Example Problem 15
Methane Hydrate Dissociation via Depressurization with Ice Formation in a One-Dimensional Open Domain

Abstract: *This problem is the third in a trilogy of methane hydrate dissociation problems involving methane production from a one-dimensional open domain using conventional approaches to dissociate methane hydrate into liquid water and methane gas. This problem involves the production of methane hydrate using depressurization, where the outlet pressure is maintained at a point above the freezing point of water on the hydrate stability curve (i.e., above the Q point). The first problem in the trilogy (Problem 13) uses thermal stimulation to dissociate methane hydrate, and the second problem (Problem 14) uses depressurization to a point above the freezing point of water on the hydrate stability curve, leading to no ice formation. This problem is solved with STOMP-WCMSE (a.k.a., STOMP-HYD), but does not involve* CO_2 *or salt. This operational mode includes options for eliminating the salt-mass and energy conservation equations. This problem is solved with the salt-mass conservation equation eliminated. This problem involves the release of methane from hydrate and the production of gaseous methane across the open domain. This problem involves three phases: aqueous, gas, and methane hydrate, but not ice.*

15.1 Problem Description

This problem involves a one-dimensional domain open on one end and closed on the other that initially contains methane hydrate in equilibrium with liquid water within the hydrate stability limit, but above the freezing point of water. At time zero, the pressure at the open end of the domain is lowered and the temperature is slightly elevated to a point outside the hydrate stability region, causing hydrate dissociation. The outlet pressure is lowered to a point below the freezing point of water on the hydrate stability curve. With the outlet pressure maintained at this point, ice forms in the column during the dissociation process. Mobile fluids (i.e., aqueous and gas) move across the open boundary in response to the dissociating hydrate and constant boundary pressure. Hydrologic

properties, thermal transport properties, initial conditions and boundary conditions for this thermal stimulation problem are provided in Table 15.1.

Table 15.1. Problem Parameters

Property	Value
Intrinsic Permeability	$k = 3.0\ x\ 10^{-13}\ m^2$
Porosity	$\phi = 0.3$
Pore Compressibility	$\beta = 5.0\ x\ 10^{-9}\ 1/Pa$
Grain Density	$\rho_{grain} = 2.6\ x\ 10^3\ kg/m^3$
Grain Specific Heat	$c_{grain} = 1.0\ x\ 10^3\ J/kg\ K$
Dry Thermal Conductivity	$k_{dry} = 2.0\ W/m\ K$
Grain Thermal Conductivity	$k_{grain} = \dfrac{k_{dry}}{(1-\phi)}$
Thermal Conductivity Model	$k_e = k_{dry} + \phi\,(s_l\ k_l + s_g\ k_g + s_h\ k_h)$
Aqueous Relative Permeability	$k_{rl} = \left(\dfrac{s_l - s_{lr}}{1 - s_{lr}}\right)^n$; $s_{lr} = 0.12, n = 3.0$
Gas Relative Permeability	$k_{rg} = \left(\dfrac{s_g - s_{gr}}{1 - s_{lr}}\right)^n$; $s_{gr} = 0.02, s_{lr} = 0.12, n = 3.0$
Initial Conditions	$T = 6°\ C;\ P = 8\ MPa;\ s_h = 0.5;\ s_l = 0.5$
Boundary Conditions @ x = 0.0 m	$T = 6°\ C;\ P = 0.5\ MPa;\ s_l = 1.0$
Boundary Conditions @ x = 1.5 m	Adiabatic, Zero Mass Flux