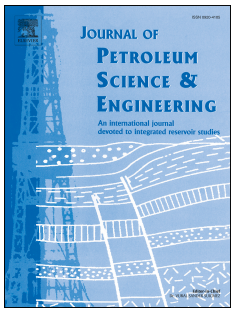
Accepted Manuscript



Effects of surface roughness and mineral heterogeneity on pore-scale steam condensation

Sahand Etemad, Arash Behrang, Peyman Mohammadmoradi, S. Hossein Hejazi, Apostolos Kantzas

PII: S0920-4105(17)30752-0

DOI: 10.1016/j.petrol.2017.09.055

Reference: PETROL 4298

To appear in: *Journal of Petroleum Science and Engineering*

Received Date: 24 July 2017

Revised Date: 21 September 2017

Accepted Date: 22 September 2017

Please cite this article as: Etemad, S., Behrang, A., Mohammadmoradi, P., Hejazi, S.H., Kantzas, A., Effects of surface roughness and mineral heterogeneity on pore-scale steam condensation, *Journal of Petroleum Science and Engineering* (2017), doi: 10.1016/j.petrol.2017.09.055.

Effects of Surface Roughness and Mineral Heterogeneity on Pore-Scale Steam Condensation

Sahand Etemad[1], Arash Behrang[1], Peyman Mohammadmoradi[1], S. Hossein Hejazi[1], Apostolos Kantzas[1,2]

1. Department of Chemical and Petroleum Engineering, University of Calgary, 2500 University Drive, Calgary, Alberta T2N 1N4, Canada
2. PERM Inc. TIPM Laboratory, Calgary, AB, Canada

Abstract

Sub-pore scale modeling of flow in porous media is gaining momentum. The concept of Digital Core Analysis deals with measurements of virtual core, and the purpose of such modeling is to replace conventional and special core analysis when the latter is not feasible. Single phase flow phenomena are nowadays fairly easy to model given a good representation of the porous medium by its digital counterpart. One of the challenging concepts in micro-scale simulation of porous media is consideration of phase change phenomena. Mass and heat transfer equations have to be considered simultaneously to capture complexities involved in the evaporation and condensation processes. Therefore, a numerical scheme based on the Volume-of-Fluid method was implemented using the OpenFOAM open-source CFD package along with four phase change models. The aforementioned approach is currently being extended in the modeling of phase change within a porous medium. Surface roughness is introduced by the incorporation of wedges of variable density and amplitude on the pore surface. A further introduced complication is that the individual grains are of different mineralogy and thus of different wettability. The problem of steam condensation in such media is addressed. It is observed that steam condenses first in the smallest of wedges, which act as nucleation sites. Water spreads on water-wet surfaces. Snap-off is observed in several cases leading to temporary trapping of vapor. Grid size effects are also addressed. The application of this modeling effort is the condensation of steam in thermal recovery methods.

Keywords: Nucleation; Mineralogy; Surface roughness; Condensate; Phase change

Nomenclature

k_{eff} = effective thermal conductivity ($\frac{W}{m.K}$)
Q = volumetric heat sources (J)
S_{α_v} = interfacial mass transfer (vaporization) ($\frac{kg}{s.m^2}$)
S_{α_l} = interfacial mass transfer (condensation) ($\frac{kg}{s.m^2}$)
$\dot{m}_i$ = overall mass transfer at the interface ($\frac{kg}{s}$)
μ = viscosity ($Pa.s$)
A_i = interfacial area density
T_{sat} = saturation temperature (K)
r = mass transfer intensity factor (s^{-1})
t_D = $\left[\frac{0.0002637\ k\ t}{\emptyset \mu c_t {r_w}^2}\right]$, dimensionless time
$T^* = \frac{T-T_R}{T^{sat}-T_R}$, Dimensionless temperature
t_g = bubble growth time (s)
t_n = nucleation time (s)
t_g^* = growth time of the last possible bubble (s)
N = characterizing the bubble nucleation time
$\vec{u}$ = velocity vector ($\frac{m}{s}$)
$\vec{F}$ = volume force ($\frac{N}{m^3}$)
ρ = density ($\frac{kg}{m^3}$)
E = energy (J)
T_i = temperature at the interface of both phases (K)
R_c = critical nucleation radius
T_R = reservoir temperature (K)