Benchmarking MELTSPREAD Against Spreading Experiments to Support Simplified Lump Spreading Model Development in the HIPPO Code

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1. Introduction

The HIPPO module is being developed within the SAFARI program to represent ex-vessel corium behavior after reactor pressure vessel failure and to provide boundary conditions for subsequent analyses such as MCCI. In SAFARI, HIPPO is integrated with the MAMBA module to evaluate MCCI, where the corium lump layer predicted by HIPPO is used to define initial and boundary conditions. In the current HIPPO_BETA 2.0 framework, the detailed geometry evolution of the lump layer is not yet modeled, although it can strongly affect MCCI behavior. To rationalize MCCI start-up conditions, corium spreading and arrest behavior should be accounted for rather than assuming immediate, fully developed MCCI at the time of melt arrival. As a preparatory step toward implementing a simplified lump spreading model in HIPPO, this study benchmarks MELTSPREAD[1] against representative spreading benchmarks and the CORINE[2] isothermal experiments, verifying the input construction and execution procedure**.**

The purpose of this work is not only to reproduce MELTSPREAD reference cases, but also to identify the key spreading characteristics that should be retained in a simplified HIPPO model. In particular, the benchmark results are used to examine how spreading extent and final melt distribution can be translated into practical geometric information for subsequent MCCI analysis in the coupled HIPPO–MAMBA framework.

2. Methods and Results

To support future simplified model development in HIPPO, the present work focused on verifying the MELTSPREAD execution workflow and demonstrating reproducibility against (1) reference/benchmark problems documented in MELTSPREAD materials and (2) a representative isothermal spreading experiment program (CORINE). In addition, the benchmark results were interpreted from the viewpoint of reduced-order model development for HIPPO, focusing on spreading extent, transient profile evolution, and viscosity effects relevant to ex-vessel debris/lump distribution.

2.1 1D dam-break

A one-dimensional dam-break-type benchmark was used first to confirm numerical setup consistency and reproducibility versus reference results. The spreading domain was discretized as a 20 m channel divided into 200 uniform cells, and variables were defined in a cell-centered manner. A time step of 0.05 s was employed.

The predicted water-height and spreading-distance profiles were compared against the corresponding reference/manual results provided for the benchmark. The report documents that the computed profiles (height and spreading distance) reproduce the reference behavior shown in the benchmark figures, supporting the adequacy of the discretization and time-marching setup for subsequent experimental benchmarking.

This case also confirms that the early front propagation and redistribution behavior can be captured consistently, which is important for constructing a simplified spreading-length description in HIPPO.

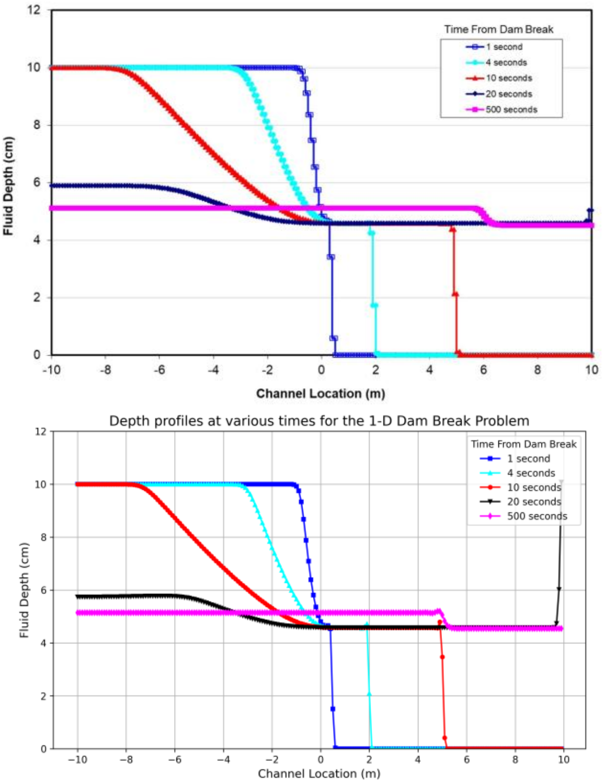

Fig. 1. Comparison of depth profiles at various times for the 1-D dam-break problem: MELTSPREAD manual (top) and present benchmark calculation (bottom).

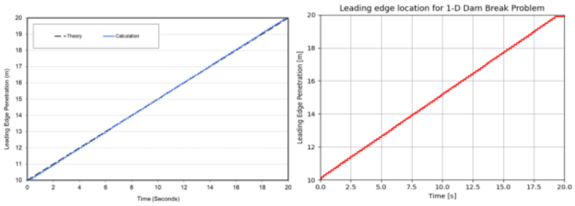

Fig. 2. Comparison of spreading length versus time for the 1-D dam-break problem: MELTSPREAD manual with the theoretical solution (left) and present benchmark calculation (right).

2.2 CORINE isothermal spreading program

After confirming baseline reproducibility, MELTSPREAD was benchmarked using the CORINE isothermal spreading experiments performed at CEA Grenoble. CORINE injects approximately 40 L of low-temperature melt simulant into a 19° sector-shaped channel to investigate gravity-driven spreading behavior. The program consists of three categories of experiments; in particular, the first category targets hydrodynamic spreading under isothermal conditions and is used to validate horizontal spreading models over regimes spanning inertia–gravity and gravity–viscous dominance.

In this work, three CORINE tests were selected from the isothermal series to span different injection conditions and viscosities: two water cases with different injection flow rates (0.5 and 1.5 L/s), and one higher-viscosity case using a hydroxyethyl cellulose (HEC) mixture at 3.0 L/s with viscosity 0.1 Pa·s. The key input conditions (including densities, viscosities, and surface tensions) were prepared as user-defined properties consistent with the selected cases.

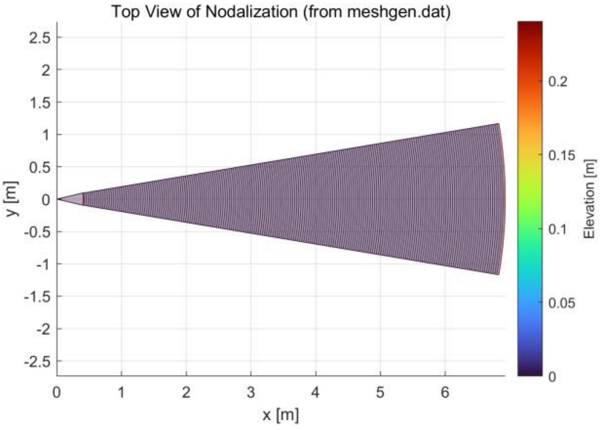

Fig. 3. Top view of the MELTSPREAD computational nodes for the CORINE experiment.

Table I: CORINE Tests Conditions

Test case	Simulant	Injection condition	Fluid properties (user-defined)
1	H2O	Constant flow rate of 0.5 kg/s from the reservoir for 130 s	$\rho = 1000, kg/m^3$, $\mu_0 = 0.826, mPa \cdot s$, $\sigma = 0.073, N/m$
2	H2O	Constant flow rate of 1.5 kg/s from the reservoir for 43.3 s	$\rho = 1000, kg/m^3$, $\mu_0 = 0.826, mPa \cdot s$, $\sigma = 0.073, N/m$
3	HEC	Constant flow rate of 3.0 kg/s from the reservoir for 21.67 s	$\rho = 1000, kg/m^3$, $\mu_0 = 0.1, Pa \cdot s$, $\sigma = 0.04, N/m$

For validation, the simulation outputs were directly compared with results presented in the MELTSPREAD manual to evaluate (i) reproducibility of the model response and (ii) appropriateness of the input construction procedure. The report concludes that the MELTSPREAD execution and analysis workflow could be performed appropriately and that the procedure was verified to a level sufficient for subsequent use in supporting lump spreading model development.

The selected CORINE cases also provide a compact basis for identifying the dominant variables needed in HIPPO: the water cases demonstrate the effect of injection condition on spreading evolution, while the HEC case highlights the reduction of spreading extent under higher viscous resistance. These observations support the use of spreading extent and final distributed geometry as reduced transfer quantities for downstream MCCI calculations.

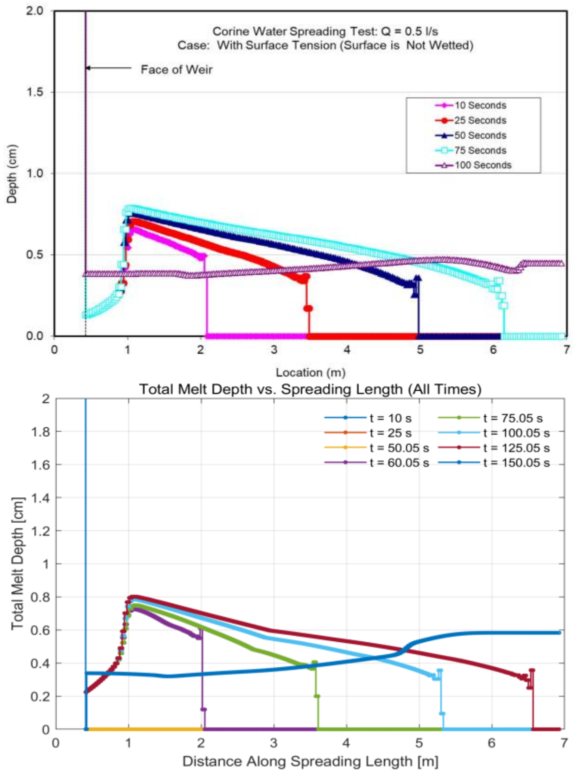

Fig. 4. Comparison of depth profiles at various times for the Case 1 (H2O 0.5L/s): MELTSPREAD manual (top) and present benchmark calculation (bottom).

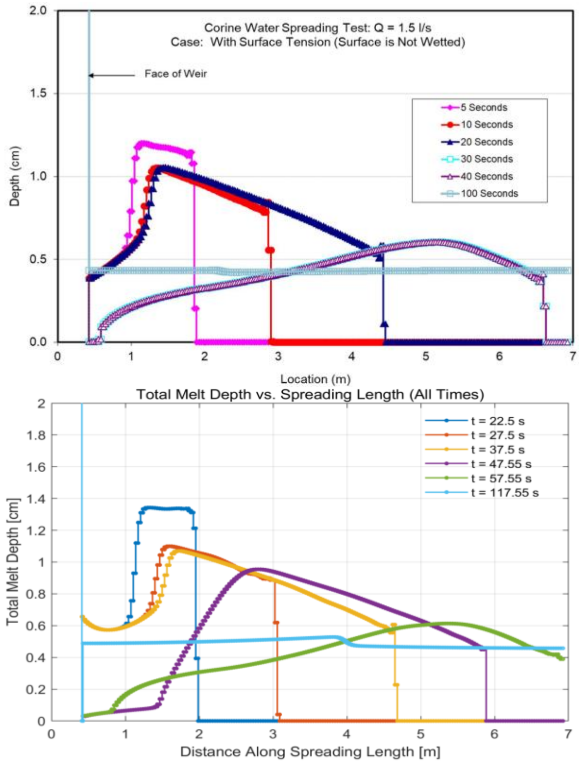

Fig. 5. Comparison of depth profiles at various times for the Case 2 (H2O 1.5L/s): MELTSPREAD manual (top) and present benchmark calculation (bottom).

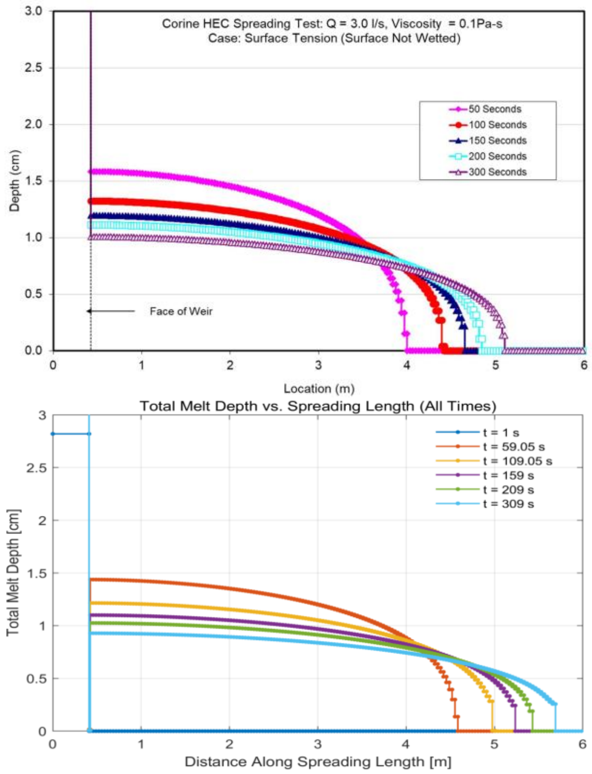

Fig. 6. Comparison of depth profiles at various times for the Case 3 (HEC 3.0L/s): MELTSPREAD manual (top) and present benchmark calculation (bottom).

3. Conclusions

This study benchmarked MELTSPREAD against reference results and representative spreading experiments to support future development of a simplified lump spreading model within the HIPPO code. The 1D benchmark confirmed that a consistent numerical setup (uniform cell-centered discretization and time marching) reproduces reference profiles documented for the benchmark problem.

MELTSPREAD was then validated using the CORINE isothermal spreading program, which provides gravity-driven spreading data in a sector-shaped geometry and includes regimes suitable for validating horizontal spreading models. Three CORINE cases were selected to span injection flow rates and viscosity conditions, and simulations were compared directly to MELTSPREAD manual results to confirm reproducibility and input preparation adequacy.

Within SAFARI, HIPPO provides boundary conditions for downstream MCCI evaluation through coupling with MAMBA, but current HIPPO_BETA 2.0 does not yet resolve the detailed lump-layer geometry that can govern MCCI behavior. The verified MELTSPREAD benchmarking presented here establishes a reliable basis for introducing a simplified spreading model into HIPPO, with the goal of rationalizing MCCI start-up boundary conditions by accounting for spreading and arrest processes more realistically.

The main insight of the present study is that the benchmark is useful not merely as a re-confirmation exercise, but as a basis for selecting the essential spreading features to be retained in HIPPO, such as early spreading evolution, viscosity-dependent arrest, and final spreading extent. These quantities are directly relevant to defining more realistic initial geometric conditions for subsequent MCCI analysis in the coupled HIPPO–MAMBA framework.

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