

Modelling proppant transport using a mesh-free method

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Summary (All headings should be Arial 12pt bold, DELETE SECTIONS THAT ARE NOT USED, DELETE GUIDANCE STATEMENTS)

Hydraulic fracturing is a critical stimulation technique widely employed in the petroleum industry for low-permeability formations. The distribution and transport of proppants within fractures are essential for maintaining high-conductivity pathways for hydrocarbon flow and preventing fracture closure under confining pressure. While numerous computational models, particularly CFD-DEM coupling methods (Gong et al. 2023; Zheng et al. 2023), have been developed to simulate proppant behavior, our present study introduces a novel application of the Moving Particle Semi-implicit (MPS) method to model proppant distribution and migration in hydraulic fractures. Through the past years, the MPS method has been applied in a wide range of engineering applications including hydraulic engineering, nuclear engineering, coastal engineering, ocean engineering, etc. This study marks the first implementation of MPS in petroleum engineering application. The model leverages MPS's inherent strength in numerical stability, momentum conservation, and robust handling of multiphase and granular flows, providing an effective numerical framework for capturing the complex particle-fluid interactions and analyzing proppant transport mechanisms in hydraulic fracturing operations.

Theory / Method / Workflow

The movement of particle flow is governed by the Navier-Stokes equations. The governing equations in the Lagrangian framework are written as:

$$\frac{D\rho}{Dt} = 0$$
$$\frac{D\mathbf{v}}{Dt} = -\frac{\nabla p}{\rho} + \frac{\nabla \cdot \boldsymbol{\tau}}{\rho} + \mathbf{g}$$

where p is pressure, ρ bulk density, \mathbf{v} velocity vector, \mathbf{g} is gravity, and $\boldsymbol{\tau}$ stress tensor.

The numerical solution of the governing equations is achieved through the mesh-free moving particle semi-implicit (MPS) method. In this approach, both fluid domain and solid boundaries are discretized into a collection of moveable particles, with uniform spacing d between adjacent particles. While a target particle i is typically surrounded by multiple neighboring particles j , not all neighboring particles influence its motion. Only particles within a specific proximity to the target particle are considered to affect its movement. The interaction between the target particle and its effective neighbors is mathematically represented through a kernel (or weighting) function, which defines the spatial range of influence. The spatial derivatives in the governing equations are then discretized using various numerical models, including gradient, divergence, and Laplacian operators (Shakibaeinia and Jin 2011; Xu and Jin 2016).

Results, Observations, Conclusions

The model validation was performed against the experimental work by Chun (Chun, Li, and Wu 2020), conducted in both vertical and horizontal fracture channels. The experimental setup consisted of a fracture cell with three 0.5-inch diameter inlets on the right side. Two outlets were

incorporated: one at the top-left corner for fluid discharge and another on the top side serving as a pressure relief point. The numerical simulation replicated these exact experimental dimensions and operating parameters for model validation process. From the simulation results, it can be observed that as more mixture is injected into the fracture cell, both sand dune length and area increase. Moreover, MPS (Multi-Point Statistics) effectively captures the eddy behavior of the mixture, a phenomenon that has also been documented in experimental studies.

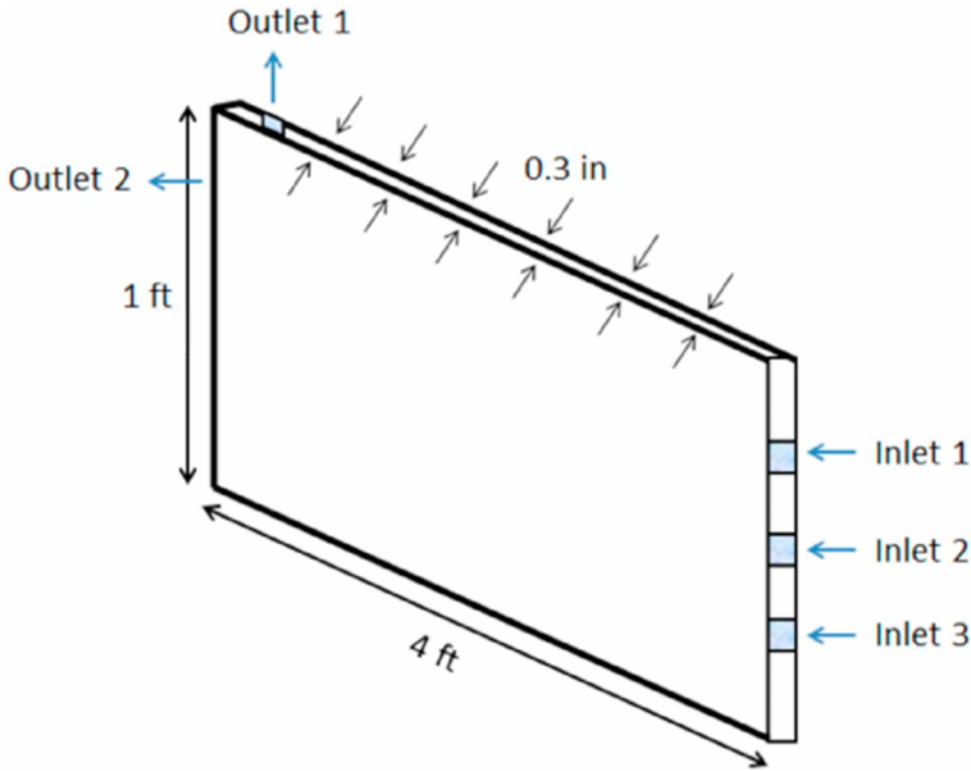


Figure 1. Schematic of the dimensions of a fracture cell used in the experimental study.

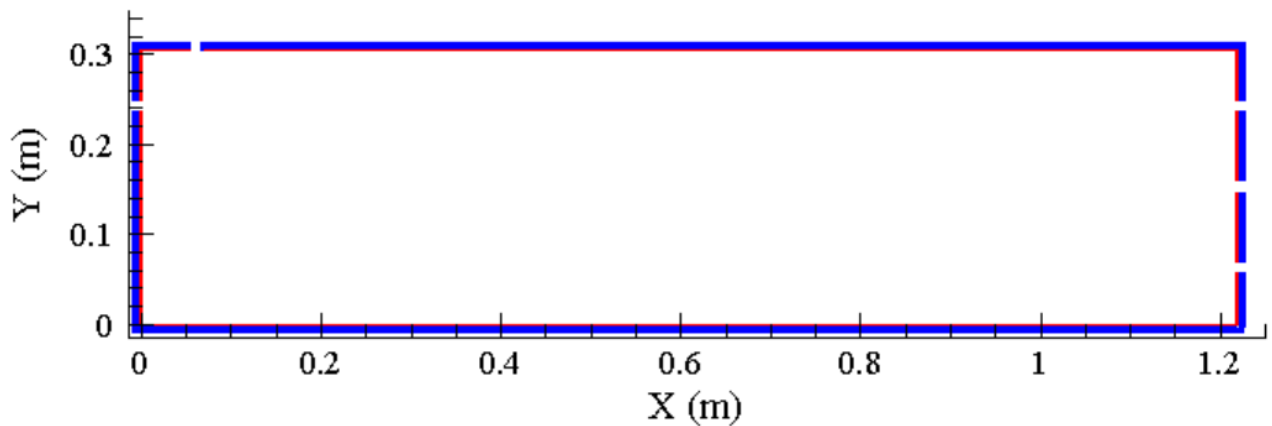


Figure 2. Particles geometry of simulation model in initial conditions.

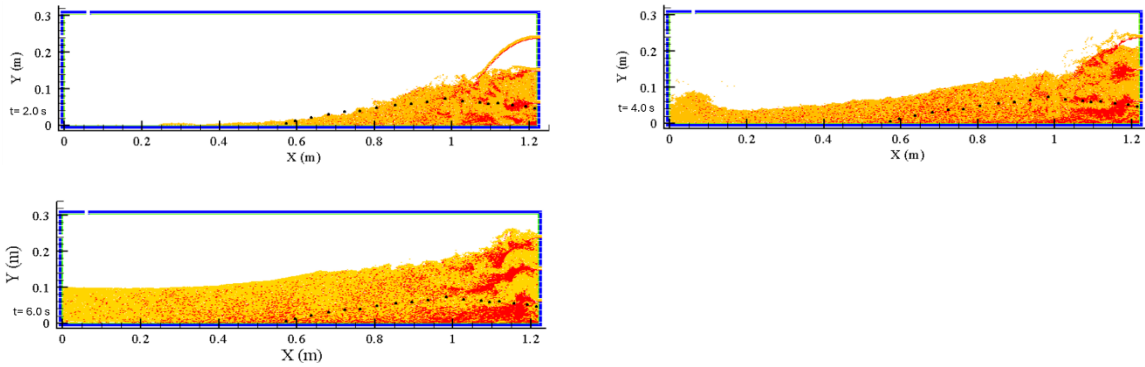


Figure 3. Simulation result profiles of proppant transport and settlement at 1) t=2s, 2) t=4s, 3) t=6s.

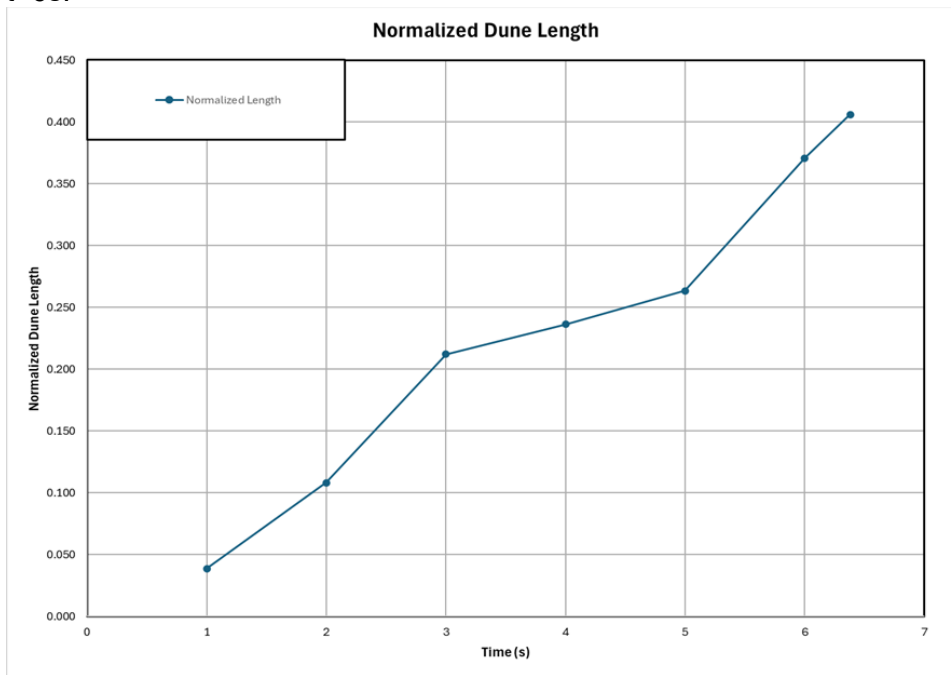


Figure 4. Normalized dune length measured from simulation model

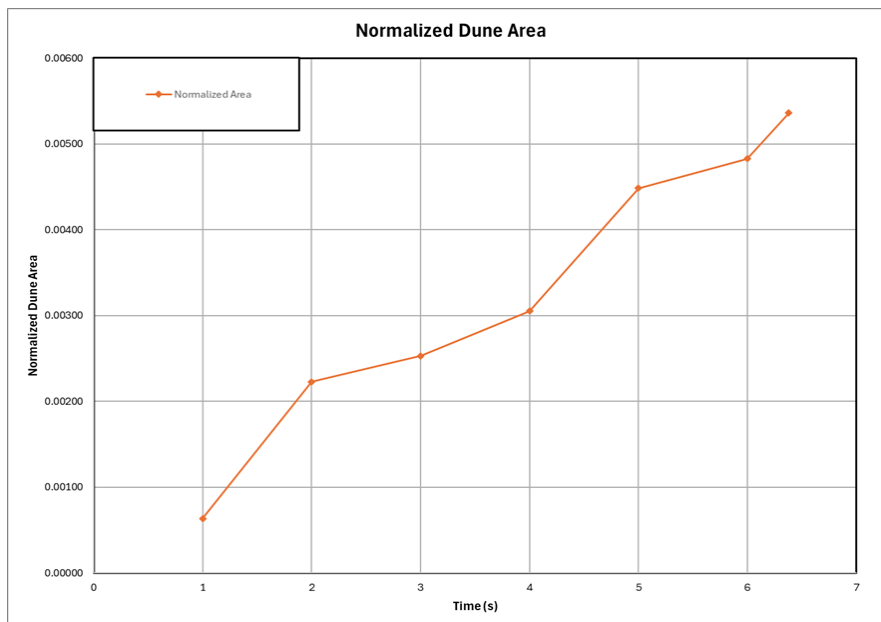


Figure 5. Normalized dune area measured from simulation model

Novel/Additive Information

While the Moving Particle Semi-implicit (MPS) method has been extensively applied across various engineering disciplines, this study presents its first application in simulating proppant transport phenomena in petroleum engineering. Previous studies have primarily employed traditional mesh-based methods for modeling proppant behavior in hydraulic fractures. The implementation of MPS in this context offers unique advantages, particularly in handling complex fluid-particle interactions and dynamic boundary conditions characteristic of proppant transport. This novel application bridges the gap between mesh-free numerical methods and practical petroleum engineering challenges, potentially providing new insights into proppant transport mechanisms that were previously difficult to capture with conventional numerical approaches.

Acknowledgements

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