PGE 392K: Numerical Simulation of Reservoirs

Assignment #11
Due Monday, December 5 (No Penalty through Fri, Dec 9)

1. (25 points). Adapt your "2-phase" IMPES simulator to be applicable for three-phase flow. In particular you will need to allow for:
   a. Pressure-dependent PVT variables, R_s, B_o, and B_g
   b. Three-phase relative permeability (see assignment #1)
   c. Calculation of Sw, So, and Sg.

   You might choose to make your simulator more flexible, but here we will only apply the code for 1D, no gravity, no capillary pressure, and no horizontal wells.

2. (75 points). Run your simulator for a 1D reservoir that is L =1000 ft, w= 100 feet, and h= 100 ft with permeability that is 10 mD and porosity is 0.20. There is a vertical, constant BHP producer at x=500 ft of 100 STB/day liquid (oil + water). After 2 years, vertical injectors at x=0 and x=L inject 50 STB/day water each. If the producer BHP reaches 14.7 psia, convert to a BHP well of 14.7 psia and leave it at that BHP for the remainder of the simulation.

   The reservoir temperature is 175 F and initial pressure is 1000 psia which is also the bubble point; S_{wi}=S_{wr}=0.10. The water, *undersaturated* oil, and formation compressibility are 3E-6 psi^{-1}, 2.87E-6 psi^{-1}, and 1.0E-6 psi^{-1}, respectively. The water viscosity and formation volume factor can be assumed constant, 0.383 cp and 1.023, respectively. Other PVT properties are pressure dependent and summarized in equations below the bubble point. 3-phase relative permeability is given by the Stone I model (see assignment #1); S_{wr} =0.1, S_{orw} = 0.4, S_{org} = 0.2, S_{gr} = 0.05, k_{rw}^0 = 0.3, k_{row}^0 =0.8, k_{rog}^0 =0.8, k_{rg}^0 =0.3, N_w =2.0, N_g=2.0, N_{ow} = 2.0, N_{og} = 2.0.

$$Rs\left(\frac{scf}{STB}\right)=\left(3.43E-05\right)p^2+9.21E-02p$$
$$B_o\left(\frac{RB}{STB}\right)=6.119E-05p+1.083$$
$$z=1.336E-08p^2-8.804E-05p+0.9952$$
$$\mu_o\left[cp\right]=4.846E-07p^2-1.533E-03p+2.375$$
$$\mu_g\left[cp\right]=5.929E-10p^2-6.764E-07p+0.01309$$

Recall that below the bubble point,

$$c_o^*=-\frac{1}{B_o}\frac{\partial B_o}{\partial p};\qquad c_o=-\frac{1}{B_o}\left(\frac{\partial B_o}{\partial p}-B_g\frac{\partial R_s}{\partial p}\right)$$
$$B_g=0.0282\frac{zT}{p}\left[\frac{\text{ft}^3}{\text{scf}}\right]$$

Where P is in psia and T is in Rankine (=°F +460).

Note: In the calculation of interblock phase transmissibilities (e.g. Tg matrix) an **upwinded** formation volume factor must be used. However, when creating T, etc. the phase transmissibilities must be multiplied by a diagonal matrix of **block** formation volume factors.

Run your simulation for 6 years using a time step of 1 day for the following cases:

a. 3 uniform grid blocks
b. 100 grid blocks and make plots of the bottomhole pressure (all wells), oil rate (producer), and surface Gas-Oil Ratio (producer) versus time.