Let us speak about well performances

The well is the "connection tool" between reservoir and surface (**Figure 1**). For obvious reasons linked to the lack of homogeneity of both the rock type (from soft shale to hard sandstone or limestone) and the pore pressure regime, it cannot be drilled in a single phase.

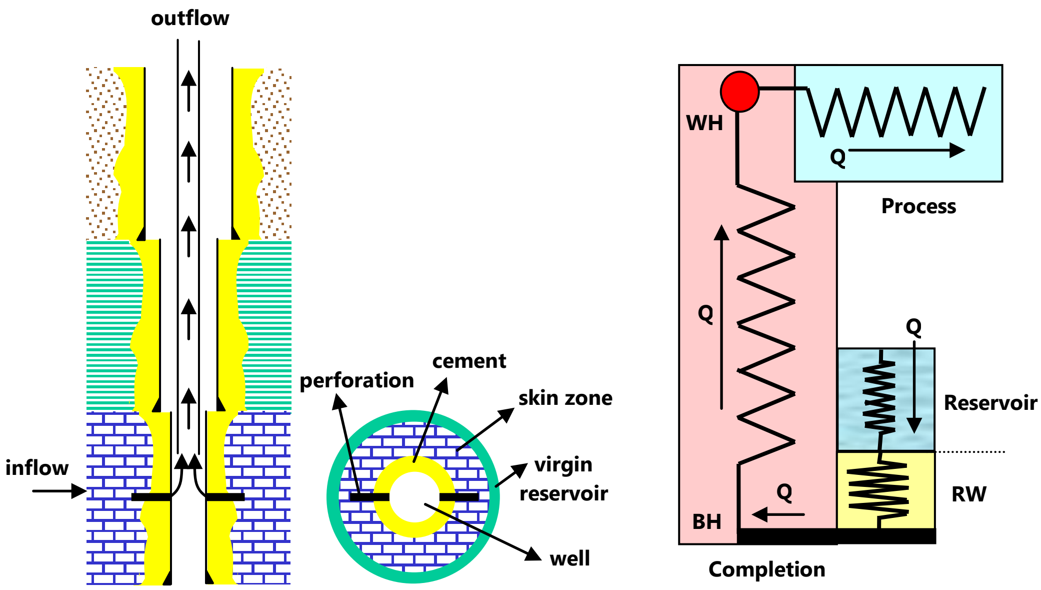

Figure 1 – Schematic well
Reservoir/well/process resistance analogy
WHP = Well Head Pressure
BHP = Bottom Hole Pressure
RWI = Reservoir Well Interface

A well is built as a telescopic structure with its diameter reduced in stages (typically 20 inches at the surface and 6 inches at the reservoir level) and covered by successive cemented casings then completed by a tubing in which the multiphasic effluent (mixture of oil, water and gas) will flow. By nature, the well therefore introduces numerous additional barriers to be overcome by the fluid before it reaches the surface. We will see that the well is however also an opportunity to provide the fluid with additional energy

The ability of the well to transfer the effluent correctly from the reservoir to the surface is called **well performance**. Well performance can be modelled as an energy problem through which an additional part of the natural energy (both mechanical energy but also heat) of the effluent will be progressively consumed through a series of resistances first in the near well bore then within the completion (**Figure 1**). For obvious reasons, the flow through the near wellbore rock which enters the well is called the INFLOW whereas the flow across the completion to the surface is called the OUTFLOW. Global well performance will depend both on inflow and outflow performances. As they are governed by very different physical phenomenon, inflow and outflow performances must be analysed separately.

Inflow performance and skin effect

The rocky zone surrounding the well (called the **R**eservoir **W**ellbore **I**nterface –**RWI**-) is governed by Darcy's equation. However, it differs from the reservoir itself by a very different flow regime (very high velocities and pressure gradients) and also by its complex history associating quick drilling and early completion phases with a long and relatively complex production phase.

The inflow performance curve of an oil well plots the BHP (Bottom Hole flowing Pressure) as a function of the flow rate Q. In the ideal case of a single phase fluid and a Darcy's law, this relationship is linear. It intersects the pressure axis (zero flow rate) at a value equal to the static reservoir pressure P_R and the flow axis at a (theoretical) value $Q_{\max}$ called the absolute open hole potential of the well. However, in actual reservoir conditions, the problem becomes more complex and additional physical phenomena must be considered.

In the vicinity of the well and since the fluid velocities are much higher than in the reservoir itself, the conventional Darcy's law (assuming the flow is laminar) ceases to be valid and a quadratic term has to be used. This quadratic term accelerates the curvature of the curve (**Figure 2**). It is particularly important in the case of gas wells for which velocities can be very high.
The rock properties of the inflow zone (i.e. the permeability) are affected early during drilling, so too are the completion operations including perforation. Depending on the case, the permeability can be reduced (detrimental effect of drilling or completion fluids) or increased (drilling-induced fracturing). During production, high velocities and high pressure gradients prevailing in the RWI can induce physical phenomena and also specific chemical reactions which positively or negatively affect the permeability.

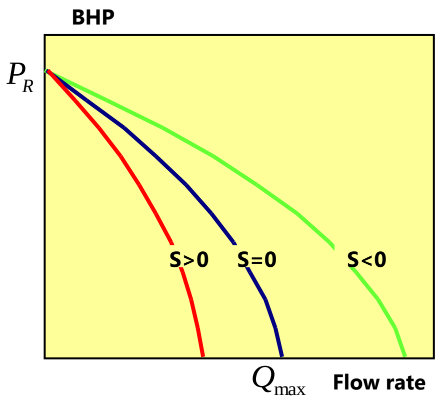

Figure 2 – Typical Inflow Performance curves
Skin and water cut saturation.

The inflow zone (radius R_s) surrounding the well (radius R) in which rock permeability is modified (permeability k_s compared to permeability k in the undisturbed zone) can be quantitatively characterised by a macroscopic parameter called the "*skin factor*", written s and defined as follows:

$$s = \left[\frac{k}{k_s} - 1\right] \ln\left[\frac{R_s}{R}\right] \qquad (13)$$

A positive skin means a damaged zone (permeability reduced in the inflow zone) whereas a negative skin corresponds to an improved inflow zone. A positive (negative) skin will displace $Q_{\max}$ respectively to the left-hand (right-hand) part of the diagram. In other words, for a same BHP, an increasing positive skin will correspond to a lower flow rate (**Figure 2**).

Outflow performances

In the well (called the outflow zone), the flow is no longer governed by Darcy's law but by conventional pipe multiphase flow theory resulting in a complex mixture between pressure, viscous and gravity forces.

The Vertical Lift Performance (VLP - **Figure 3**) curve of a well expresses the BHP required to lift the fluid to the surface as a function of the flow rate Q. Each VLP curve corresponds to specific well operating conditions such as the well profile, tubing size and wellhead pressure but also depends on the fluid properties. In the *BHP/Q* diagram, the VLP curve has a U shape resulting from the superposition of two opposite effects (friction and gravity) which can be understood as follows:

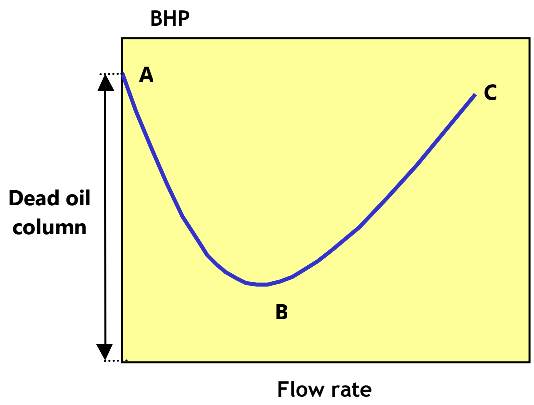

Figure 3 – Vertical lift performance curve

- at high flow rates, friction which grows with respect to flow rate governs the VLP curves (point C in **Figure 3**),
- as fluid continuously rises in the tubing, increasing amounts of gas come out of the solution and reduce the hydrodynamic weight of the column. Therefore, at medium flow rate values (point B in **Figure 3**), the average density of the fluids in the well is reduced and the same applies to BHP.
- however, at very low flow rate the gas bubbles slip through the oil and the weight of the fluid in the well bore gradually approaches the weight of a column of dead oil (point A of **Figure 3**)

The intersection of the VLP and IP curves (green star in **Figure 4**) determines a well's natural flowing condition. It is called the "operating point". In the *BHP/Q* diagram, any event occurring during the life of a well, either in the Reservoir Well Interface or in the well itself, will displace both the inflow and/or outflow curves and thus the functioning point with (positive or negative) consequences on flow.

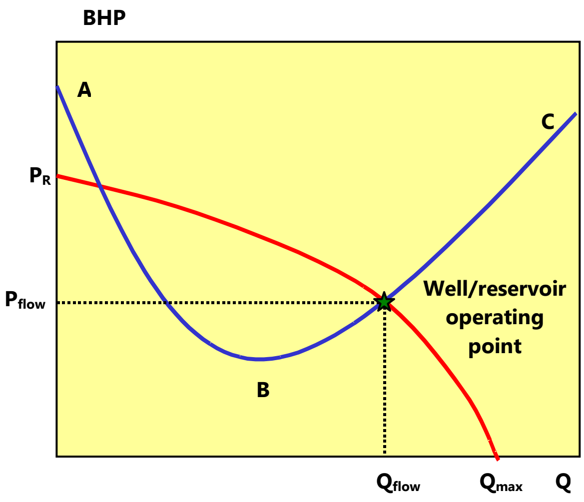

Figure 4 – Well operating point