NTNU – Trondheim
Norwegian University of Science and Technology

Department of Petroleum Engineering and Applied Geophysics

Examination paper for TPG4160 Reservoir Simulation

Academic contact during examination: Jon Kleppe

Phone: 91897300/73594925

Examination date: June 5, 2015

Examination time (from-to): 9:00-13:00

Permitted examination support material: D/No printed or hand-written support material is allowed. A specific basic calculator is allowed.

Other information:

Language: English

Number of pages: 6

Number of pages enclosed: 0

Checked by:

Date Signature

Question 1 (12 points)

a) Make sketches of *Black Oil* fluid properties B_o, B_g, B_w, R_{so}, μ_o, μ_g, μ_w. Label bubble point pressure, and saturated and undersaturated regions.
b) Express reservoir densities for the three fluids in terms of B_o, B_g, B_w, R_{so}, ρ_{oS}, ρ_{gS}, ρ_{wS}.
c) Express the density of the part of the reservoir oil that remains liquid at the surface.
d) Express the density of the part of the reservoir oil that becomes gas at the surface.
e) Express the gas density using real gas equation.
f) Write the definition for fluid compressibility.
g) Write an expression for pore compressibility

Question 2 (12 points)

For a completely water-wet system, make sketches of saturation functions (including labels for important points/areas)

a) Oil-water system: imbibition and drainage k_{rw}, k_{row}, P_{cow} vs. S_w
b) Oil-gas system: imbibition and drainage k_{rg}, k_{rog}, P_{cog} vs. S_g
c) Typical contours of three-phase k_{ro} in a ternary (triangular) diagram (axes S_o, S_w, S_g)

Question 3 (8 points)

Explain briefly the following terms as applied to reservoir simulation (short sentence and/or a formula for each):

a) Control volume
b) Mass balance
c) Taylor series
d) Numerical dispersion
e) Explicit
f) Implicit
g) Stability
h) Upstream weighting
i) Variable bubble point
j) Harmonic average
k) Transmissibility
l) Storage coefficient
m) Coefficient matrix
n) IMPES
o) Fully implicit
p) Cross section
q) Coning
r) PI
s) Stone´s relative permeability models
t) Discretization
u) History matching
v) Prediction
w) Black Oil
x) Compositional
y) Dual porosity
z) Dual permeability

Question 4 (12 points)

The discretized form of the left hand side of the oil equation may be written in terms of transmissibility and pressure differences, as:

$$\frac{\partial}{\partial x}\left(\frac{kk_{ro}}{\mu_o B_o}\frac{\partial P_o}{\partial x}\right)_i \approx T_{xoi+1/2}(P_{oi+1}-P_{oi})+T_{xoi-1/2}(P_{oi-1}-P_{oi})$$

Using the following transmissibility as example,

$$T_{xoi+1/2}=\frac{2k_{i+1/2}\lambda_{oi+1/2}}{\Delta x_i\left(\Delta x_{i+1}+\Delta x_i\right)}$$

a) What is the averaging method normally applied to absolute permeability between grid blocks ($k_{i+1/2}$)? Why? Write the expression for average permeability between grid blocks (i+1) and (i).
b) Write an expression for the selection of the conventional upstream mobility term ($\lambda_{oi+1/2}$) for use in the transmissibility term of the oil equation above for flow between the grid blocks (i+1) and (i).
c) Make a sketch of a typical Buckley-Leverett saturation profile resulting from the displacement of oil by water (i.e., analytical solution). Then, show how the corresponding profile, if calculated in a numerical simulation model, typically is influenced by:
d) choice of mobilities between the grid blocks (Sketch curves for saturations computed with upstream or average mobility terms, respectively).
e) time step size
f) capillary pressure

Question 5 (6 points)

In the Exercise 3, the effect of gas injection in under-saturated oil is investigated. Two different cases (swelling and no-swelling case) are compared.

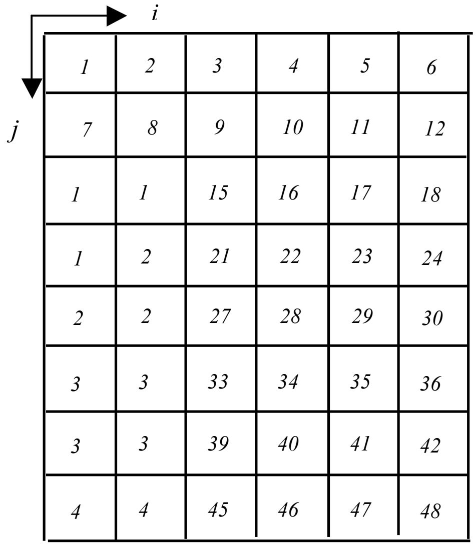
a) What is the difference between these two cases in terms of R_{so} (Explain with plots of B_o and R_{so} vs. pressure).
b) How do these two cases influence the GOR and field oil production (Explain with plots of GOR and field oil production vs. time).

Question 6 (15 points)

For two-dimensional (x,y), one phase flow, the pressure equation is:

$$e_{i,j}P_{i,j-1}+a_{i,j}P_{i-1,j}+b_{i,j}P_{i,j}+c_{i,j}P_{i+1,j}+f_{i,j}P_{i,j+1}=d_{i,j} \qquad i=1,N_x, j=1,N_y$$

applicable to the following grid system:



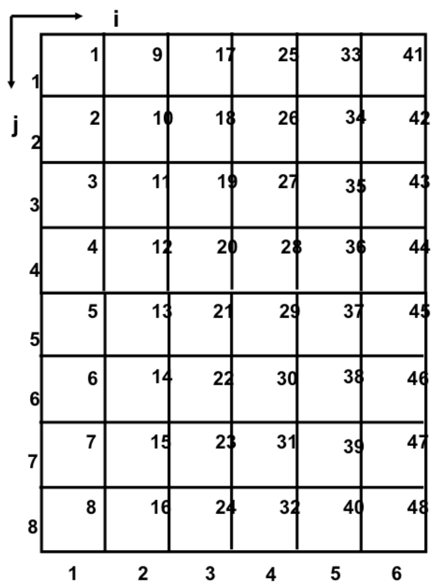
List the block number for all gridblocks where:

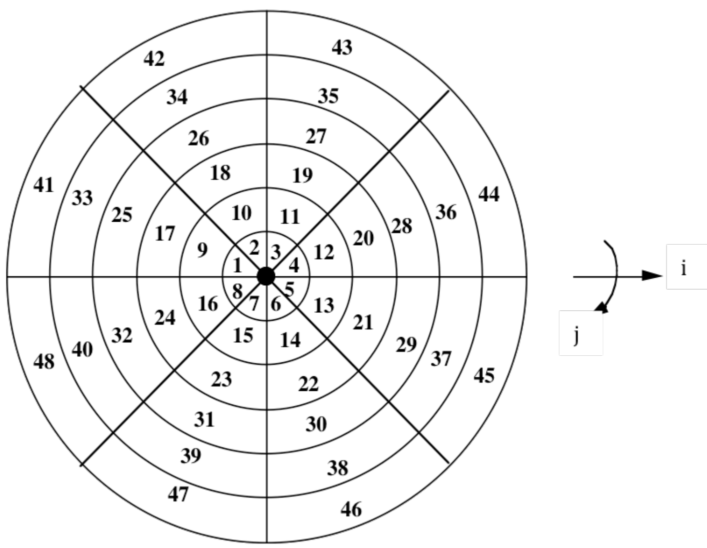
$a_{i,j} = 0$
$c_{i,j} = 0$
$e_{i,j} = 0$
$f_{i,j} = 0$

<u>Question 7</u> *(10 points)*
Below are grids for two 6 by 8 grids, one in x-y rectangular coordinates, and one in r-Θ cylindrical coordinates. The pressure equation for one-phase flow for both systems is:

$$e_{i,j}P_{i,j-1} + a_{i,j}P_{i-1,j} + b_{i,j}P_{i,j} + c_{i,j}P_{i+1,j} + f_{i,j}P_{i,j+1} = d_{i,j} \quad i = 1,...,N_1, \quad j = 1,...,N_2$$

Sketch the coefficient matrix for both systems (approximately, with lines and the appropriate coefficient name). Show the key differences between the two on the cylindrical coefficient matrix.





<u>Question 8</u> (16 points)
The pressure equation for single-phase slightly compressible flow is

$$TP^{t+\Delta t} = B$$

Where T is the transmissibility matrix. For an n-cell simulation the pressure vector is

$$P^{t+\Delta t} = \begin{pmatrix} P_1 \\ . \\ . \\ . \\ . \\ P_n \end{pmatrix}^{t+\Delta t}$$

In the following you are to show the structure of T for cases a – d below. Show the nonzero parts of T with an x and the zero parts with an o.
(make a 10x10 grid for each case representing the coefficient matrix and enter x or o in the squares)

a. Standard ordering by rows:

6	7	8	9	10
1	2	3	4	5

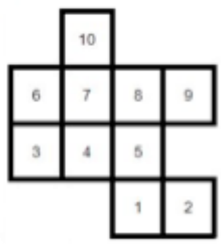
b. Standard ordering by columns:

2	4	6	8	10
1	3	5	7	9

c. Checkerboard (Cyclic-2) Ordering:

8	4	9	5	10
1	6	2	7	3

d. Irregular Ordering:



<u>Question 9</u> (11 points)

a) Write the oil-water equations (one-dimensional, horizontal flow) in discrete form using transmissibilities and storage coefficients, including production/injection terms.
b) What are the primary variables (unknowns)?
c) What is the main challenge in solving the equations for pressures and saturations?
d) What are the assumptions for solving the equations using the simplified IMPES method?
e) List the advantages and disadvantages of IMPES reservoir simulation compared to fully implicit reservoir simulation in terms of accuracy, stability and cost.
f) In what kind of problems may the IMPES method not be well suited for?

<u>Question 10</u> *(8 points)*
For two-phase flow (constant flow area) the right hand side of the gas equation may be written (undersaturated oil case):

$$\frac{\partial}{\partial t}\left(R_{so}\frac{\phi S_o}{B_o}\right)$$

The corresponding discretized form is:

$$C_{pog_i}\left(P_{o_i}-P_{o_i}^{t}\right)+C_{pbg_i}\left(P_{bp_i}-P_{bp_i}^{t}\right)+C_{swg_i}\left(S_{w_i}-S_{w_i}^{t}\right)$$

a) Sketch typical curves that show the pressure dependencies of B_o and R_{so}.

b) Show the complete derivations of the three coefficients $C_{pog_i}, C_{pbg_i}, C_{swg_i}$.