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Geoscientific Model Development Discussions

Interactive comment on "*HydrothermalFoam* v1.0: a 3-D hydro-thermo-transport model for natural submarine hydrothermal systems" *by* Zhikui Guo et al.

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We thank the reviewer for his time, precise summary, and positive evaluation of the manuscript.

Reply to reviewer's comments, all reviewer comments are in blue and our replies are in black.

1. Table 1, definition of the time step: If possible, write times in lowercase, otherwise they can be confused with temperature.

   Thanks, we have change ΔT to Δt in Table 1.

2. Eq. (2): This is not an equation. "= 0" is missing

   Corrected.

3. Eq. (4): This equation is correct even in the compressible regime but only if the rock porosity, density and heat capacity are constant in time, and if the fluid heat capacity is constant both in space and time. These assumptions should be stated explicitly in the text. However, I am afraid that the assumptions on the fluid heat capacity are not fulfilled in this paper, because Cp_f is treated as a VolScalarField, and also because a detailed thermodynamics for water is used (Figure 1, L113 and Listing 4). In this Lagrangian formulation, to correclty consider the variability of the fluid heat capacity, a term proportional to its partial time derivative and another proportional to its gradient should be added.

   Also the the co-reviewer Cyprien Soulaine had concerns about the energy equation. We have therefore posted a detailed derivation as an author comment, which we hope resolves these questions.

   In short: yes, the solid matrix is incompressible and has constant properties. The fluid properties are determined from the EOS of pure water and vary with pressure and temperature. The reason why density and specific heat end up outside the derivatives is not because they are assumed constant, but because of the thermodynamic identities between enthalpy and temperature - and the use of the mass conservation equation. We hope that the derivation will clarify these questions!

4. Given a certain resolution, the typical time scale for which this approximation holds should be given. For example, using the data in Table 1, the given rock thermal diffusivity is lambda_r/(Cp_r*rho_r) $\sim$ 6e-7 m2/s. This means that, roughly, the typical thermal equilibrium time for a resolution of 100 m is order of 500 years. Thus, for the approximation to hold, the typical time of the dynamics at this resolution should be larger than, roughly, 500 years. In other words, the equilibrium

time is related to the natural time step used by the simulation. The regime where this equilibrium assumption holds should be given, to allow the user to use the code in its proper regime of approximations. For an example on this issue, see Remark 2.1 in: Cerminara, M., & Fasano, A. (2012). Modeling the dynamics of a geothermal reservoir fed by gravity driven flow through overstanding saturated rocks. Journal of Volcanology and Geother- mal Research, 233–234, 37–54. https://doi.org/10.1016/j.jvolgeores.2012.03.005

Cool paper and elegant way of investigating the equilibration time scales! However, we think this issue is resolved by the derivation of the energy equation.

5. L123: The description is not following the terms order in Eq. (5). Please correct this.

   The terms order of Eq. (5) has been revised to be consistent with the text.

6. Eq. (6): This reformulation iterates the problem with the spatial variations of the fluid heat capacity, see comment above on Eq. (4) and below on Eq. (7).

   This all goes back to how the energy equation is written. The way we did it, and which we feel is correct, requires these mathematical reformulations in order to implement the equation in Finite Volumes, which are great for solving divergence terms but not that much for velocity times gradient terms.

   It can be debated if a scheme that takes specific enthalpy or internal energy as a primary variable instead of temperature would have been a better choice. In an energy-based scheme, we could have kept the energy equation in clean conservative/divergence form, which is better for FV solutions. We chose temperature as primary variable because it is so intuitive for the user but the downside is that it requires some re-formulation of the energy equation.

7. Eq. (7): The term proportional to the divergence of (rho_f*Cp_f*U) should not be present when the spatial dependence of the fluid heat capacity is correctly taken

into account. A term for its temporal dependence is still missing.

Please see derivation as spelled out in the author comment.

8. L171: Here should be clearly stated that the EOS is used in the single phase regime, no phase transition is admitted in this formulation.

   Yes, we should have made that clear - it's fixed now!

9. L119 (should be L219): Usually in OpenFOAM, spatial schemes are first or second order, not high order. Using the upwind interpolation makes the code first order in space. Some word on the time scheme used is also needed.

   We have rephrased the sentence to "In the following benchmark tests (section 5), the advective discretization scheme is set to upwind to ensure consistency with HYDROTHERM. It should be noted that all of the basic numerical schemes of OpenFOAM are also valid for *HydrothermalFOAM* solver."

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