An Improved MPS Algorithm for Modelling Crust Behavior in Corium Spreading

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Crust does not immobilize when modeled by highly viscous fluid in the original MPS. A new algorithm is proposed for pressure/viscosity coupling to solve this problem. The VULCANO VE-U7 experiment is simulated for validation.

Keywords: MPS method, Corium spreading, Crust formation, High viscosity, Solution algorithm, Implicit method

1. Introduction

Predicting corium spreading is of great significance in a postulated severe accident of a nuclear reactor. Corium spreading involves a free surface flow, which is significantly influenced by crust formation (solidification) owing to heat transfer. The Lagrangian moving particle semi-implicit (MPS) method is suitable for such flows. The crust formation is usually modeled by drastic increase of viscosity based on an implicit viscosity approach. However, conventional MPS has difficulties in simulating crust immobilization even though it exhibits extremely high viscosity. Therefore, a new solution algorithm is proposed to solve this problem in the present study.

2. New solution algorithm and simulations

When viscosity is high, an implicit method for the viscosity term is necessary to avoid the extremely small width of time steps. In conventional MPS, the viscosity term is calculated before pressure terms. In this situation, the velocity variance caused by pressure gradient is not diffused by the viscosity term, causing some spurious motion of particles with high viscosity. This is the main reason why solidified crust particles do not immobilize. To consider diffusion of velocity change caused by pressure gradient, a new solution algorithm is proposed where the viscosity term is implicitly calculated after pressure terms. In this manner, all the velocity and velocity changes will be diffused in time. As the result, crust can be modeled by viscosity increase, and curst will be immobilized when touching solid wall while it follows the bulk fluid flow when forming at free surface.

The developed model is firstly applied to leakage of high viscosity fluid from a damaged tanker. When the conventional MPS algorithm is used, fluid always leaks no matter how high the viscosity is. When the proposed algorithm is used, the leakage of fluid will stop with increase of viscosity. These results verify the proposed algorithm. Then, the VULCANO VEU7 experiment [1] is simulated. The developed method well predicted termination mechanism of the corium spreading by the crust formation as observed in the experiment, in which the molten corium was confined inside the crust shell.

3. Conclusion

A new solution algorithm is proposed to take diffusion of velocity changes by pressure gradient into account for simulating high viscosity flow by MPS. With the new algorithm, curst formation can be simply modeled by viscosity increase.

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References

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