

## Correlations for Joule-Thomson Coefficients of Geothermal Waters Containing CO<sub>2</sub>

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### ABSTRACT

Reliable Joule-Thomson (J-T) coefficients of geothermal fluids containing CO<sub>2</sub> are important for non-isothermal reservoir flow simulation, well stream simulation, and process simulation. The J-T coefficients of fluids can be experimentally determined. However, it is difficult to conduct laboratory measurements because precise PVT data for cross interpolation is required for accurate estimation of the coefficients. Thus, experimentally measured J-T coefficients of water-CO<sub>2</sub> mixtures are almost non-existent. Consequently, it is necessary to estimate J-T coefficients by using an accurate equation of state (EoS); however, programming and running a complicated EoS is not an easy task. Accurate EoS modeling requires many parameters, and finding the right volumetric root could be problematic and is not trivial. This paper presents useful correlations for the estimation of J-T coefficients of water-CO<sub>2</sub> mixtures. Isenthalpic expansions are modelled for binary mixtures of water and CO<sub>2</sub> at different concentrations by using Gallagher, Crovetto, and Sengers EoS (1993). The EoS implemented in this study predicts both phase equilibrium and volumetric properties accurately for a temperature range of 400–1000 K and a pressure range of 0–100 MPa and 30% mole fraction of CO<sub>2</sub>. Pure component properties are estimated for water and compared with the ones in the literature. In addition, the effects of temperature and pressure on the J-T coefficients are investigated. The EoS given in this study applies for the temperature and pressure conditions which are limited to the ones encountered in typical geothermal reservoirs, and the correlations are derived based on the results of the EoS. The effect of CO<sub>2</sub> content on both the J-T coefficients and the inversion curves is also studied. The proposed correlations are derived in the temperature range of 400–550 K, and the pressure range of 8–30 MPa.

### 1. INTRODUCTION

Interest in temperature transient analysis in recent years has grown rapidly due to the recent advances and improvements in resolution of downhole temperature gauges. Interpretation and analysis of transient sandface temperatures alone or jointly with transient pressure data could yield important information regarding near-wellbore and far-field reservoir characteristics (Onur and Cinar, 2016; Palabiyik et al., 2016). For the majority of well testing applications temperature is measured along with pressure, but analyzing temperature data is not a common practice in well test analysis. Developing techniques for temperature transient analysis could help to acquire more information regarding the well/reservoir system without any additional costs.

There are a number of studies in petroleum and geothermal engineering literature emphasizing certain trends in the temperature changes, when the effects of Joule-Thomson (J-T) heating/cooling, transient adiabatic fluid expansion/compression, conduction, and convection are included in modeling of sandface temperatures during constant-rate drawdown and buildup tests; for instance see, Gang and Pritchett (1977,1984); Sui et al. (2008a, 2008b); App (2009, 2010); Duru and Horne (2010a, 2010b, 2011a, 2011b); Ramazanov et al. (2010); Palabiyik et al. (2013, 2015); App and Yoshioka (2013); Sidorova et al. (2015); and Onur and Palabiyik (2015).

Modeling temperature behavior within the reservoir and in the well requires thermal parameters regarding the fluid/rock system such as thermal conductivity, heat capacity, enthalpy etc. There are two approaches in modelling Joule-Thomson (J-T) effects while modelling temperature behavior: 1) J-T effects are included implicitly through enthalpy variation with respect to temperature and pressure, Eq. 1 shows the energy balance including enthalpy (Palabiyik et al., 2016). 2) Energy balance is derived with respect to temperature and the J-T effects are accounted for explicitly with an additional term in the expression, Eq. 2 shows the energy balance with respect to temperature for a 1D radial heat flow (Palabiyik et al., 2016). The second approach is temperature explicit and needed for analytical solutions of temperature for well test analysis applications. In such a case J-T coefficient is needed for the solution of temperatures (Palabiyik et al., 2016):

$$\frac{\partial}{\partial t}[\phi \rho_s H_s + (1-\phi) \rho_f H_f] - \frac{\partial(\phi \rho)}{\partial t} + \nabla \cdot (\rho_s H_s \mathbf{v}_s) - \nabla \cdot (k \nabla T) = 0 \quad (1)$$

$$[\phi \rho_s c_{p,s} + (1-\phi) \rho_f c_{p,f}] \frac{\partial T}{\partial t} - \phi(\rho_s c_{p,s} \mu_s + 1) \frac{\partial p}{\partial t} - \rho_s c_{p,s} \frac{k}{\mu_s} \frac{\partial p}{\partial r} \frac{\partial T}{\partial r} + \mu_s \rho_s c_{p,s} \frac{k}{\mu_s} \left( \frac{\partial p}{\partial r} \right)^2 - \frac{k}{r} \frac{\partial}{\partial r} \left( r \frac{\partial T}{\partial r} \right) = 0 \quad (2)$$

The J-T coefficients of fluids can be experimentally determined. However, it is difficult to conduct laboratory measurements because precise PVT data for cross interpolation is required for accurate estimation of the coefficients. Thus, experimentally measured J-T coefficients of water-CO<sub>2</sub> mixtures are almost non-existent. Consequently, it is necessary to estimate J-T coefficients by using an

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