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Department of Petroleum Engineering and Applied Geophysics

Examination paper for TPG4160 Reservoir Simulation

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

Other information:

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Number of pages: 6

Number of pages enclosed: 0

Checked by:

Date Signature

Question 1 (3+3+3 points)

This question relates to the Gullfaks H1 Segment project work.

a) Which geological factors are causing the good communication in the Lower Brent Group of the H1 Segment of the Gullfaks Field
b) Describe briefly how chemical injection is accounted for in the Eclipse simulations that you did
c) What are the main uncertainties in the simulation results?

Question 2 *(4,5+2+4+2+3+5+2 points)*

The simple, one-dimensional, linear, horizontal, one-phase diffusivity equation may be written as:

$$\frac{\partial^2 P}{\partial x^2} = \left(\frac{\phi \mu c}{k}\right)\frac{\partial P}{\partial t}.$$

a) List the steps involved in deriving the diffusivity equation
b) Sketch the one-dimensional, horizontal porous system that the equation applies to, in both continuous and discrete form.
c) Using Taylor series expansions, derive the finite difference approximations needed for the discretization of the equation (for constant grid block size).
d) What are the error terms associated with these approximations?
e) Write the difference equation on explicit form, and outline a procedure for pressure solution.
f) Write the difference equation on implicit form, and outline a procedure for pressure solution.
g) Why is the explicit form seldom used?

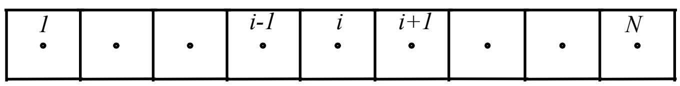
Question 3 (2+3+3+4 points)

Sketch the coefficient matrix for the following systems, indicating non-zero diagonals with approximate lines. Label the diagonals. What is the bandwidth?

a) One-dimensional (x), one phase flow, with the pressure equation:

$$a_i P_{i-1} + b_i P_i + c_i P_{i+1} = d_i, \quad i = 1,N$$

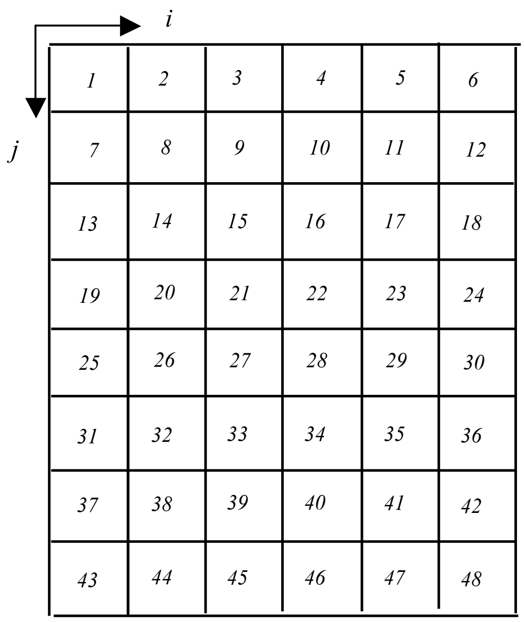
applicable to the following grid system:



b) Two-dimensional (x,y), one phase flow, with the pressure equation:

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

Applicable to the following grid system:



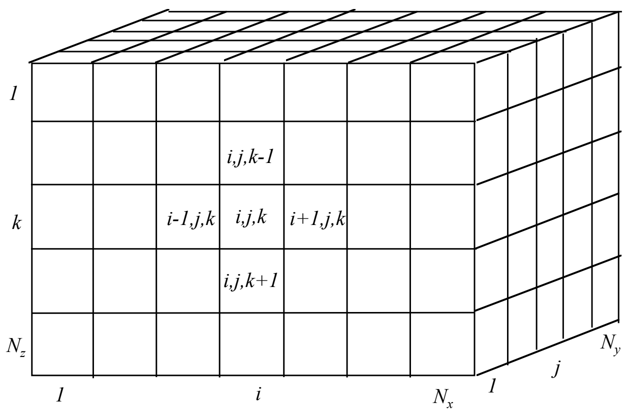
c) As question b) above, but now the numbering of the grid starts in the j-direction.

d) Three-dimensional (*x,y,z*), one phase flow, with the pressure equation:

$$g_{i,j,k}P_{i,j,k-1} + e_{i,j,k}P_{i,j-1,k} + a_{i,j,k}P_{i-1,j,k} + b_{i,j,k}P_{i,j,k}$$

$$+ c_{i,j,k}P_{i+1,j,k} + f_{i,j,k}P_{i,j+1,k} + h_{i,j,k}P_{i,j,k+1} = d_{i,j,k} \qquad i = 1,N_x, j = 1,N_y, k = 1,N_z$$

applicable to the following grid system (grid blocks numbered in the sequence of x,y,z)



Question 4 *(5+5+5 points)*

For two-phase flow of oil and gas in a horizontal, one dimensional, linear porous medium, the flow equations may be written as:

$$\frac{\partial}{\partial x}\left(\frac{kk_{ro}}{\mu_o B_o}\frac{\partial P_o}{\partial x}\right) - q'_o = \frac{\partial}{\partial t}\left(\frac{\phi S_o}{B_o}\right)$$

and

$$\frac{\partial}{\partial x}\left(\frac{kk_{rg}}{\mu_g B_g}\frac{\partial P_g}{\partial x} + R_{so}\frac{kk_{ro}}{\mu_o B_o}\frac{\partial P_o}{\partial x}\right) - q'_g - R_{so}q'_o = \frac{\partial}{\partial t}\left(\frac{\phi S_g}{B_g} + R_{so}\frac{\phi S_o}{B_o}\right),$$

where

$$P_{cog} = P_g - P_o$$

$$S_o + S_g = 1.$$

a) Write the two flow equations on discretized forms in terms of transmissibilities, storage coefficients and pressure differences (no derivations).
b) List the assumptions for IMPES solution, and outline briefly how we solve for pressures and saturations
c) Outline briefly how we can solve for pressures and saturations by Newtonian iteration (ie. fully implicit solution).

Question 5 (*27x0,5 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

<u>Question 6</u> *(3+3+3 points)*

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

$$T_{xo_{i+1/2}}(P_{oi+1} - P_{oi}) + T_{xo_{i-1/2}}(P_{oi-1} - P_{oi})$$

Using the following transmissibility as example,

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

a) What type of averaging method is normally applied to absolute permeability between grid blocks? Why? Write the expression for average permeability between grid blocks (*i*-1) and (*i*).
b) Write an expression for the selection of the conventional *<u>upstream mobility term</u>* 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 (ie. analytical solution). Then, show how the corresponding profile, if calculated in a numerical simulation model, typically is influenced by the choice of mobilities between the grid blocks (sketch typical curves for saturation profiles computed with upstream or average mobility terms, respectively).

<u>Question 7</u> (3+1+1+1+1+3 points)

For a one-dimensional, horizontal, 3-phase oil, water, gas system, the general flow equations are (including well terms):

$$\frac{\partial}{\partial x}\left(\frac{kk_{ro}}{\mu_o B_o}\frac{\partial P_o}{\partial x}\right) - q'_o = \frac{\partial}{\partial t}\left(\frac{\phi S_o}{B_o}\right),$$

$$\frac{\partial}{\partial x}\left(\frac{kk_{rg}}{\mu_g B_g}\frac{\partial P_g}{\partial x} + R_{so}\frac{kk_{ro}}{\mu_o B_o}\frac{\partial P_o}{\partial x}\right) - q'_g - R_{so}q'_o = \frac{\partial}{\partial t}\left(\frac{\phi S_g}{B_g} + R_{so}\frac{\phi S_o}{B_o}\right)$$

$$\frac{\partial}{\partial x}\left(\frac{kk_{rw}}{\mu_w B_w}\frac{\partial P_w}{\partial x}\right) - q'_w = \frac{\partial}{\partial t}\left(\frac{\phi S_w}{B_w}\right)$$

a) Explain briefly the physical meaning of each term in all three equations.
b) What are the criteria for **saturated** flow? What are the functional dependencies of R_{so} and B_o?
c) What are the primary unknowns when solving the **saturated** equations?
d) What are the criteria for **undersaturated** flow? What are the functional dependencies of R_{so} and B_o?
e) What are the primary unknowns when solving the **undersaturated** equations?
f) Rewrite the equations above for **undersaturated** flow conditions.

Question 8 (2+5+2 points)

For a one-dimensional, vertical (z), 3 phase oil, water, gas system, outline how initial pressures and saturations may be computed in a simulation model, assuming that equilibrium conditions apply:

a) Sketch the reservoir, with a grid superimposed, including gas-oil-contact (GOC) and water-oil-contact (WOC).
b) Sketch the oil-gas and oil-water capillary pressure curves, and show the how the initial equilibrium pressures and saturations are determined in the continuous system.
c) Sketch the initial saturations as they are applied to the grid blocks.