Simulation of Multiphase Thermo-Fluid Phenomena by a Local Meshless Numerical Approach

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Thesis Summary

Keywords: multiphase, fluid flow, heat transfer, meshless, local, parallel, OpenMP, pressure-velocity

Received: April 20, 2012

In this paper, the summary of the doctoral thesis focused on the local meshless based solution procedure for solving a multiphase thermo-fluid flow is presented.

Povzetek: V članku je predstavljen povzetek doktorskega dela, namenjenega reševanju večfaznega toplotno kapljevinskega toka preko lokalne brezmrežne numerične metode.

1 Introduction

The computational modelling of multiphase systems has become a highly popular research subject due to its pronounced influence in better understanding of nature as well as in the development of advanced technologies. Melting of the polar ice caps, the global oceans dynamics, various weather systems, water transport, soil erosion and denudation, magma transport and manufacturing of nano-materials, improving casting processes, energetic studies, exploitation of natural resources, welding, casting and advanced solidifications are typical contemporary examples where multiphase systems play an important role. The understanding and modelling of more and more complex physical systems allows the community to address important issues, like environmental consequences of some specific action, on one side and improving technological processes, on the other side. The understanding of natural processes is a key factor in improving our relation to the environment and the quality of life with better and cleaner industrial capacities. Several natural and technological phenomena fall into category of multiphase thermo-fluid flow problems and presented thesis addresses some of them.

In the dissertation [1] a new numerical approach towards solving multi-phase thermo-fluid problems is treated. The volume averaged governing equations for mass, energy, momentum, and species transfer on the macroscopic level, together with the species transfer on the microscopic level are considered [2]. The main issues in solving such physical models occur due to strong nonlinearities and the strong couplings. Such situations are dealt within the dissertation by solving a spectrum of benchmark problems.

2 Methodology

The involved systems of governing equations are solved by local meshless [3] technique based on the Local Radial Basis Function Collocation Method (LRBFCM) [4]. In the thesis, the classical LBRFCM is enhanced with several new functionalities. The basis functions selection and approximation type are generalized. The influence domain selection is dynamic and depends on the node distribution topology. The local approximation system is stabilized by shaping the basis functions. An effective algorithm for adding and/or removing discretization nodes on/from the computational domain is presented. The introduced features increase the applicability and stability of the original LRBFCM.

To minimize computational cost and maximize parallelization efficiency, basic idea throughout the dissertation is to keep the locality of the algorithm. The strong form and the explicit time scheme are used. Furthermore, a local approach to the fluid flow computation is required. Respectively, a local pressure-velocity coupling algorithm is introduced, which allows construction of completely local mass conservation corrections. The proposed pressure-velocity coupling is based on the mass continuity violation, where the pressure correction is proportionally linked to the divergence of the computed velocity field. Some of the cases in the dissertation deal with highly convective dominant problems that might behave unstable. An adaptive upwind strategy [5] is incorporated in the solution procedure in order to stabilize such situations.

The presented solution procedure is almost ideally parallelizable, as it is completely local. There is minimal communication with other parts of the computational domain. It is shown that for shared memory systems the OpenMP parallelization is trivial and effective [6].

The bulk part of the work needed to produce the results was implementation of the solution procedure in the C++ programming language.

3 Presentation of Results

To assess the proposed numerical method a spectra of tests are performed. The spatial discretization convergence, the time discretization convergence and the deformation of the regular node distribution impact on the accuracy are tested on two-dimensional diffusion equation with Dirichlet jump. Dirichlet jump problem has been also used to compare different numerical approaches (FEM, MLPG and FDM) with the presented LRBFCM.

The performance of the method is in the convection regimes assessed on two original tests, developed from the classical Smith and Hutton test [7]. The first test is focused on the impact of the node distribution density jump. The second test is dedicated to the comparison of the dynamic node distribution with the adaptive upwind strategy. Additional test of the nodes adaptivity approach is done by solving the two dimensional Burgers' equation [8] and comparing the results against published data.

The proposed local pressure-velocity coupling algorithm is tested on de Vahl Davis benchmark test [9] and tall cavity, natural convection in the porous media [10], double diffusive natural convection and melting of a pure material driven by a natural convection. To assess the characteristics of the proposed numerical approach numerous analyses and comparisons with the published data are performed. The comprehensive verification procedure shows good agreements with the previously published data, based on different numerical methods.

The final part of the dissertation represents the application of the proposed numerical model and developed solution procedure in a macrosegregation simulation [11]. The solidification of a binary alloy (Al-4.5%Cu) is considered. The results are verified against the classical FVM approach. The simulations of the macrosegregation are for the first time presented with perfect agreement of two entirely different numerical methods.

4 Conclusion

The represented achievements establish better understanding of the meshless numerical methods and broaden their application. The gained knowledge is expected to be directly applied in scientific and technological problems, where the multicomponent and multiphase fluid flow plays an important role. The developed code is written with a lot effort put in the optimization and the parallelization thus it can be used for treatment of more complex situations.

Acknowledgement

I would like to thank the Slovenian Research Agency for support in the framework of the projects Young Researcher Programme 1000-06-310232.

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