A Geothermal Rock-Fluid-Bit Interaction Framework to Predict the Behavior of Nanofluids during Drilling

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Background and Introduction

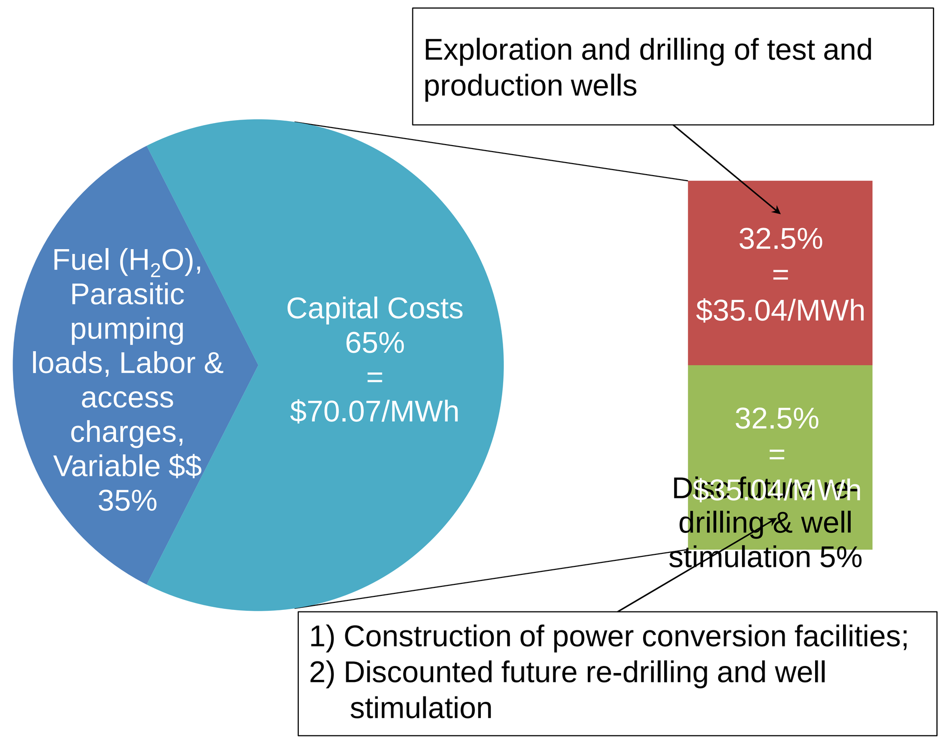


Figure 1. Capital cost estimates for geothermal power production by the California Energy Commission in 2006 (The Future of Geothermal Energy: Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century, 2006).

- Compared to the fixed costs of oil and gas drilling ($15.61/MWh), the exploration and drilling for geothermal resources is a cost-prohibitive process that accounts for a up to 50% ($35.04/MWh) of the capital costs for the project (See Figure 1).
- High capital costs of exploration and drilling into geothermal rock formations can be attributed to the low rates of penetration and short drill bit lifetimes. These contributing factors result from drilling into rock formations that have high compressive strengths (as much as 35,000 psi) and are at elevated temperatures (~ 315°C).
- One component of the drilling process that is critical to reducing the costs of exploring geothermal rock formations is the drilling fluid. These drilling fluids (or "muds") are particulate-fluid slurries that are incredibly multi-functional in that they: 1) prevent oil/gas flow during drilling, 2) lubricate the drill bit, 3) transport cuttings from production zone, and prevent 4) fluid/particle infiltration of the rock formation. During drilling, the drilling fluid is pumped down the inside of the drill pipe and sprayed out of nozzles on to the drill bit as the fluid cools, lubricates, and suspends rock cuttings.

Proposal

Because of the complexity of rock-fluid-bit interaction, it is difficult to predict the behavior of the drilling fluid in the bit/rock interface. Also, since the bit cutter can fail due to excessive frictional heating and wear, there is a need for smarter, drilling fluids which can be optimized to achieve a desired thermal performance in geothermal environments. To address these two problems, this proposal aims to develop a computational modeling framework to predict the behavior of nanofluids during drilling.

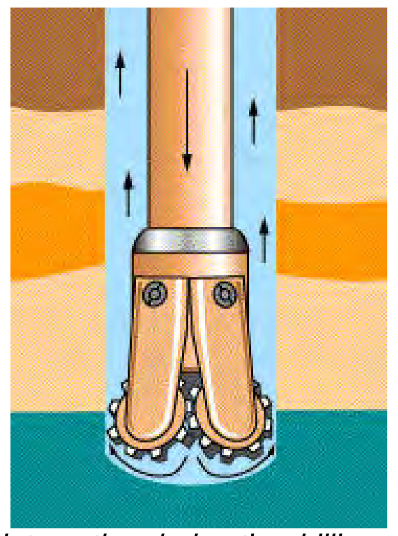


Figure 2. Pictorial representation of the rock-fluid-bit interaction during the drilling process into geothermal rock formations. (www.howstuff works.com).

Approach

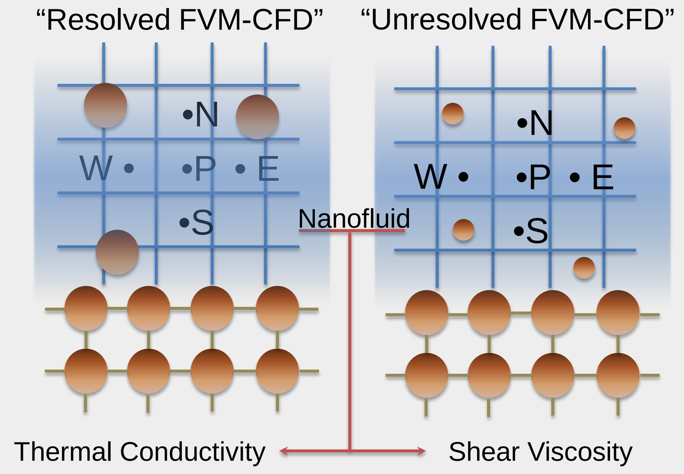
The goal of the proposed work is to develop an experimentally-validated rock- fluid-bit interaction modeling framework to predict the behavior of nanofluids during rock cutting. This will be accomplished in the following three independent yet partially overlapping phases, where (1) a modification of an existing multiphase slurry rate of penetration (ROP) model to incorporate nanofluid thermal and rheological phenomena, (2) a parametric study of rock-fluid-cutter interactions using computer simulations, and (3) a parametric experimental analysis of cutter-on-rock with nanofluids will all be performed.

A multiphysics, multiphase rotary drilling ROP model was recently developed by Dr. Fred Higgs, III to elucidate some of the underlying physics which occur during well drilling by integrating the effects of the drill bit, the drilling fluid, and the rock formation into a single computational framework. Within this framework, the multiphase fluid is modeled as an isothermal, Eulerian-Lagrangian fluid using an in-house computational fluid dynamics (CFD) code, where the fluid phase is treated as a Eulerian continuum and the dispersed solid phase is treated as rigid particles which interact with the fluid continua through forces.

Phase 1

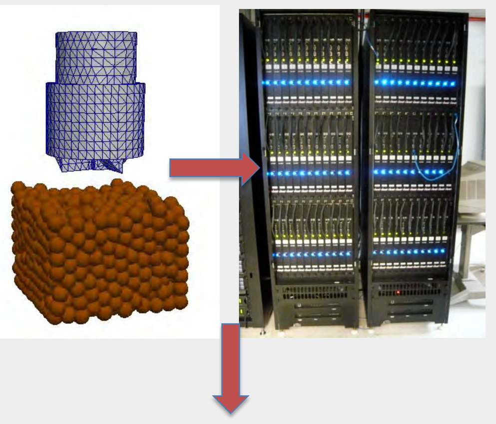
A current in-house multiphysics/multiphase drilling fluid rate-of-penetration (ROP) model is being modified to incorporate thermal characteristics of the drilling fluid by using both unresolved and resolved CFD techniques to capture the energy transfer between the rock-fluid-bit.

Due to the complexity of modeling the thermal effects of the nanofluid, its unique transport behavior will be captured through a constitutive model for the fluid's effective thermal conductivity. For example, the thermal conductivity can be modeled as a function of the temperature, solid volume fraction, particle size, and particle thermal conductivity.



Phase 2

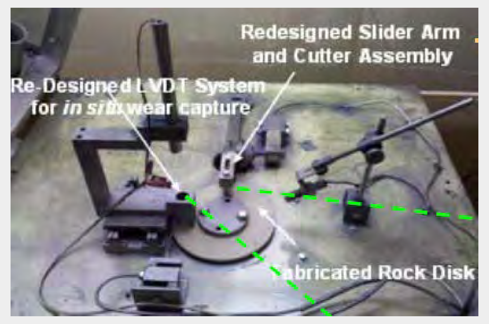
This phase will consists of parametric cutter-on-rock simulations in the presence of different nanofluids using the high-performance resources of the NETL Pittsburgh. The parameters that will be varied in the nanofluid are the solid fraction, particle size, and thermal conductivity of the solid. Drilling (i.e., cutting) process parameters will also be varied such as the weight on bit (WOB) and speed. He will be hosted by Dr. Isaac Gamwo, who will serve as the on-site NETL research mentor.



ROP = *f*(WOB,w,nanoparticle size, solid fraction, thermal conductivity, shear viscosity)

Phase 3

This phase will consist of parametric cutter-on-rock experiments on an in-house-built single cutter-on-rock tribometer (see figure below) which can measure the tangential cutting force and depth of cut *in situ*. A temperature probe will be added in this work to measure the temperature of the cutter *in situ*. Tests will be done to measure the cutting force, depth of cut and cutter temperature in situ, for different nanofluids. These nanofluids will be made in-house using a carrier fluid (e.g., water) with a solid (dispersed) phase. The following parameters for the solid phase will be varied: solid fraction, particle size, and thermal conductivity. The machine parameters will also be varied such as the weight on the cutter and speed.. In this work, rock from geothermal rock formations will also be sought for testing from industrial drilling partners and the DOE geothermal test facilities, such as those at Sandia National Laboratories.



Impact

The incorporation of the complex thermal and rheological characteristics of nanofluids into a single multiphysics, multiphase rock-fluid-bit interaction framework is a novel concept that would enable discovery in emerging geothermal and existing fossil fuel drilling. First, it would fill a significant void in the knowledge base of the understanding of thermophysical characteristics of nanofluids in a dynamic environment. Second, the potential increase to ROPs with the implementation of nanofluids can enhance the feasibility of using geothermal as a renewal energy resource. Third, experimental data collected can be used as the basis for an engineering standard that determines optimal operating conditions for ultra-deep drilling.

Acknowledgments

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An experimentally-validated computational framework to enable nanofluid drilling technology