VARIABLE BUBBLE POINT PROBLEMS

Under some conditions of production and injection, a reservoir will go frm being undersaturated to saturated, and vice versa. Therefore, we need to discuss how to handle such situations, relative to the previously derived flow equations for under-saturated and saturated conditions.

Undersaturated systems

Criteria:

$$P_o > P_{bp}$$

and

$$S_g = 0.$$

Flow equations (for simplicity, horizontal flow, constant area and in one dimension):

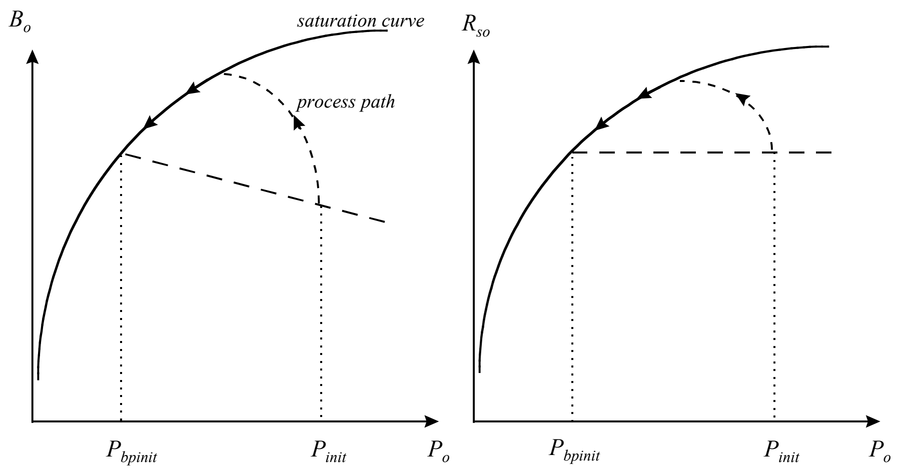
$$\frac{\partial}{\partial x}\left(\frac{kk_{ro}}{\mu_o B_o}\frac{\partial P_o}{\partial x}\right) - q'_o = \frac{\partial}{\partial t}\left(\frac{\phi S_o}{B_o}\right),$$

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

and

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

Injection of gas into an undersaturated oil, results in an increase in solution gas, and thus in formation volume factor. Assuming production so that reservoir pressure is decreasing, the process path may be as follows:



As we inject gas into the under-saturated oil, and at the same time produce the reservoir at a higher reservoir rate, oil pressure is decreasing and bubble point pressure is increasing. The system remains under-saturated in any one grid block only as long as $P_{o_i} > P_{bp_i}$. However, if the solution of the discrete equations results in a computed bubble point pressure in a grid block higher than the oil pressure in the grid block, we need to switch to the saturated equations for that particular grid block. Ideally, we would repeat the time step using saturated equations for the grid block in question. However, for systems of many grid blocks, this is not practical, and we therefore for each grid block crossing the bubble point, estimate the pressure at which the crossing occurred, and make an material balance correction of the fluid in place in that grid block.

Saturated systems

Criteria

$$P_o = P_{bp}$$

and

$$S_g \geq 0.$$

The flow equations become:

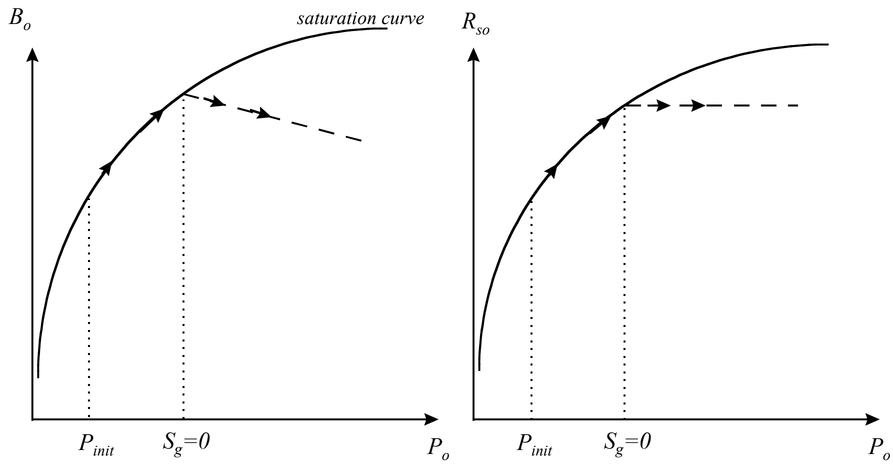
$$\frac{\partial}{\partial x}\left(\frac{kk_{ro}}{\mu_o B_o}\frac{\partial P_o}{\partial x}\right) - q'_o = \frac{\partial}{\partial t}\left(\frac{\phi S_o}{B_o}\right),$$

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

and

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

If we are at saturated conditions, and the pressure of the reservoir is increasing, for instance by re-pressuring of the reservoir by water injection, the process path will be as follows:



Here, as we solve for oil pressure and water and gas saturations. Then we check at the end of each time step if $S_g < 0$. If that is the case, the grid block in question has just passed into under-saturated area. Again, it is not practical to rerun the time step, and we estimate the bubble point pressure at the crossing point, and make a material balance correction of the fluid in place for the grid block in question before proceeding with the simulation.