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Examination paper for TPG4160 Reservoir Simulation

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<u>Question 1</u> (5 points)

This question relates to the Gulltopp Field project work.

a) The reservoir pressure of Gulltopp was slowly declining before production start in 2008. Why?
b) Was the amount of outflow from Gulltopp before production start in 2008 significant compared to the total produced volumes until 2014? Why or why not?
c) What was the main driving mechanism during production of Gulltopp?
d) What were the main uncertainties in the simulation results?
e) Discuss briefly how oil recovery from Gulltopp could have been improved using alternative development strategies.

<u>Question 2</u> (10 points)

List all steps and standard relationships/formulas involved in deriving partial differential flow equations for flow in porous media. Black-Oil, one-phase, one-dimensional, horizontal flow is sufficient.

<u>Question 3</u> (10 points)

List all steps and standard approximations for converting a continuous partial differential equation to discrete form. Include a sketch of the continuous and the discrete (gridded) flow system. Include standard approximations needed for the simple diffusivity equation:

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

<u>Question 4</u> (9 points)

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

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

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 the choice of mobilities between the grid blocks (sketch curves for saturations computed with upstream or average mobility terms, respectively).

Question 5 (12 points)

For two-phase flow of oil and water in a horizontal, one-dimensional porous medium, the flow equations can be written (including well terms):

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

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

where

$$P_w = P_o - P_{cow}$$

$$S_o + S_w = 1$$

a) Write the two flow equations on discretized forms in terms of transmissibilities, storage coefficients and pressure and saturation differences (do not derive).
b) List the assumptions for IMPES solution, and outline **briefly** how we solve for pressures and saturations.
c) What are the limitations of the IMPES solution?

Question 6 (12 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 7 (12 points)

For two-phase flow (constant flow area) the right hand side of the oil and gas equations may be written (saturated oil case):

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

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

The corresponding discretized forms are:

$$C_{poo_i}\left(P_{o_i}-P_{o_i}^t\right)+C_{sgo_i}\left(S_{g_i}-S_{g_i}^t\right)$$

$$C_{pog_i}\left(P_{o_i}-P_{o_i}^t\right)+C_{sgg_i}\left(S_{g_i}-S_{g_i}^t\right)$$

a) Sketch typical curves that show the pressure dependencies of B_o, R_{so}.
b) Show the complete derivations of the four coefficients $C_{poo_i}, C_{sgo_i}, C_{pog_i}, C_{sgg_i}$.

Question 8 (10 points)

Normally, we use either a *Black Oil* fluid description or a *compositional* fluid description in reservoir simulation.

a) What are the *components* and the *phases* used in *Black Oil* modeling?
b) What are the *components* and the *phases* used in *compositional* modeling?
c) Write the standard flow equations for the components required for *Black Oil* modeling (one dimensional, horizontal, constant flow area).
d) Write the standard flow equations the components required for *compositional* modeling (one dimensional, horizontal, constant flow area). Let
   C_{kg} = *mass fraction of component k present in the gas phase*
   C_{ko} = *mass fraction of component k present in the oil phase*.
e) A *Black Oil* fluid description may be regarded as a subset of a *compositional* fluid description. Define the pseudo-components required in order to reduce the *compositional* equations to *Black Oil* equations (one-dimensional, horizontal, constant flow area)

Question 9 (10 points)

Normally, we use either a *conventional single porosity* model or a *fractured* dual porosity model in simulation of a reservoir.

a) Describe the main differences between a *conventional* reservoir and a *fractured* reservoir, in terms of the physics of the systems.
b) How can we identify a fractured reservoir from standard reservoir data?
c) Explain **briefly** the primary concept used in deriving the flow equations for a dual-porosity model.
d) Write the basic equations (one-phase, one-dimension) for
   - a two-porosity, two-permeability system
   - a two-porosity, one-permeability system
e) In terms of the physics of reservoir flow, what is the key difference between the two formulations in question d)?

f) How is the fluid exchange term in the flow equations in question d) represented? What are the shortcomings of this representation?

<u>Question 10</u> (10 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.