Simulation of a Fluidic Oscillator DTH Hammer Drill

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Introduction

Drilling is a major cost driver in any geothermal project. For many rock formations, Down-the-Hole (DTH) air percussion drilling has superior Rate-of-Penetration (ROP) and thus greatly reduces drilling time and cost. However, its effectiveness decreases with increasing depth due to the low specific gravity of air, leading to challenges with borehole stability, cuttings removal, and ingress of reservoir fluids. This can be overcome by water DTH hammers, but problems arise as current DTH water hammers require clean water due to their percussion mechanism being sensitive to particles. Therefore, drilling fluids containing particles lead to early failure of internal hammer components. As a part of the H2020 Geo-Drill project [1], a novel DTH hammer capable of using drill mud is under development. Its percussion mechanism is based on a bi-stable fluidic switch. Other Geo-Drill technologies under development are advanced coatings and 3D-printed sensors. The focus of this poster is the development of a new multi-physics software for simulation of the Geo-Drill and other drilling systems and drilling operations.

Simulations and Software Development

A feature-rich, new FEM-based multi-physics simulation software [2] is under development for applications in many different areas. For the Geo-Drill project, the main objective is to develop simulation technologies and models that enables the software to predictively simulate the whole drilling process and system, such that it can be used to improve drill monitoring by complementing sensor readings, as well as improve and optimize the design and control of future drilling systems.

Computational Fluid Dynamics

CFD simulations were carried out for several different fluidic switch geometries. To accurately capture turbulence as well as transients, Large Eddy Simulation (LES) was used. The drilling fluid was modelled as non-Newtonian with a Herschel-Bulkley (HB) model. Rheological testing was performed to tune the HB model parameters.

Two-way coupled Fluid-Structure Interaction (FSI) based on an Arbitrary Lagrangian-Eulerian approach was used to analyze the interaction between the fluidic switch and the moving piston. The FSI simulation and Geo-Drill experimental testing of the percussion mechanism provided input to the development of a simplified DTH model. To improve drilling performance, CFD and experimental test results were used to carry out shape optimization of the fluidic switch and the percussion mechanism. The optimization combined Design-of-Experiments (Latin Hypercube Sampling) with meta-modelling (Kriging) and Genetic Algorithms.

LES of annular flow with a rotating drill string was performed at different flow rates, diameter ratios, and rotational speeds. The computational results were used to create 1D models of annular flows, including non-Newtonian fluids.

Geothermal Flow Assurance

A 1D FEM pipe network geothermal flow assurance simulation software module has been developed. It includes features such as two-phase flows, multi-component fluids, steady state and dynamic (transient) flows, incompressible and compressible flows, non-Newtonian fluids, equilibrium & reaction kinetics geochemistry, models for pumps, valves, thermal energy storages, heat exchangers, insulation, wells, insulation, corrosion/erosion/scaling, buried pipe, and PID controllers. New models for non-Newtonian fluids, annular flows with rotating drill string, and the Geo-Drill DTH hammer were developed and implemented.

Thermo-mechanical

A 3D FEM non-linear thermo-mechanical simulation software module has been developed. This module will be coupled to the 1D flow assurance simulator for more accurate simulation of the rock formation as well as buried pipes in general.

Structural Dynamics

A 1D FEM structural dynamics simulation software module has been developed. It contains generalized 1D elements with 6 Degree-of-Freedoms/node. This module is used to simulate the drill string dynamics. To capture FSI effects along the hole drill string, including geometrical protrusions such as joints, sleeves, etc., a method has been developed to calculate added mass and added damping for general geometries.

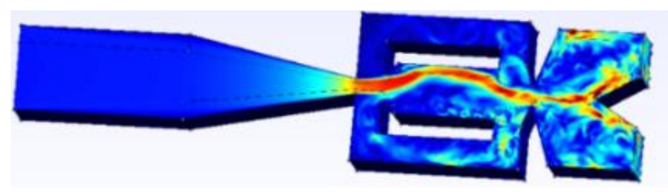

Figure 1. LES & shape optimization of a fluidic switch

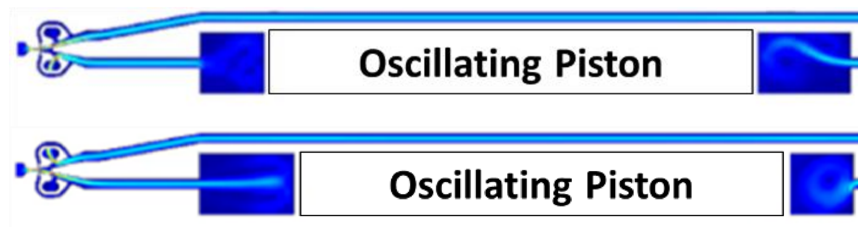

Figure 2. Fluid-Structure Interaction simulation of the percussion mechanism

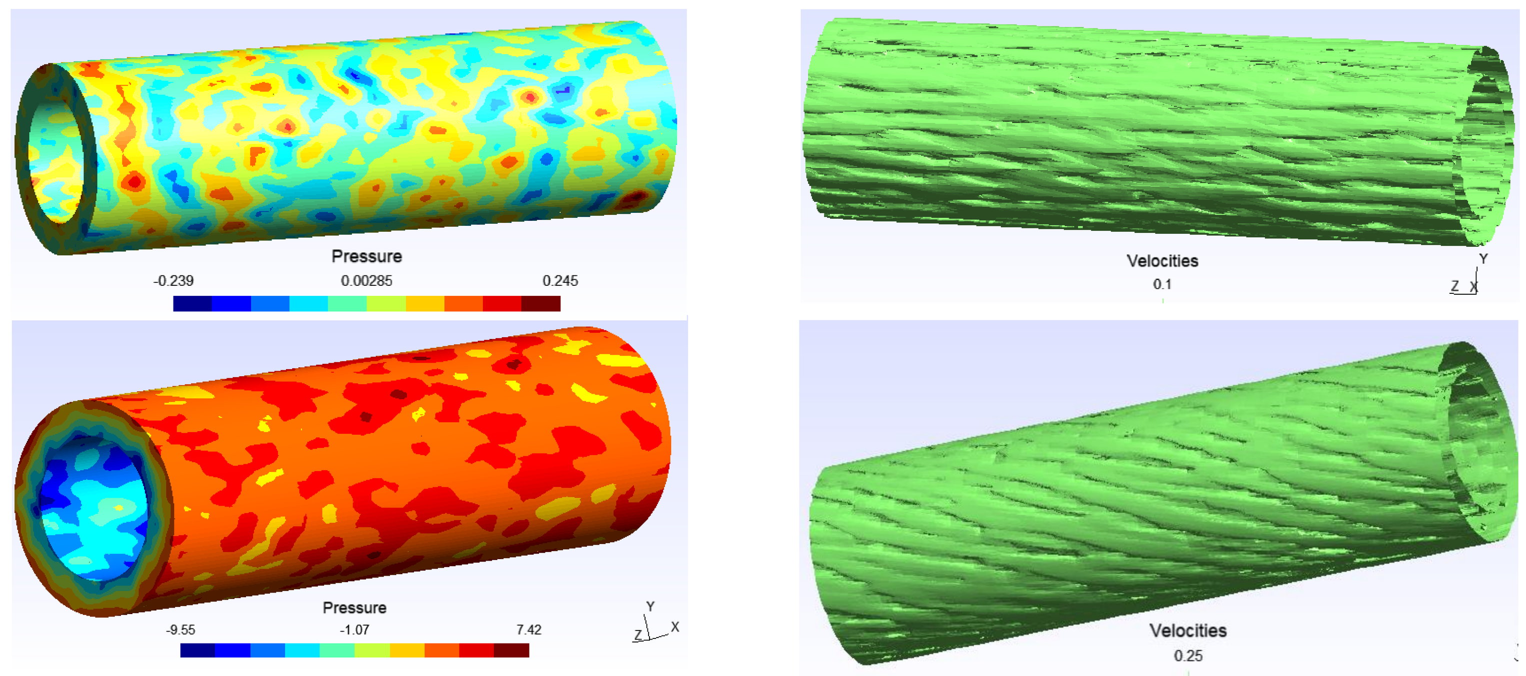

Figure 3. LES of annular flow: a) pressure fluctuations; b) velocity iso-surfaces. With rotating drill string: c) pressure fluctuations; d) velocity iso-surfaces

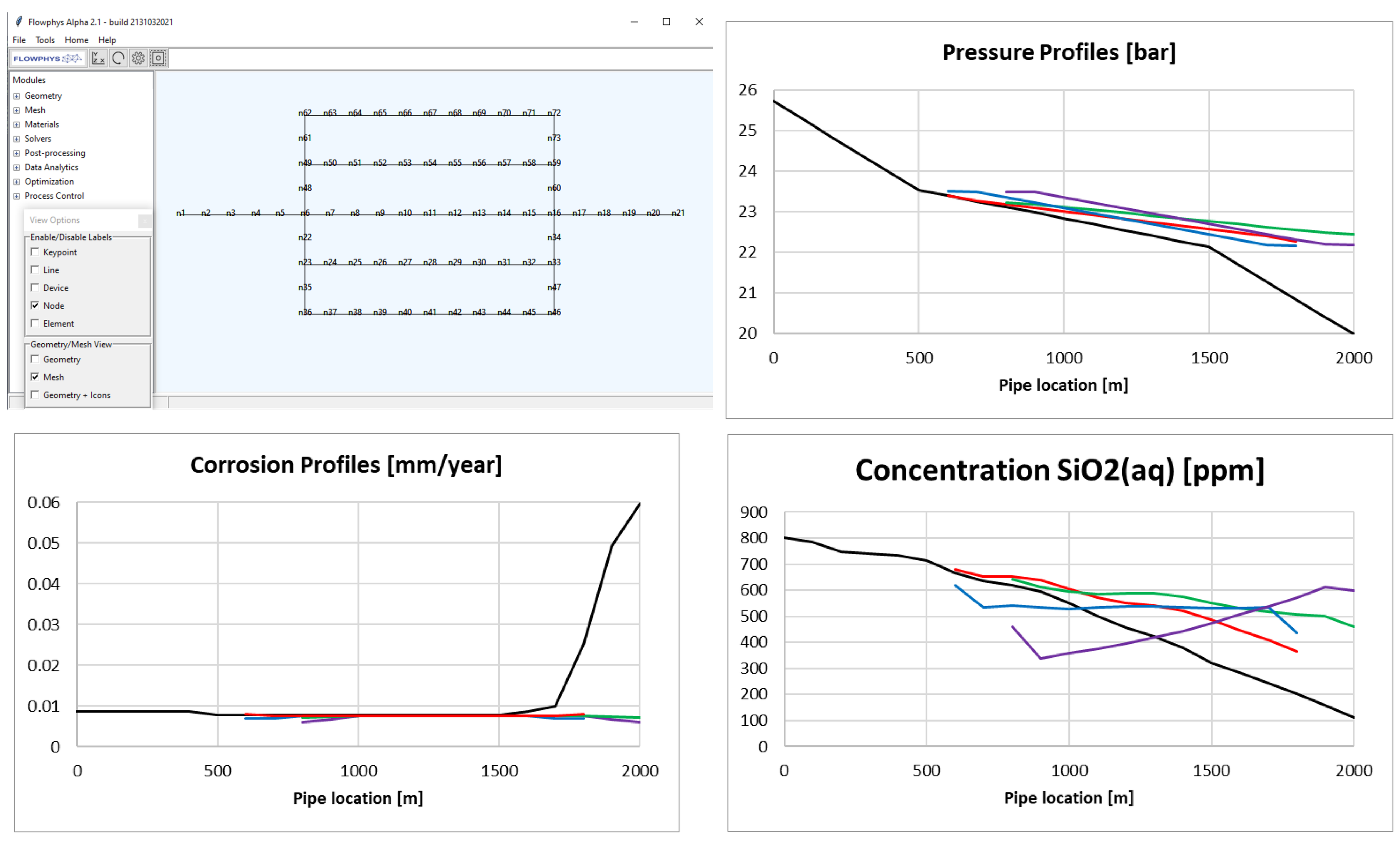

Figure 4. Geothermal Flow Assurance software: a) GUI showing a network model; b)-d) Simulation results for pressure, corrosion rate, concentrations. In addition, flow rate, temperature, density, volume/mass fractions, saturation indices, erosion rates, scaling rates are also available

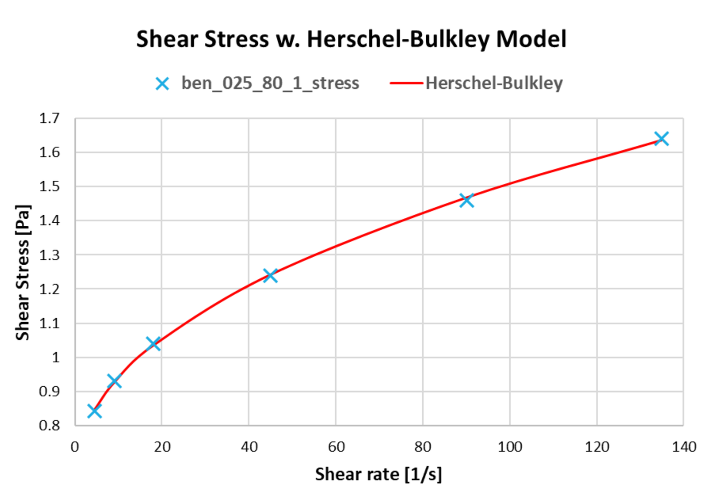

Figure 5. Herschel-Bulkley non-Newtonian fluid model tuned to rheological testing data. Implemented in both the 1D and 3D software.

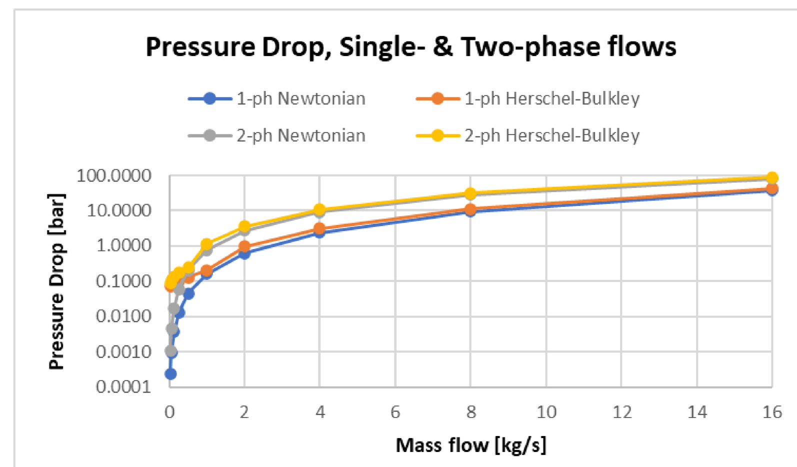

Figure 6. 1D flow assurance simulation results for single- and two-phase flows with Newtonian and non-Newtonian fluids (Herschel-Bulkley model)

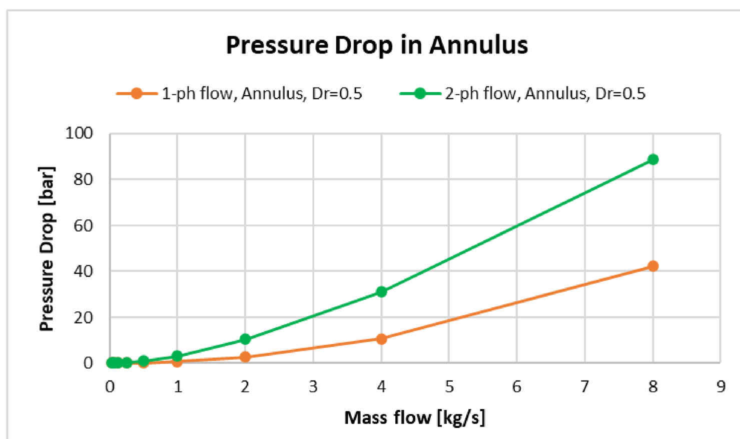

Figure 7. 1D flow assurance simulation results for annular fsingle- and two-phase flows

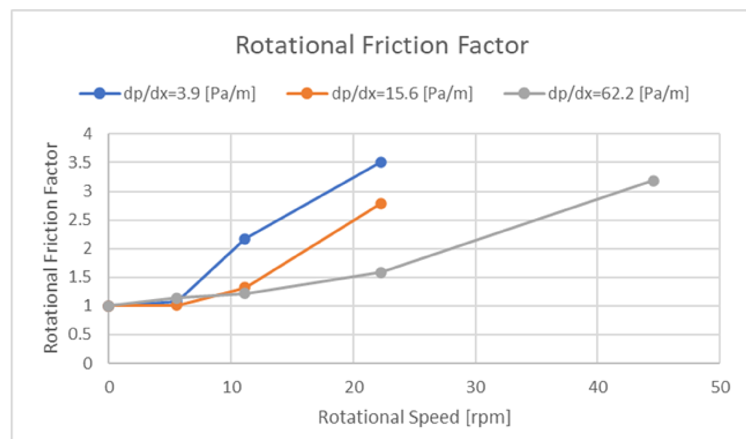

Figure 8. 3D CFD-LES results for annular flow with a rotating drill sting. Results are used to develop 1D models of rotating non-Newtonian fluids

Conclusions

A new multi-physics simulation software is under development, with the aim to enable simulation and optimization of geothermal drilling equipment and operations. By combining 3D simulation results with Geo-Drill experimental test campaign results, new models suitable for fast geothermal 1D flow assurance simulations have been developed. With this, the software is capable of both detailed design and shape optimization, as well as system modelling with faster-than-real-time drilling operation control, monitoring, and optimization.

References

[1] https://www.geodrill-project.eu/; [2] www.flowphys.com;

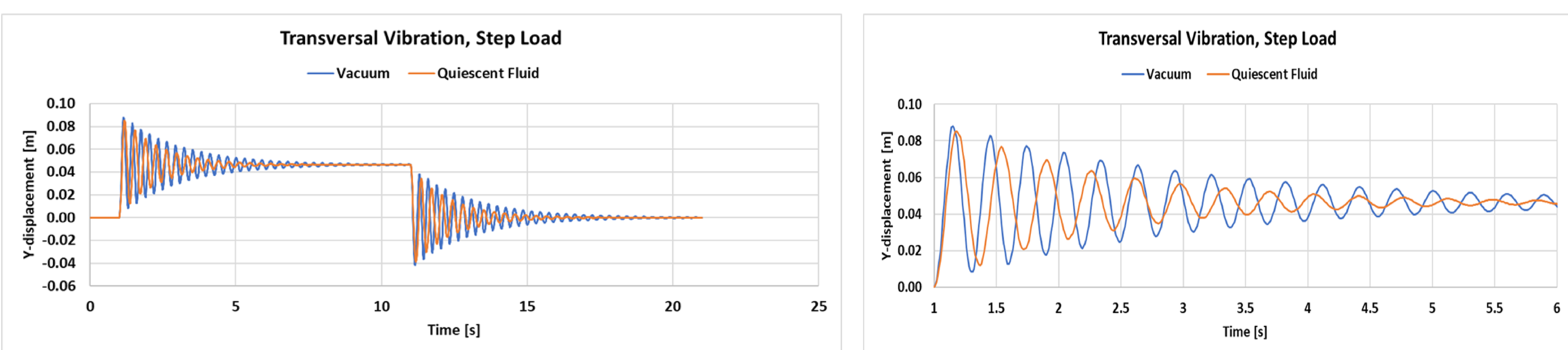

Figure 9. Structural dynamics of drill string, with added mass & added damping derived from CFD-FSI calculations

Acknowledgements

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