Simulation of the Manufacturing Process of Foamed Cement

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Introduction

Wellbore cements are used to surround the metal drill string placed in the center of a well, providing stability to the conduit which enable fluid migration to and from subsurfaces, as well as achieving zonal isolation. Foamed cement has been used widely by the petroleum industry as a high-stress resistant, low-density material to withstand extreme downhole environments inherent to offshore wellbores. As a slurry, foamed cement is a non-Newtonian fluid comprised of cement, surfactants and nitrogen gas.

Current standards for the testing of foamed cement, as described in the industry standard American Petroleum Institute Recommended Practices 10B-4, measure the properties of foamed cement created in a laboratory blender at atmospheric conditions.[1] However, contemporary practices do not measure these properties at the conditions in which they are placed in subsurface well casings. A lack of understanding in how foamed cement sets under subsurface field conditions can lead to risk assessment uncertainties and compromised well integrity.

Following the explosion and sinking of the *Deepwater Horizon* drilling rig on April 20th, 2010, an oil spill flowed into the Gulf of Mexico for 87 days, leaving 11 dead and 17 wounded. After numerous investigations, a 2011 U.S. government report suggested defective cement on site played a crucial role in the tragedy.[2]

Procedure

It is well known that geometric features play an influential role on the internal pressure and velocity fields of a fluid. This research project aimed to investigate these effects on cement during the NETL manufacturing process. Numerical simulations were conducted on a fluid with density and viscosity comparable to the cement produced by NETL. Three key geometric configurations were selected to mimic the sudden contractions and expansions in the NETL manufacturing process. They consisted of combinations of two cylindrical components: a chamber, and a valve. The chamber was of 6 inch length with 1 or 2 inch diameters. The valve was of 1/4 inch diameter. The Sudden Contraction case consisted of the chamber followed by the valve, while the Sudden Expansion case was comprised of the valve followed by the chamber. The Sudden Contraction to Sudden Expansion case was composed of two chambers connected by the valve, varying in lengths of 0.5, 1, and 1.5 inches. The volumetric flow rate was set to a value found by averaging several cycles of the NETL manufacturing process.

Methods

Simulations were run via the steady-state simpleFoam solver within OpenFOAM 2.3.1. OpenFOAM is an open source computational fluid dynamics software. It exercises the use of numerical solvers to approximate solutions to continuum mechanics problems. Datasets were rendered using ParaView, a data analysis and visualization application. Microsoft Excel was used for data tabulation and plotting.

References & Acknowledgements

[1] American Petroleum Institute, *Recommended Practice on Preparation and Testing of Foamed Cement Slurries at Atmospheric Pressure 10B-4* (July 2004)("API RP 10B-4")
[2] Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE)/U.S. Coast Guard Joint Investigation Team (14 September 2011). "Deepwater Horizon Joint Investigation Team Releases Final Report" (Press release). U.S. Government.

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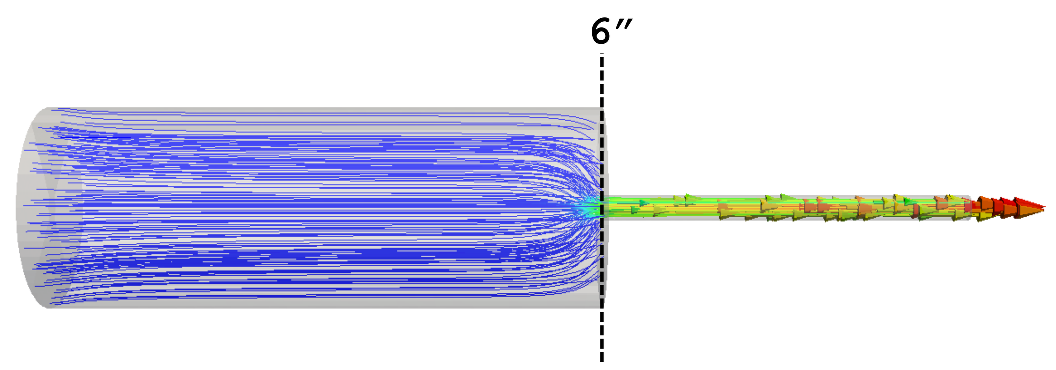
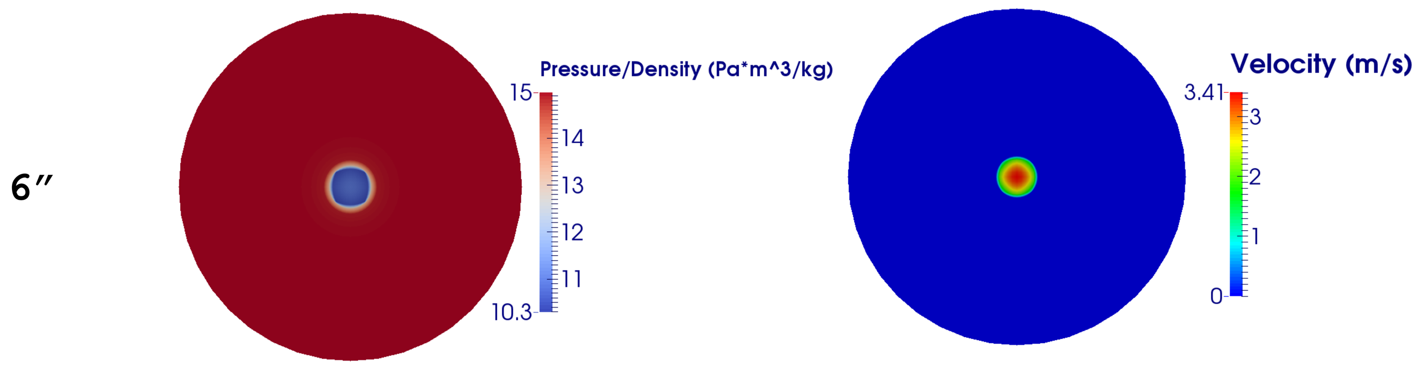
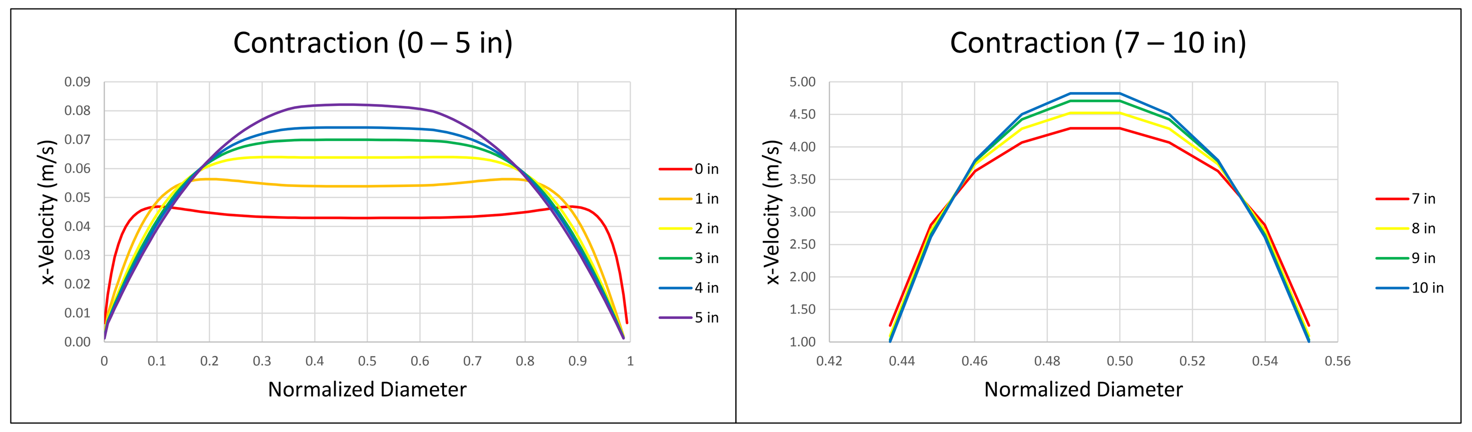
Sudden Contraction

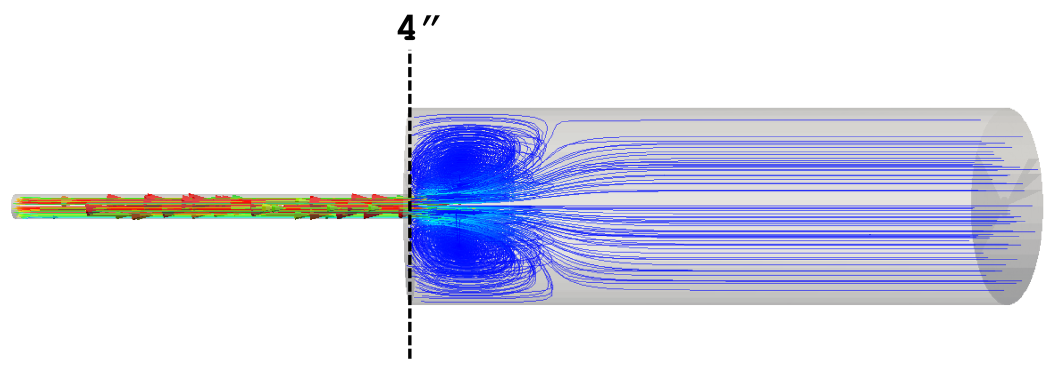




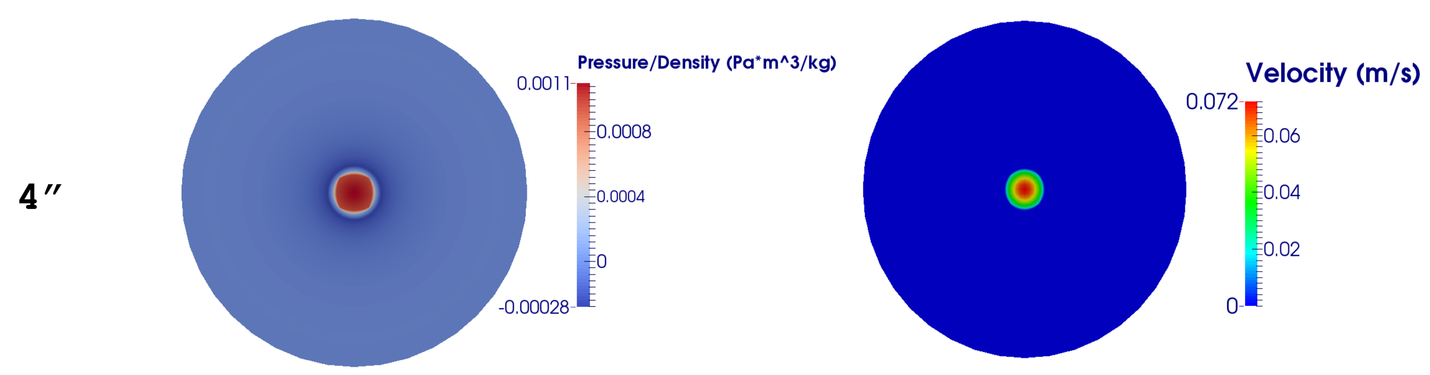


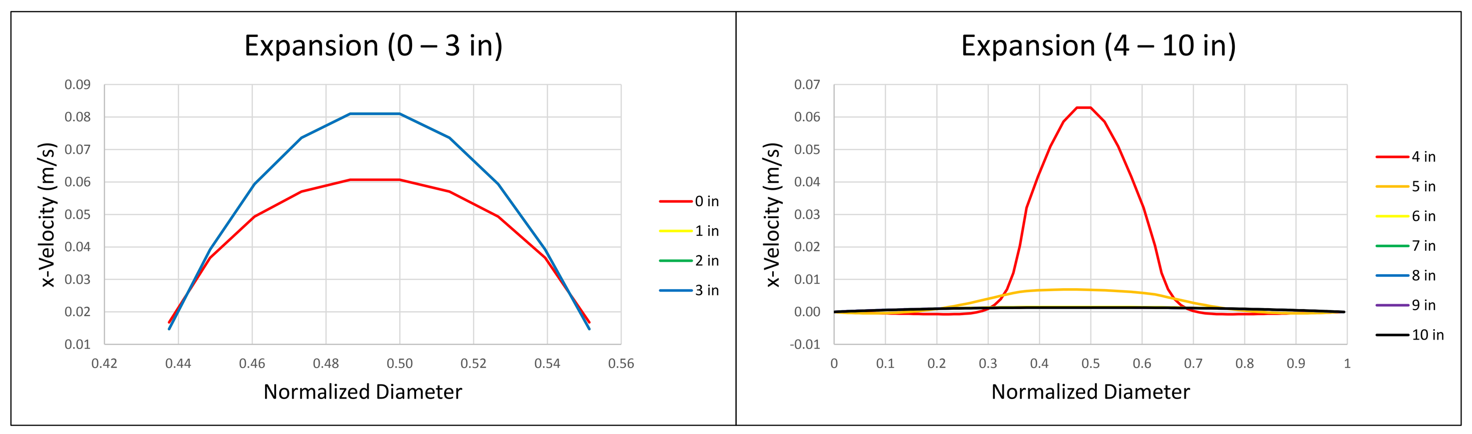
The velocity profile achieved a uniform parabolic shape.

Sudden Expansion



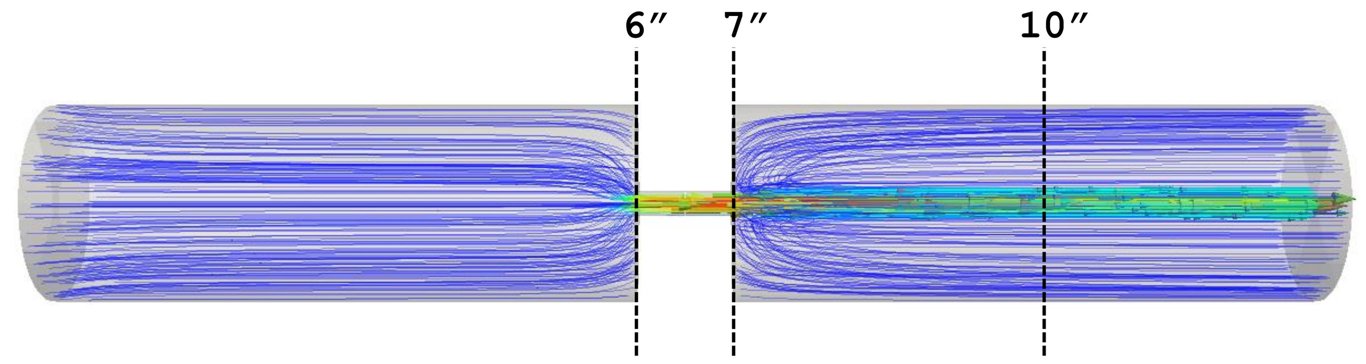
Cement exhibited notable recirculation following a sudden expansion.



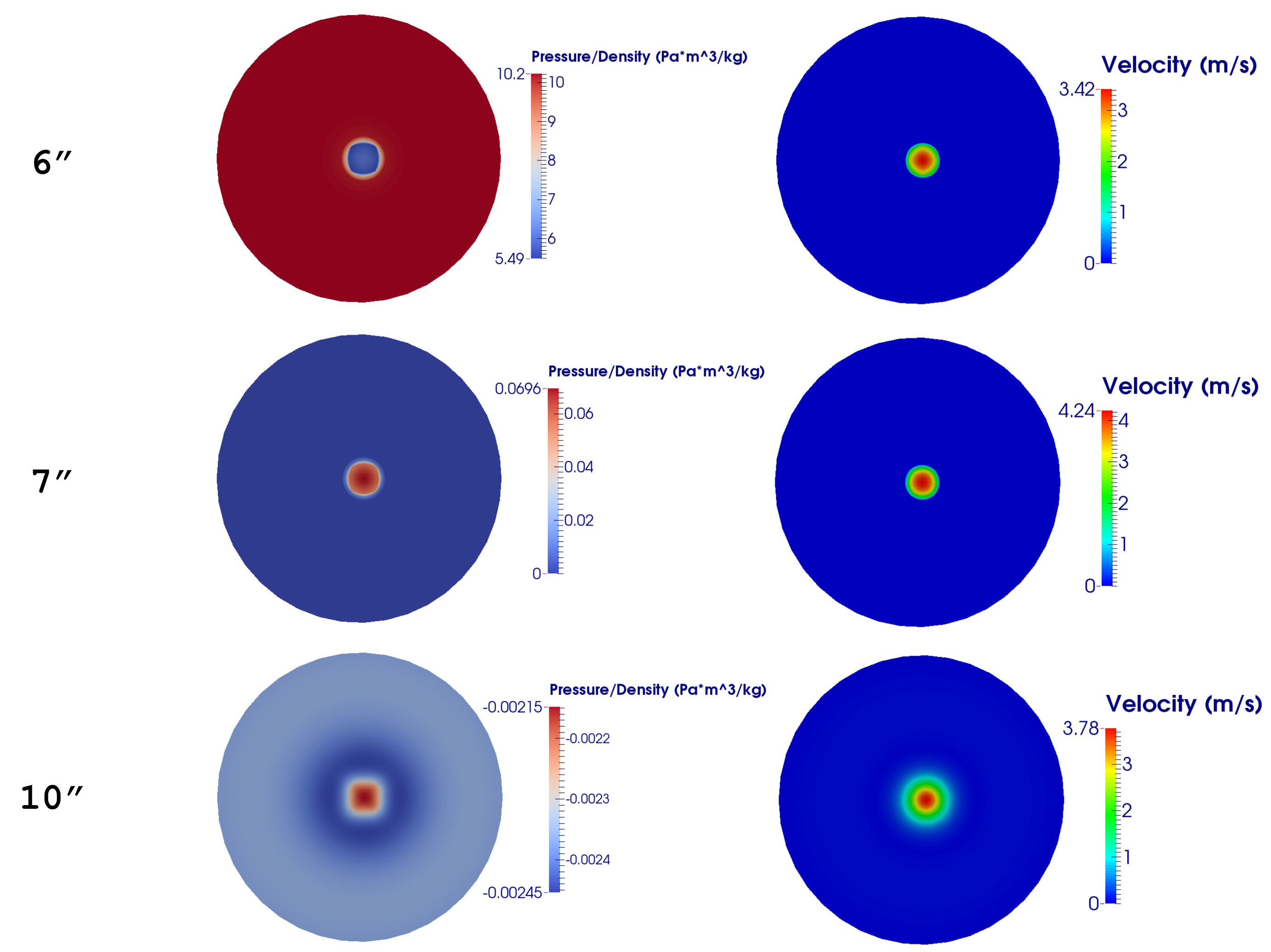


The velocity profile developed and regressed quickly.

Sudden Contraction to Sudden Expansion

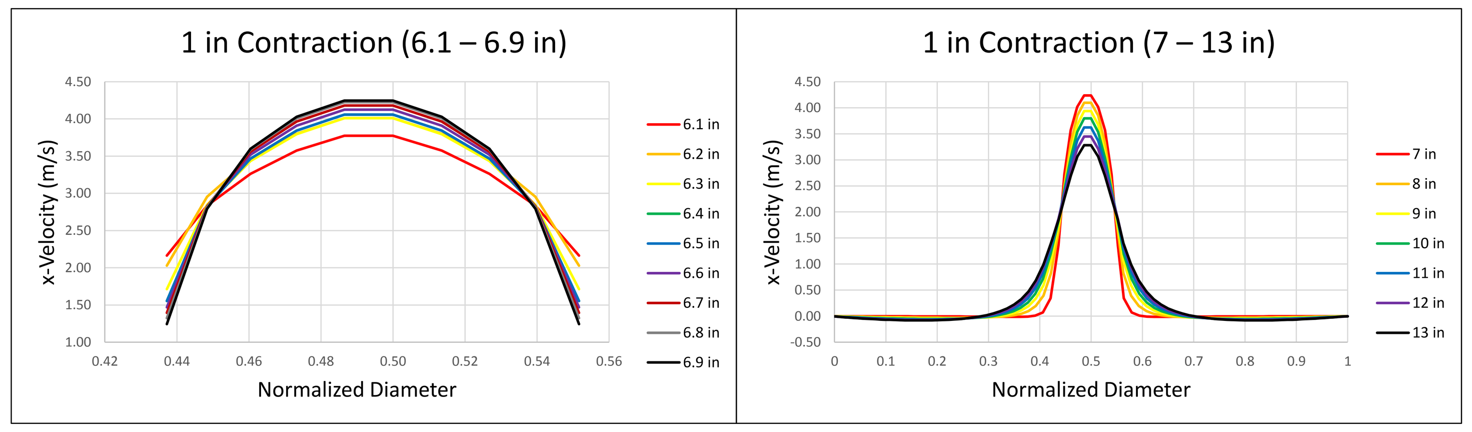


Cement did not exhibit any recirculation following a sudden expansion when preceded by a sudden contraction, unlike the Sudden Expansion case.



There was a steep pressure gradient across the valve.

The velocity profile maintains its general shape following a sudden expansion, unlike the Sudden Expansion case.



The variation of valve length had minimal effects on the velocity profiles in the Sudden Contraction to Sudden Expansion cases.

Moving Forward

Further work is needed to better understand the physics of foamed cement. Cement behaves as a non-Newtonian fluid; however, these simulations were conducted with a Newtonian assumption. Furthermore, it must contain nitrogen bubbles in order to truly represent foamed cement and no second phase was simulated in this work.