Learn from the experts

Well Testing Network

Meeting, Oslo, September 2018

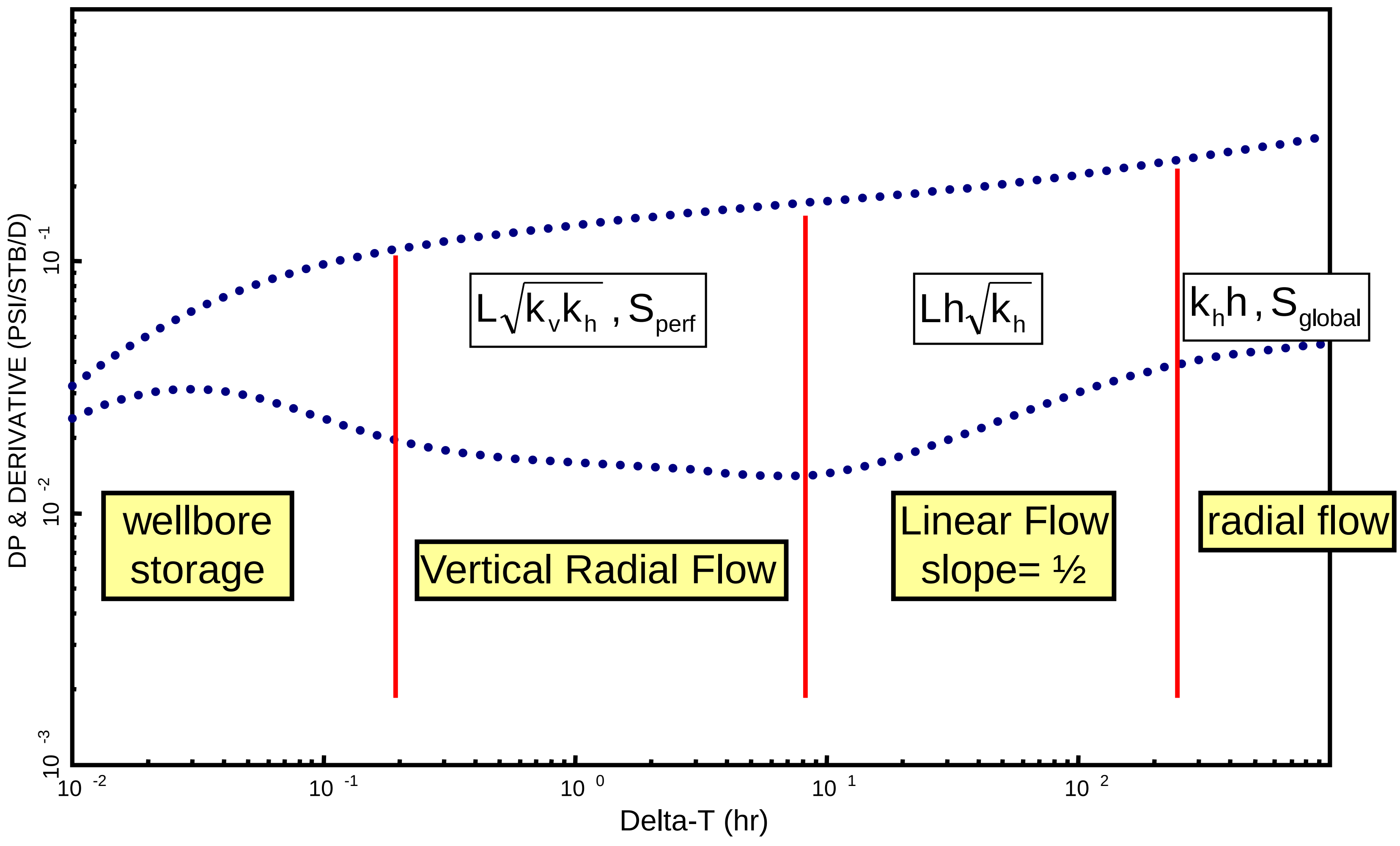
Horizontal Well Responses

by Piers Johnson of

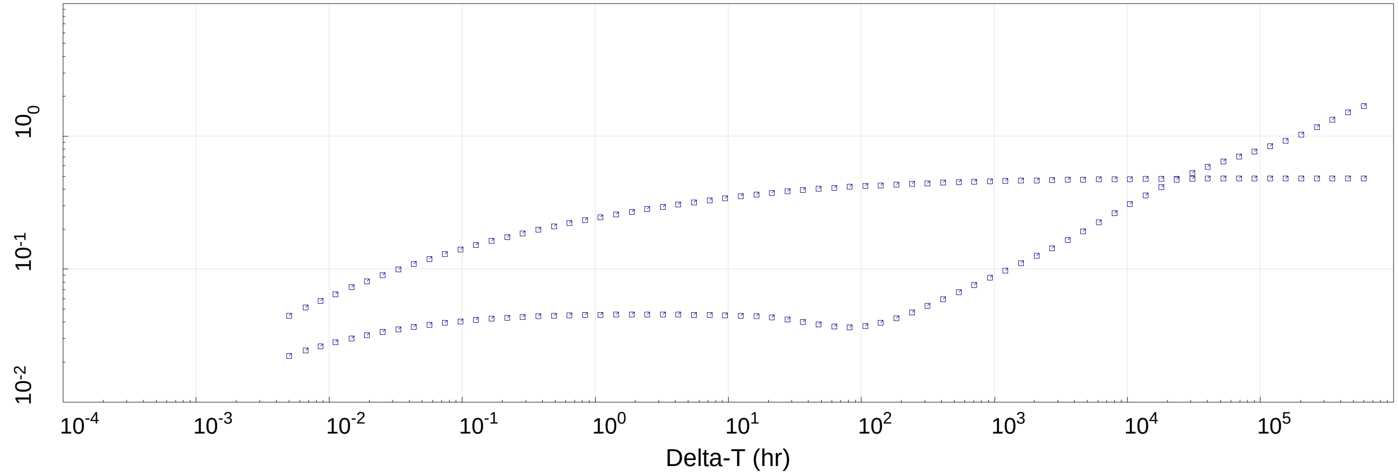
Oilfield Production Consultants (OPC) Ltd

ISO 9001:2000 1st POINT ASSESSMENT Registration No. 43049 Achilles

Derivative Plot Characteristics: Horizontal Well



Typical long horizontal well response



This log-log plot above represents an extremely long horizontal well in an oil field and is fabricated/synthetic data. This is of course rarely measured/seen. Points to note are:

- This is a VERY long Shut In (~600,000hrs)
- This is a relatively low permeability system (1-10mD)
- This is a VERY long horizontal sections (L=20,000')

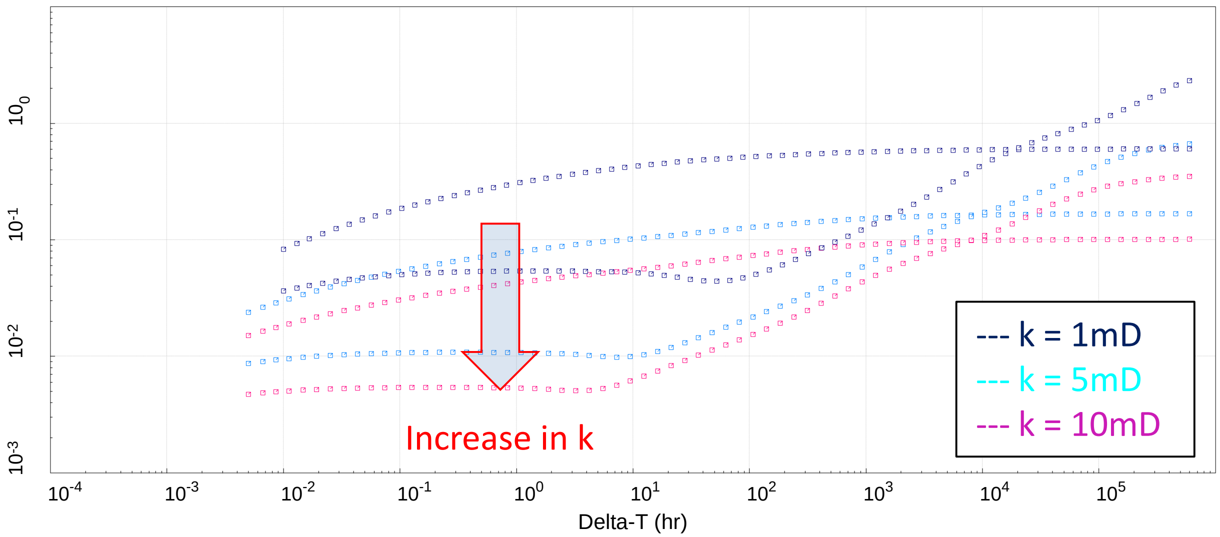
One thing to note in these examples is how the derivative curve crosses dP curve. This is due to a combination of:

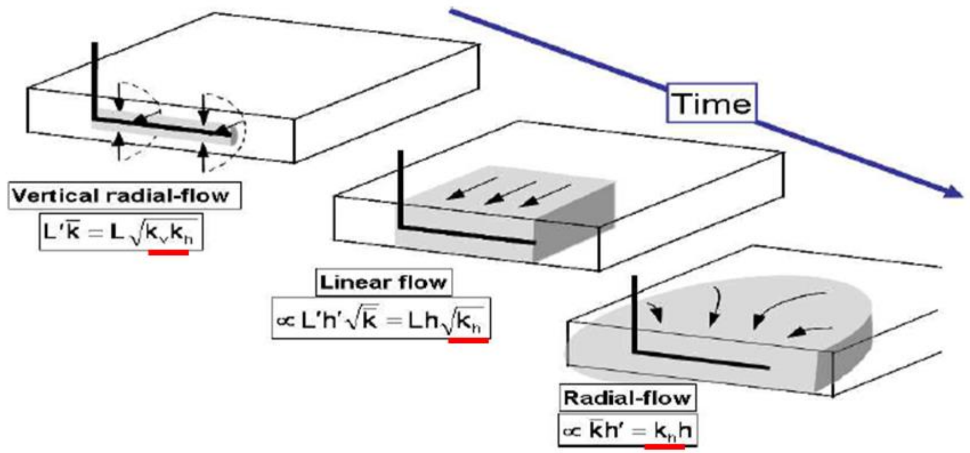
- Very low global skin from long horizontal section (20,000') and mechanical skin = 0.
- Low reservoir thickness.
- Very long shut in times.

Horizontal permeability changing

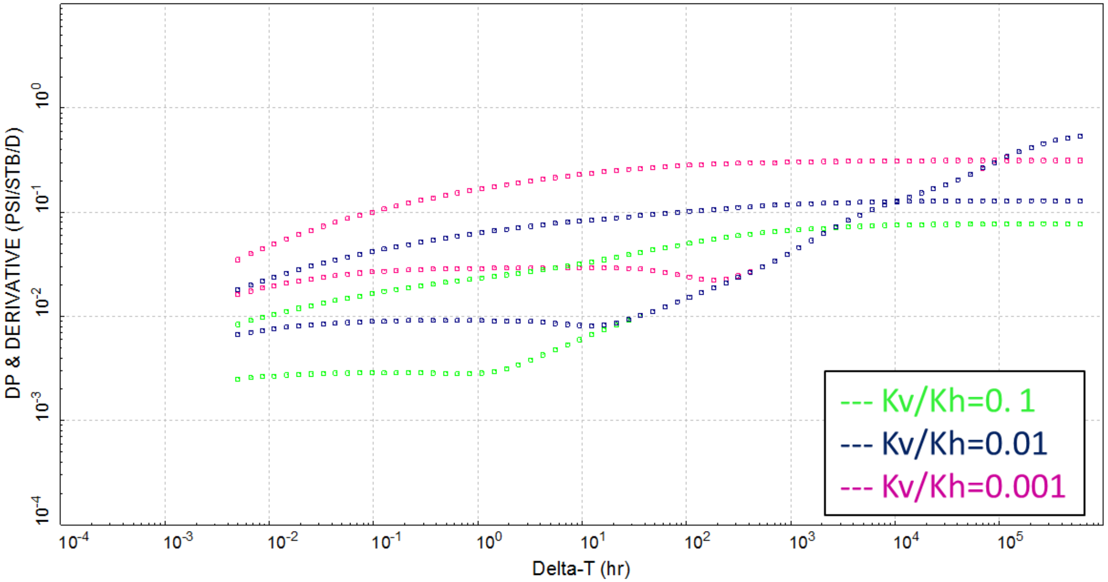
Horizontal permeability, k

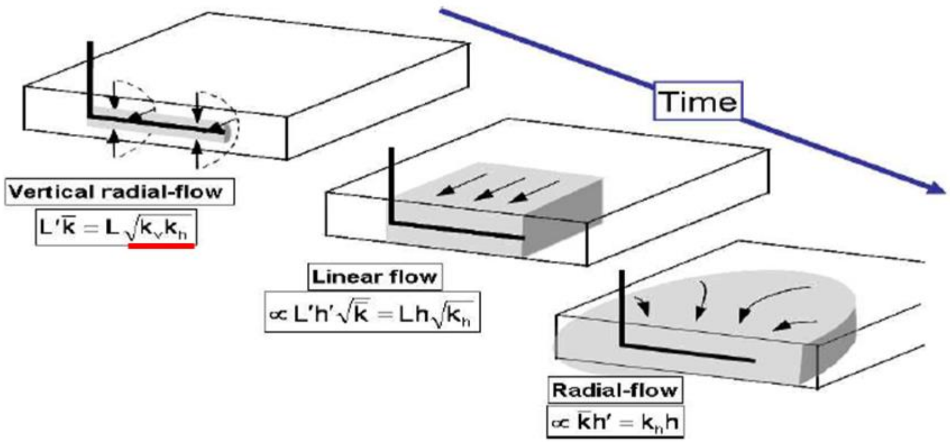
- Transition from vertical radial flow to linear flow regime (1/2 slope) occurs earlier when permeability is increased.
- The pressure transient moves faster in higher k mediums, according to hydraulic diffusivity/radius of investigation equations.
- Faster pressure transient means radial flow stabilisation observed in 5mD and 10mD cases. 1mD case shows no such flow regime transition. BU not sufficiently long enough which may lead to interpretation errors.
- This shows the challenge of using PTA to analyse horizontal wells tight reservoirs, particularly with v. long lateral sections.
- Downwards shift (increase in mobility) in all stabilisations due to increase in permeability. All flow regimes in reservoir are a function of horizontal permeability.
- MORE INFORMATION REQUIRED!





Changing kv/h

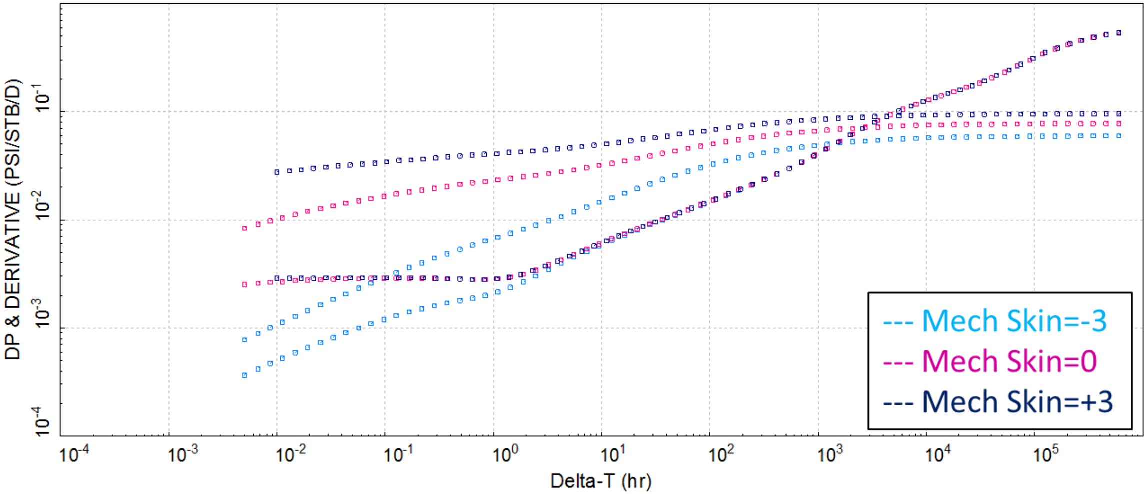


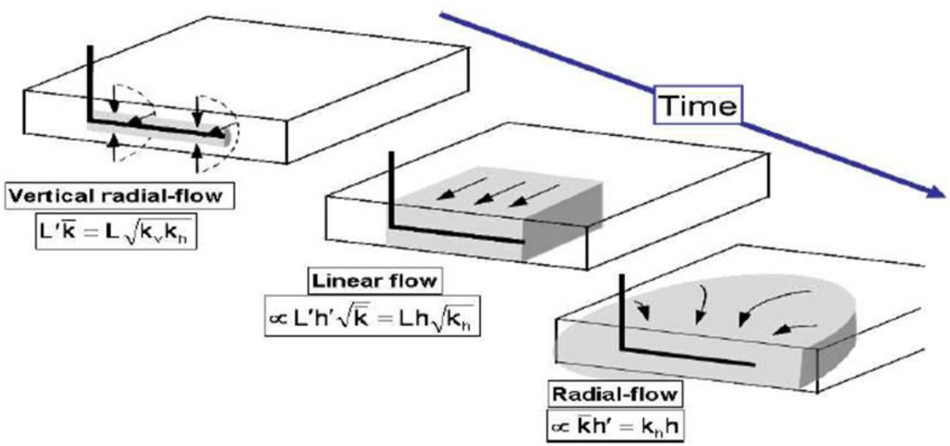


Sensitivity on kv/kh:

- Higher Kv/kh results in a lower vertical radial flow stabilisation.
- No vertical permeability results in a poor productivity well.
- Kv/Kh estimated by PTA is a global value, and is **often much less than the Kv/Kh estimated by core**. Any vertical heterogeneity, such as shale layers within a sand body (layering) can significantly impact this.

Mechanical skin changing

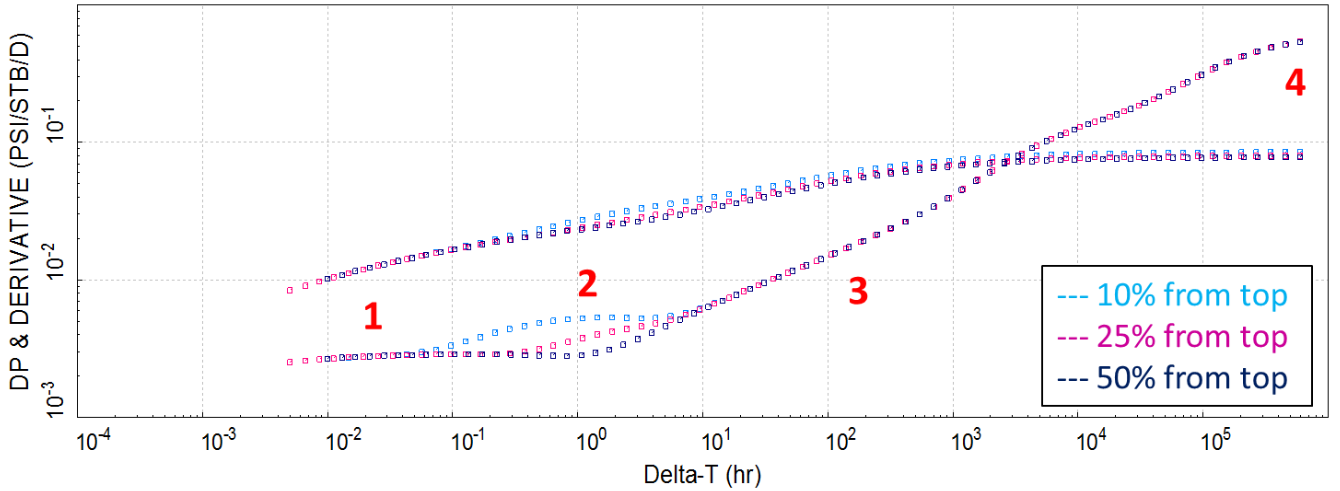


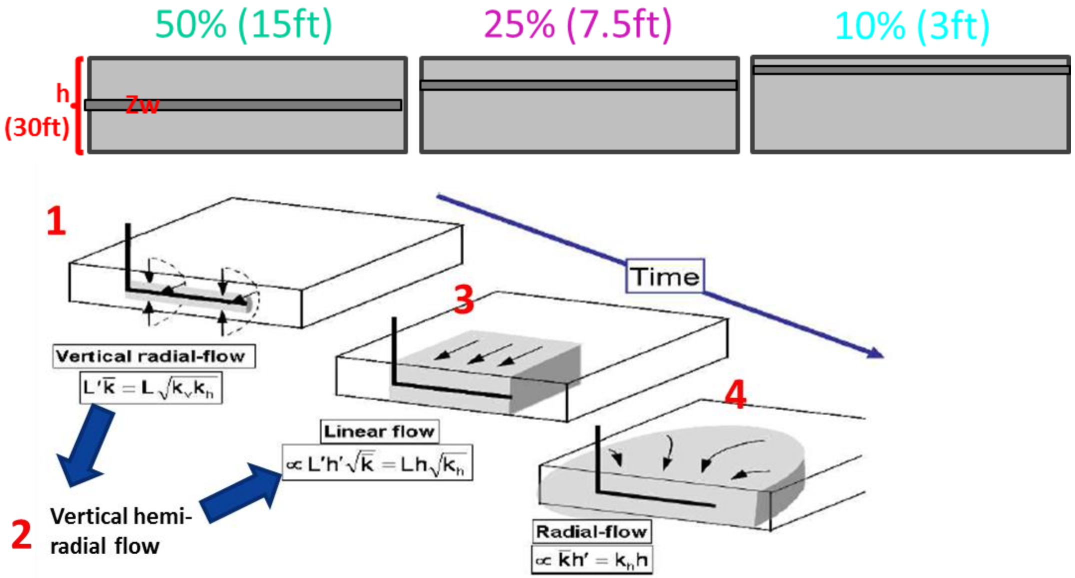


Mechanical Skin variation:

- With a mechanical skin of -3, there is a much faster transition between vertical radial flow and linear flow.
- Vertical radial flow is not observed in the light blue derivative (S= -3)
- With skin =0 and =+3, there is no change in the derivative character, however an increase in the Dp->Dp' distance is observed, characteristic of increased Global skin.

Well position in reservoir changing

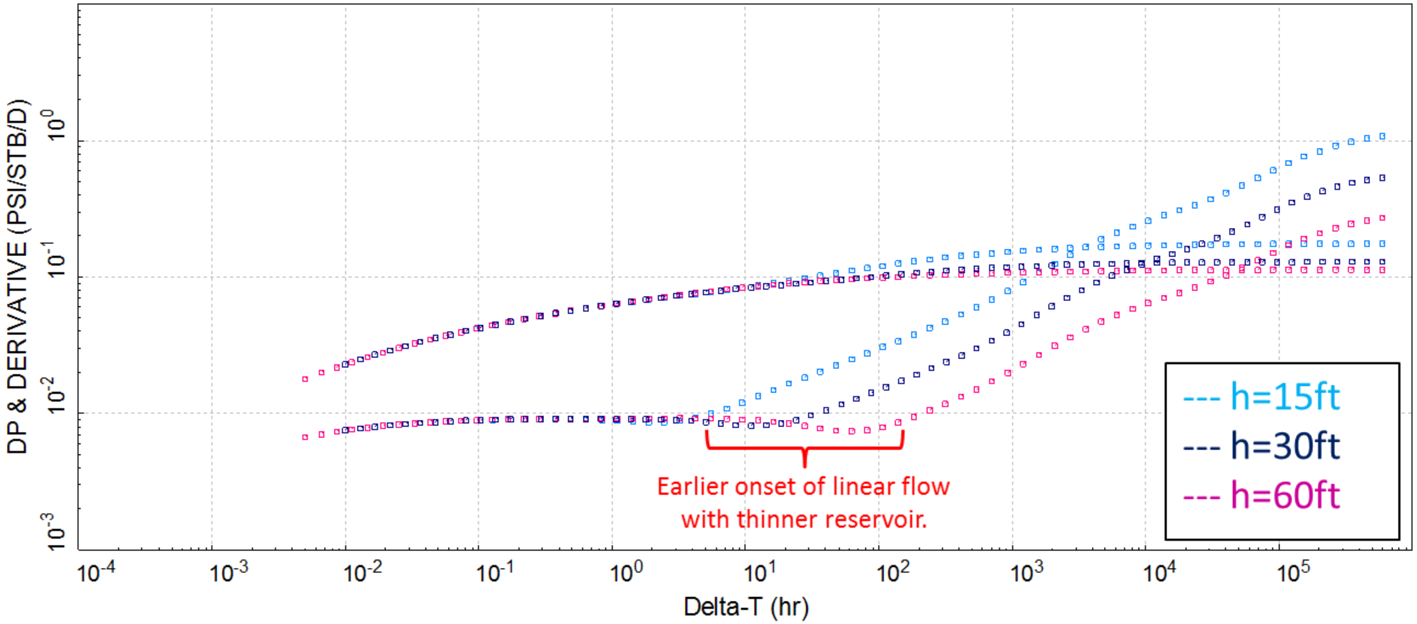


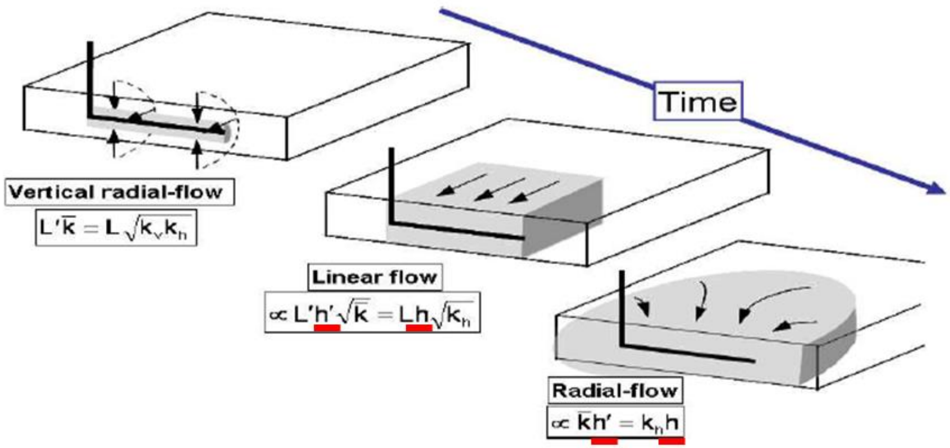


Position in reservoir (Zw/h):

- Transition from vertical radial flow to "vertical hemi-radial flow" when transient encounters the top of the reservoir but before the bottom is encountered (and subsequent transition to linear flow).
- Derivative character the same if distance from top 75% and 90% of h respectively.
- "Vertical hemi-radial flow" analogous to a vertical well offset in a channel.

Reservoir thickness changing

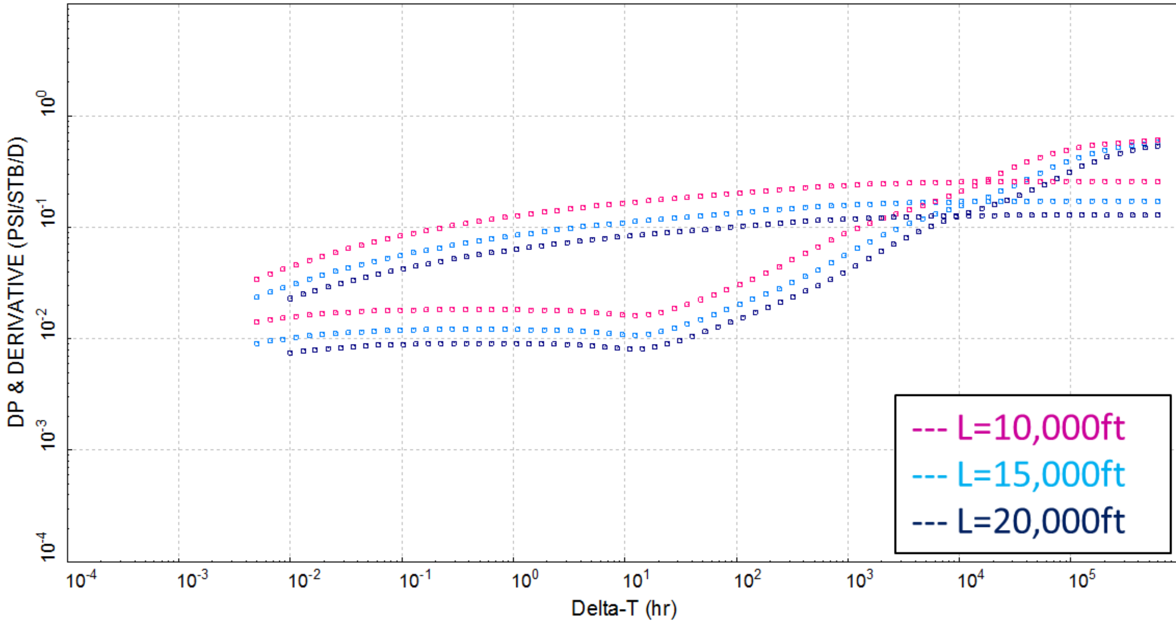




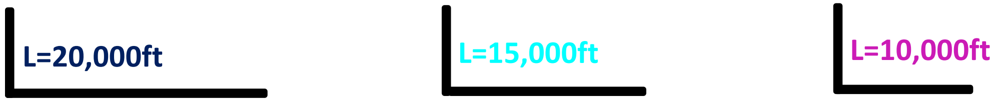
<u>Reservoir thickness, h:</u>

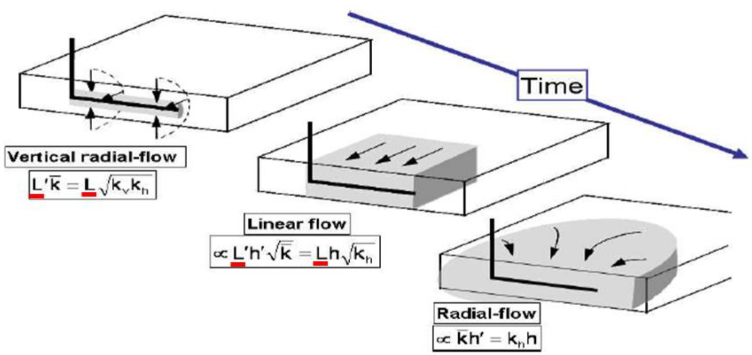
- Transient has less distance to travel to reach top of the reservoir, resulting in an earlier transition from vertical radial flow into linear flow.
- As h increases, kh of radial flow stabilisation also changes as a result.
- Vertical radial flow stabil is not a function of h, hence the overlap between cases, but both linear flow and radial flow are.

Horizontal drain length



Radial flow stabilisation level consistent despite changing L, but stabilisation occurs faster with lower L

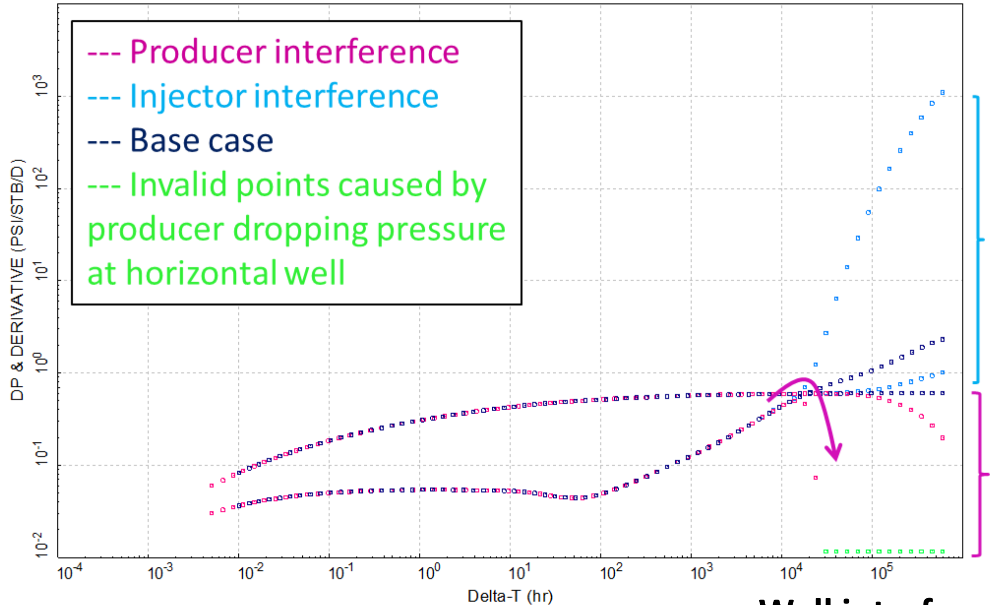




Horizontal length, L:

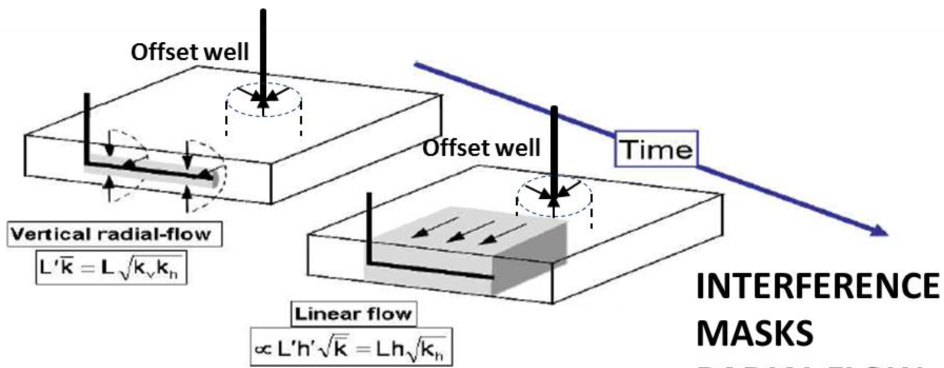
- Global skin increases as lateral length decreases. Radial flow not a function of L, whereas vertical radial flow and linear flow are.
- Shorter laterals display radial flow in shorter time, this is because the transient has shorter distance to travel before the transition to radial flow.
- Very common for horizontal wells not to produce over their full length, L.

Horizontal well with the interference effect



Derivative shows greater than unit slope upturn, caused by interference by **injector** at 7000ft.

Derivative roll-over due to drop in pressure in horizontal well caused by interference from **producer** at 7000ft.



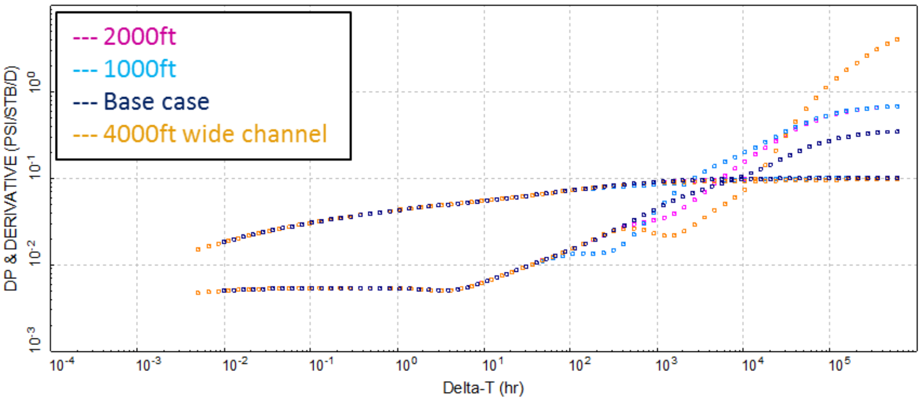
INTERFERENCE MASKS RADIAL FLOW BEHAVIOUR

Well interference:

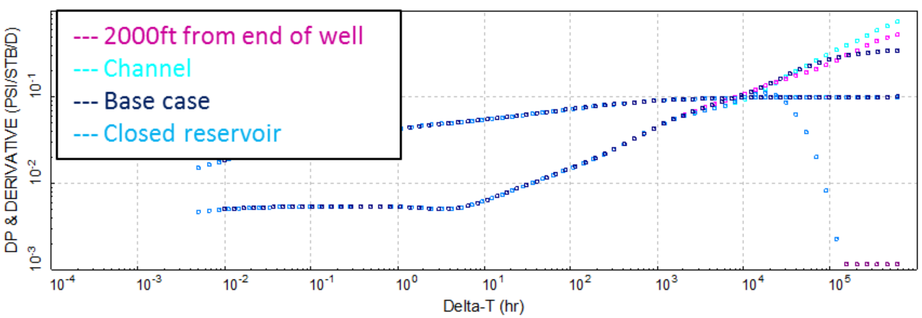
- Both producer and injector interference cases modelled.
- Time for offset well to influence shut in horizontal well can be estimated by radius of investigation equation (assuming the two are in communication).
- Interference can mask different flow regimes, potentially leading to incorrect interpretation.
- Field/well SI schedules can be timed/planned to optimise information gained from shut in.

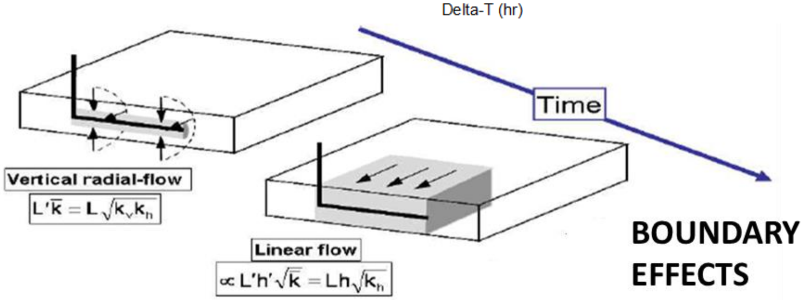
Boundary responses

Boundaries parallel to horizontal



Boundaries perpendicular to horizontal

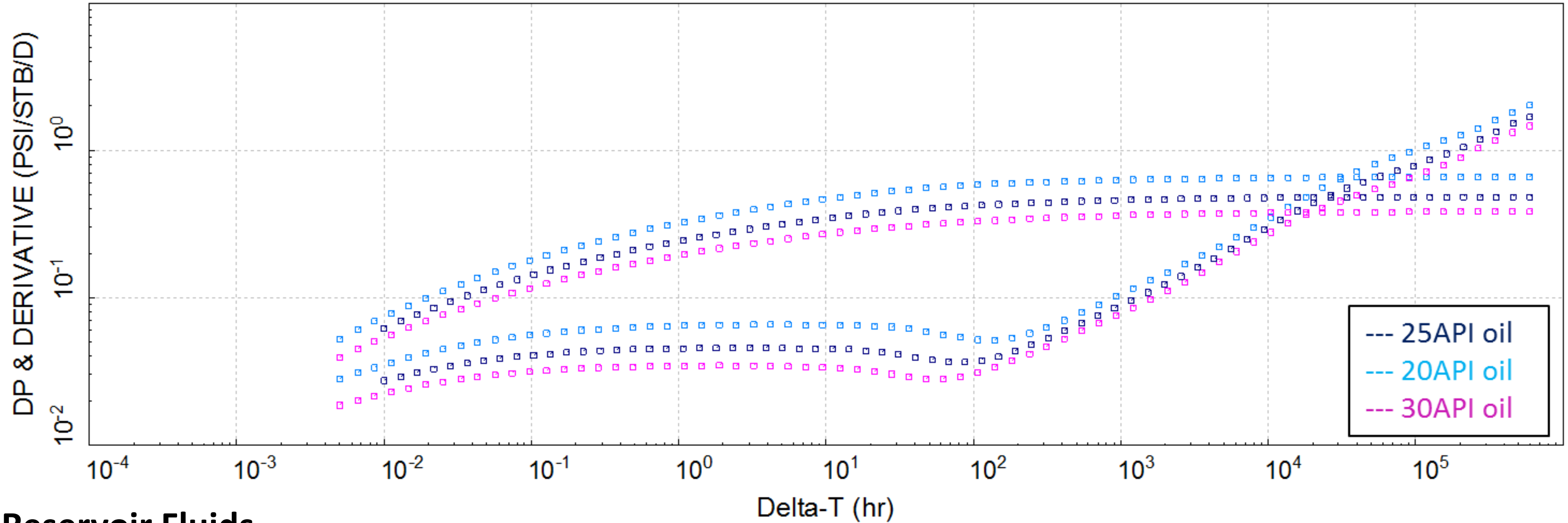




<u>Reservoir Boundaries:</u>

- 10mD case used to demonstrate changing stabilisation in late time better.
- Depending on distance from wellbore, these will mask radial flow stabilisation.
- When single boundary, a stabilisation observed with mobility 2x radial flow stabilisation, analogous to a single fault stabilisation in a vertical well system.
- This is a particular issue when horizontal section is v. long or the fault is close as the time taken to transition to radial flow is longer and the fault stabil may be misinterpreted as the radial flow stabil.
- Boundaries parallel and perpendicular yield different derivative characters.
- In the lower derivative plot, the boundary is further from the well, hence it affecting the derivative later.
- A horizontal well set in a perpendicular orientated channel shows an almost uniform linear flow ½ slope.
- Closed reservoirs have similar depletion derivative characteristics (roll-overs) as vertical wells.

Fluid properties changing



Reservoir Fluids

- Higher API oil has a lower viscosity and consequently a higher mobility.
- This results in a downwards shift in both stabilisations and upturns.
- 20API, SG= 0.75 Bo=1.05, GOR~625scf/bbl (Elsharkawy) Visc= 1.8cP (Beggs-Robinson), 1.69E-05 (Elsharkawy)
- 25API, SG= 0.75 Bo=1.1, GOR~650scf/bbl (Elsharkawy), Visc= 1.2cP (Beggs-Robinson), 1.74E-05 (Elsharkawy)
- 30API, SG=0.75 Bo=1.15, GOR~670scf/bbl (Elsharkawy), Visc=0.87cP (Beggs-Robinson), 1.78E-05 (Elsharkawy)
- For Bo correlations, Tres assumed 150F, calculated using a gradient of 1.5F/100ft and surface T of ~90F and an approximate depth calculated using a normal pressure gradient.

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(Alternative) Interference Testing

by Piers Johnson of

Oilfield Production Consultants (OPC) Ltd

9001:2000 Registration No. 43049

OPC UK LTD | 1 – 2 Apollo Studio, Charlton King's Road | London NW5 2SB | +44 (0)207 4281111 | london@opc.co.uk | www.opc.co.uk