. E.* 17(1):25–76.
11. *Monaghan, J. J.* 1992. Smoothed particle hydrodynamics. *Annu. Rev. Astron. Astr.* 30(1):543–674.
12. Monaghan, J. J., and J. C. Lattanzio. 1985. A refined particle method for astrophysical problems. *Astron. Astrophys.* 149:135–143.

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