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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Steady State Non-isothermal Well Flow in a Slanted Aquifer: Mathematical formulation and Field Application to a Deep Fault in the Xinzhou Geothermal Field in Guangdong, China" *by* Guoping Lu and Bill X. Hu

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Interactive comment on "Steady State Non-isothermal Well Flow in a Slanted Aquifer: Mathematical formulation and Field Application to a Deep Fault in the Xinzhou Geothermal Field in Guangdong, China" by Guoping Lu and Bill X. Hu Anonymous Referee #1 Received and published: 10 April 2019

Comment: "In this paper an analytical solution is developed for well flow in a non-isothermal slanted aquifer. The temperature distribution is considered to be given.

Thus Darcy's law and continuity equations are solved. The analytical solution is applied to the Fault in the Xinzhou Geothermal Field in Guangdong (China). The topic is interesting and fits well with the journal. "

Response: Thanks for the positive feedback.

Comment: "My concern is with the organization and focus of the paper. I have also a technical concern regarding the developed solution. The paper is not well written. It misses structure and organization. Hence, I strongly suggest to do a thorough reorganization and possible re-writing of parts of the manuscript. "

Response: We have done some reorganization of the manuscript in creating a new section Case study. All the relevant materials regarding the study site are moved to this case study. And we add a section in the Discussion for drilling fluid effect and implication.

We went through a thorough editing of the text to improve the flow of English.

Comment: "Technically, I have a problem with the way in which Darcy's law is presented. I am not sure that the viscosity should be within the gradient operator. I am not familiar with this form and I am not sure that this is correct. This may help in getting the analytical solution (especially, for the non-isothermal radial flow in a horizontal confined aquifer) as viscosity will be in the right hand side but I think this is not correct. I suggest major revisions. "

Response: We have re-organize part of the manuscript. Specifically, we move the text regarding site description to a newly created section Case Study. And we did a thorough editing to improve the English flow.

The viscosity and density both are state variable. Therefore it is right for them appear within the gradient operator.

The viscosity appears within the gradient operator because it is a variable dependent of temperature and pressure, which are functions of space (and time). There is no reasonable argument to put the viscosity outside the operand.

For a verification of the analytical solution, we have tried our best to find a ready example in literature but failed to find one. The best source is the code T2Well (Pan et al., 2011) which does not have a case close to our aquifer even in the simplest horizontal scenario. To our surprise, we could not find any lead for one example, even after consulting several experts in this field (Tianfu Xu, the author of Toughreact code, Lawrence Berkeley National Lab; Keni Zhang, author of the parallel version of Tough2 code, among others) .

To do a numerical validation is not a easy task; in fact, it could take tremendous more effort than expected. This is because the coupling of thermal with flow is inherently complicated. In Tough2 code (Pruess et al., 1999), it takes an extraordinary large gridblock (e.g., 10e30) to keep the temperature constant. This in turn leads to constant pressure for the gridblock. Therefore, the approach for a realistic case needs a thermal field created for this purpose, rendering a very complicated procedure and much effort. In the regard, a validation of the numerical solution is associated with too much work.

We believe our analytical approach is sound.

We opt to not provide a numerical validation in this revision. However, we will bear this in mind and do our best to work this problem for another paper in this relevant area.

Thanks for reasonable doubt. But we beg to disagree.

Reference: Pan, Lehua, Curtis M. Oldenburg, Yu-Shu Wu and Karsten Pruess. 2011. T2Well/ECO2N Version 1.0: Multiphase and Non-Isothermal Model for Coupled Wellbore-Reservoir Flow of Carbon Dioxide and Variable Salinity Water. Lawrence Berkeley National Laboratory. LBNL-4291E.

Comment: My comments are below: - Please justify why the viscosity is included in the gradient operator. This is essential because form me this is not correct. - Comparison against numerical solution (using an existing model) will confirm the accuracy of the

developed solution

Response: Just like density, viscosity is also a state variable. If density is needed inside the gradient operator, so is viscosity.

The viscosity reflects the fact that fluid property is affected by state variables temperature and pressure. Therefore the viscosity is a dependent variable of temperature and pressure. In simplified calculations, the viscosity is expressed as constitutive relation for temperature and pressure.

The viscosity is included in the gradient operator for easing of operation. If it were taken out of the gradient, the viscosity is hard to be determined for a specific value proper in a calculation. More is that the viscosity is a measure for resistance to flowing against a "force". In this sense, it acts like permeability (regulated by viscosity) for resistance to fluid flow. Because it is a variable just like density, so they should be both placed inside the gradient operator.

Reference: Pan, Lehua, Curtis M. Oldenburg, Yu-Shu Wu and Karsten Pruess. 2011. T2Well/ECO2N Version 1.0: Multiphase and Non-Isothermal Model for Coupled Wellbore-Reservoir Flow of Carbon Dioxide and Variable Salinity Water. Lawrence Berkeley National Laboratory. LBNL-4291E.

Comment: - Please revise the introduction and state clearly the objective of the paper (which is for me analytical solution for non-isothermal flow). The introduction is too long. - Figures 4a and 4b not cited in the text. - Please revise: “Consequently it is a critical concept in practice that a dome-shaped water head surface would be present in its equilibrium state water potential, as a proper observation needed to understand geothermal flow fields. “ - In section 2.1 please include a vertical cross section representation of the site. - Please split Figure 1 in 2 figures - Tables 2 and 3 are cited in the text before table 1.

Response: We state our main objective in the text..

We moved part of the text for field site description to the newly created field site section, and removed parts of the text.

Added citation for Figures 4a and 4b. Thanks.

Revised the text " Consequently it is a critical concept in practice that a dome-shaped water head surface would be present in its equilibrium state water potential, as a proper observation needed to understand geothermal flow fields. ". The revision is " In practice it is a critical concept that ground water hydraulic-head surface could rise to a higher level at an elevated temperature and that a dome-shaped water head surface could be present in its equilibrium-state. Consequently an elevated-water column concept is needed for the on-site observations to be properly organized to understand geothermal flow fields. "

In previous Section 2. We added a cross section for the site and split Figure 1 into 2 figures. We re-arranged the text so Table 1 is cited before Tables 2 and 3.

Comment: - There is no need for table 1 which is standard in thermodynamics. Response: It appears overdone with the data in Table 1 for the density and viscosity data with temperatures and pressures. It takes non trivial effort to put together these data as they come from several none-common sources and often with incomplete data set.

But to the contrary, the table is handy and useful in several ways: 1. It has new contribution of the authors. It provides new formula for viscosity values for saturated pressures and increased pressures, respectively. 2. It provides the trend of changes in density and viscosity with pressures, which are not changed significantly as pressure increases. 3. In comparison with the revised code for calculation of density and viscosity, the interpolated data come as handy and accurate enough.

The table and the section have been heavily revised to enhance clarity and readability.

Comment: "- At line 192: “also listed is the density values” should be “also listed are the density values” - I did not understand why properties of saturated water are presented

(+ properties at P=5.1MPa). At line 195, it is mentioned that density is function of P and T. The discussion here is ambiguous. I think variation of density and viscosity in terms of pressure and temperature is standard in thermodynamics and there are several existing models to do that (as n Tough2 simulator used in this paper). Authors can simply mention that they used Tough2 simulator and there is no need for further discussion. (Section 3 can be removed). "

Response: The editorials have been made.

The density and viscosity of the table is for completeness in calculations. And two standalone formula have been provided for viscosity calculations.

Even though it is a standard that density and viscosity are varied in terms of temperature and pressure, it is convenient and useful to provide a table for accessibility and readability of the text. The relevant data for calculations in existing models are hard to access because there is no module to direct input to obtain the desire results. For example, the viscosity data are hard-wire in the coding for TOUGH2 code.

Comment: "- Please remove “The negative sign in front of the left side stands for the flow pointing to the opposite of the gradient” as it is standard. - Line 244 is not clear - Line 281 “Non isothermal radial flow in a horizontal confined aquifer 281 Assuming in a horizontal confined aquifer, in the non-isothermal scenario, fluid density 282 and viscosity are variables of temperature (Figure 4c)” Please revise this sentence and explain how the temperature is variable. - Grammatical and editing check (figure numbering and citation, equations). - Results are not well discussed and illustrated.

Response: We made the editorials. Thanks. We revised the text as: " For the non-isothermal scenario in a horizontal confined aquifer (Figure 4c), fluid has a lighter density and a lower viscosity at a higher temperature. The resultant hydraulic head surface is thus affected. Typically a dome-shape hydraulic head surface is formed, as the aquifer contacted with heat source possesses. Lighter pore water could would rise up in a borehole to a higher hydraulic head than denser pore water. Conversely, colder water injection into a heated aquifer could result in a funnel-shape head surface. "

We revised the case study section to provide more explanations for the results.

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