A MODEL FOR DEEP GEOTHERMAL BRINES: STATE SPACE DESCRIPTION AND THERMODYNAMIC PROPERTIES

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Abstract

To facilitate the simulation of heat and fluid transport in deep geophysical environments, this thesis proposes correlations for calculation of density, enthalpy and viscosity values for brine (H_2O + NaCl) over a wide range of temperature T, pressure p and mass fraction of sodium chloride X. Although geothermal fluids are not pure H_2O-NaCl systems, they are mainly composed of H_2O and NaCl and in this thesis we model geothermal fluids as brines. Firstly T-p-X state space delineations of such a model fluid are described. Then using experimental and calculated data, approximate correlations for the three properties are given in terms of the primary variables T, p and X. These correlations cover the entire T-p-X state space and can be used in subroutines suitable for use in numerical simulation programs. The case of one-dimensional, steady vertical flows is described and our correlations for the state space delineations and the thermodynamic properties are tested on such flows.

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Nomenclature

The unit volume and area referred to here are the unit volume and area of the fluid-saturated porous medium, i.e. the fluid-filled geothermal system.

A_e	Internal energy per unit volume, J/m^3
A_m	Total mass per unit volume, kg/m^3
A_m^γ	Mass per unit volume of the sodium chloride ($\gamma = c$), rock ($\gamma = r$) or water ($\gamma = w$), kg/m^3
C	Chemical composition
c	Specific heat at constant volume, kJ/kg K = J/g K
$\mathbf{g}$, g	Acceleration due to gravity, m/s^2
h	Specific enthalpy, kJ/kg = J/g
k	Permeability, m^2
k_{ri}	Relative permeability of the liquid ($i = \ell$) or the gas ($i = g$), dimensionless
K	Thermal conductivity, W/m K
m_γ	Mass flux per unit area of the sodium chloride ($\gamma = c$) or the water ($\gamma = w$), kg/m^2 s
NCG	Non-condensible gas(es)
p	Pressure, bars absolute
q_e	Rate of production or injection of energy per unit volume, J/m^3 s
q_m^γ	Rate of production or injection of mass per unit volume of the sodium chloride ($\gamma = c$) or the water ($\gamma = w$), kg/m^3 s
Q_e, q	Energy flux per unit area, J/m^2 s
Q_m	Total mass flux per unit area, kg/m^2 s
Q_m^γ	Mass flux per unit area of the sodium chloride ($\gamma = c$) or the water ($\gamma = w$), kg/m^2 s

Q_{mi}	Mass flux of liquid ($i = \ell$) or gas ($i = g$) per unit area, kg/m^2 s
Q^{γ}_{mi}	Mass flux per unit area of γ in the i phase, $\gamma = w$ (water) or c (sodium chloride), $i = \ell$ (liquid) or g (gas), kg/m^2 s
t	Time , s
T	Temperature, °C
TDS	Total dissolved solids
S	Saturation, dimensionless
u	Specific internal energy, kJ/kg = J/g
V	Volume, m^3
VPL	Vapour pressure lowering
$\mathbf{x}$	Position vector, m
X	Mass fraction of sodium chloride, dimensionless
z	Vertical coordinate, m

Subscripts

b	Brine
bg	Brine gas or vapour
$b\ell$	Brine liquid
c	Sodium chloride
cap	Capillary
cg	Sodium chloride gas
$c\ell$	Sodium chloride liquid
$c\ sat$	Sodium chloride saturation
$cg\ sat$	Saturated sodium chloride gas
$c\ell\ sat$	Saturated sodium chloride liquid
$CRIT$	Critical
e	Energy
f	Fluid
g	Gas or vapour
gs	Gas phase of the two-phase fluid
$g\ SAT\ (= bg\ sat)$	Halite-saturated gas on the three-phase surface
$g\ sol$	Maximum solubility in water gas (vapour) or halite-saturated gas

ℓ	Liquid
ℓs	Liquid phase of the two-phase fluid
$\ell\ SAT\ (= b\ell\ sat)$	Halite-saturated liquid on the three-phase surface
$\ell\ sol$	Maximum solubility in liquid water or halite-saturated liquid
m	Mass
mg	Mass of gas
$m\ell$	Mass of liquid
r	Rock
SAT	Saturation
w	Water
$w\ sat$	Water saturation
$wg\ sat$	Saturated water gas
$w\ell\ sat$	Saturated liquid water
1000	1000 bars absolute
$2b$	Region 2b

Superscripts

c	Sodium chloride
w	Water

Greek letters

ε	Volume fraction of pore space occupied by the fluid or voidage, dimensionless
μ	Dynamic viscosity, kg/m s
$\nu = \mu/\rho$	Kinematic viscosity, m^2/s
ρ	Density, kg/m^3
ϕ	Porosity, dimensionless

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