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Correct Energy Conservation in Geothermal Wellbore Simulation - Corrigendum

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Abstract

An error in a previous publication on the interpretation of static steam dryness versus flowing steam quality in the coding of the simulator GWELL is corrected here. GWELL does in fact have the correct derivation of flowing steam quality in its CO2 subroutine. The mathematics behind this derivation is briefly reviewed in this corrigendum. WELLSIM also passes the energy test mentioned in that publication.

Keywords:
Geothermal wellbore simulation, Energy conservation, Static versus flowing steam quality, GWELL, corrigendum, WELLSIM, SwelFlo

1. Introduction

A geothermal wellbore simulator typically solves conservation of mass, momentum and energy equations in the steady-state, for flow of vapour and liquid phases of water up a geothermal well.

This corrigendum is intended to correct the statement made in McGuinness (2014), that the simulator GWELL (Aunzo et al., 1991) fails to use the flowing steam quality $X_{\rm flo}$ and hence does not conserve energy or momentum. It is also intended to allay the concerns raised in McGuinness (2014) that a commercially available geothermal wellbore simulator (WELLSIM) was giving very different enthalpies to the simulator *SwelFlo* (2013) written by the author. These apparent differences were mainly due to this author's misconception in interpreting the usage of the subroutine CO2 in GWELL.

The quick and easy way to test the code of a geothermal wellbore simulator reported in McGuinness (2014), to see whether energy conservation is being correctly implemented or not, is not affected by the error noted here.

2. Conservation of Carbon Dioxide

2.1. Static Fluid

The total mass of carbon dioxide in a mass M of two-phase static fluid is given as the sum of the masses in vapor and liquid phases as

$$X_{CO_2}M = X_{CV}XM + X_{CL}(1-X)M \tag{1}$$

and this serves to define the (static) mass fraction X_{CO_2} of carbon dioxide. X is the static vapor phase mass fraction, X_{CV} is the fraction of the vapor mass that is carbon dioxide, and X_{CL} is the fraction of the liquid phase mass that is carbon dioxide. This equation rearranges to give the static vapor mass fraction in terms of the total mass fraction

$$X = \frac{X_{CO_2} - X_{CL}}{X_{CV} - X_{CL}}\ , \tag{2}$$

This is exactly the formula used in the subroutine CO2 in GWELL, and provides a value for the static steam mass fraction or dryness X.

2.2. Flowing Fluid

However, in a flowing two-phase fluid, the mass of carbon dioxide flowing through a cross-section of area A per unit time is

$$X^{\rm flo}_{CO_2}QA = X_{CV}X_{\rm flo}QA + X_{CL}(1-X_{\rm flo})QA \tag{3}$$

where Q is the mass flux of the two-phase fluid, kg/(m^2 s), and $X_{\rm flo}$ is the flowing steam quality or flowing mass fraction that is vapor. This serves to define the flowing mass fraction of carbon dioxide in the two-phase fluid, $X^{\rm flo}_{CO_2}$. This rearranges to give the formula for the flowing steam quality:

$$X_{\rm flo} = \frac{X^{\rm flo}_{CO_2} - X_{CL}}{X_{CV} - X_{CL}}\ . \tag{4}$$

Note that this is the same equation as that for static dryness in the previous subsection.

3. Conclusions

The decision about which dryness is being produced by the use of this formula is clear: if the fluid is static, the static dryness is obtained, but if the fluid is flowing, as is the case in geothermal wellbore simulations, then this formula gives the flowing steam quality $X_{\rm flo}$. Hence the use of this formula in the subroutine CO2 in GWELL provides a value for the flowing steam quality when simulating a flowing two-phase fluid, and not the static dryness as was believed in the work reported by McGuinness (2014). Consequentially, the variable X used in GWELL's energy and momentum subroutines is in fact correctly the flowing steam quality.

The mass fraction of carbon dioxide being used is then to be interpreted as a flowing mass fraction of carbon dioxide. The distinction is not critical in the typical case that feed points are single phase, but is important for two-phase feedpoints and in interpreting the typically two-phase output of a geothermal well.

The commercial simulator WELLSIM referred to in McGuinness (2014) now gives almost identical results to *SwelFlo* for the simple simulation referred to there, when the partial pressure of carbon dioxide is set to match, and WELLSIM is correctly conserving energy according to the test derived in McGuinness (2014). Furthermore, the tabulated results for GWELL in McGuinness (2014) are incorrect due to the confusion over flowing versus static dryness.

References

Aunzo, Z.P., Bjornsson, G., Bodvarsson, G., 1991. Wellbore models GWELL, GWNACL, and HOLA User's Guide. Lawrence Berkeley Lab, University of California, Earth Sciences Division Report LBL-31428, UC-251. 103 pp.

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SwelFlo (2013) is a commercially available geothermal wellbore simulator developed by the author, based on GWELL (see swelflo.com).