Monitoring and Modelling Condensate Banking Effects with the Ichthys Field Production Data

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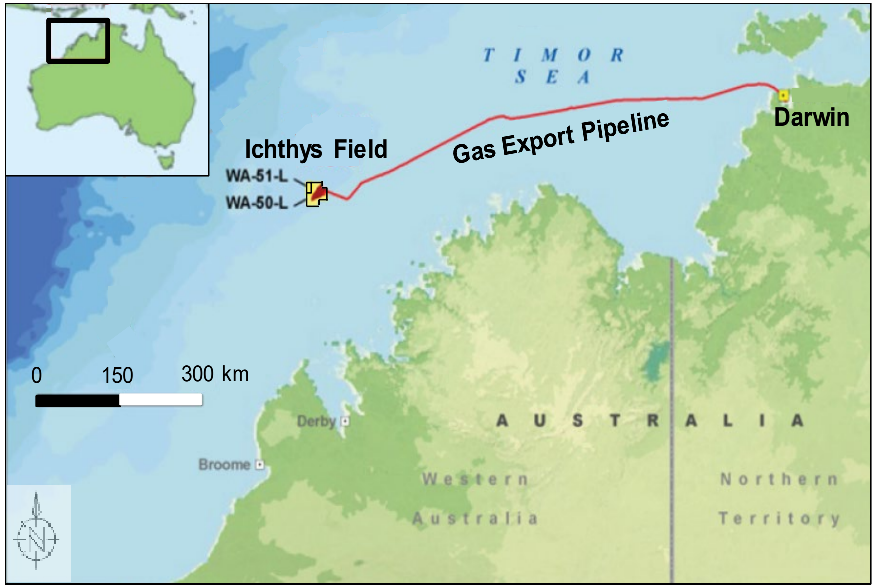
Agenda

- ❑ Introduction
- ❑ Condensate banking monitoring
- ❑ Well modelling for condensate banking effect
  - Workflow
  - Results
- ❑ Conclusions

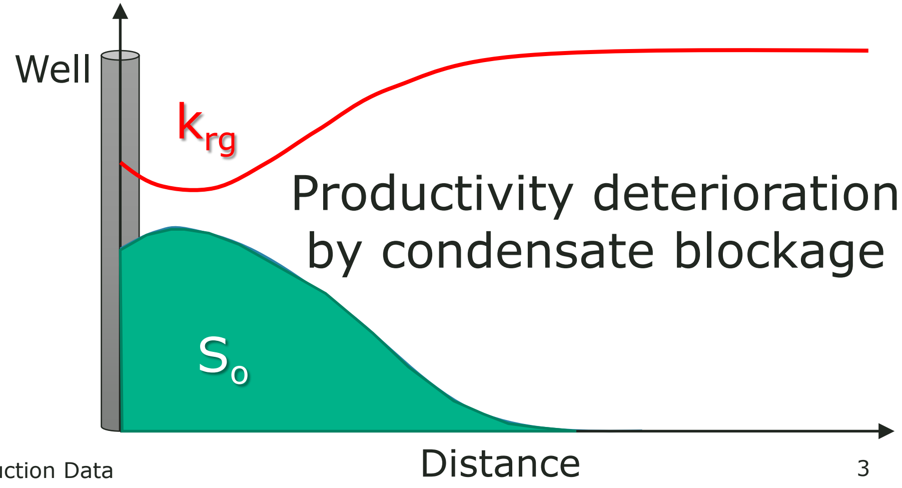
Ichthys Field – Brewster Member

- ❑ Commenced production in July 2018
- ❑ Relatively liquid-rich gas condensate field (sandstone)
  - CGR: ~50 stb/MMscf
- ❑ Uncertainty in condensate banking (CB) effect
- ❑ Subsea wells with permanent downhole gauge (PDHG)



Study Objectives

- ❑ Evaluate CB effect on well productivity
- ❑ Establish well modelling methodology to incorporate CB effect in full-field reservoir simulation

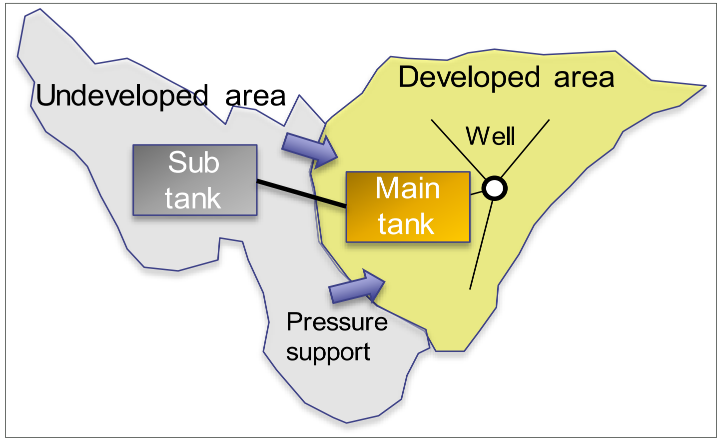


Reservoir Pressure Matching

- Conducted high rate test ($p_{wf} < p_d$)
  - Well A: Ave. k ~20 mD, 5-month test
  - Well B: Ave. k ~6 mD, 1-month test
- Productivity monitoring by deliverability plot, based on pseudo-steady state inflow equation

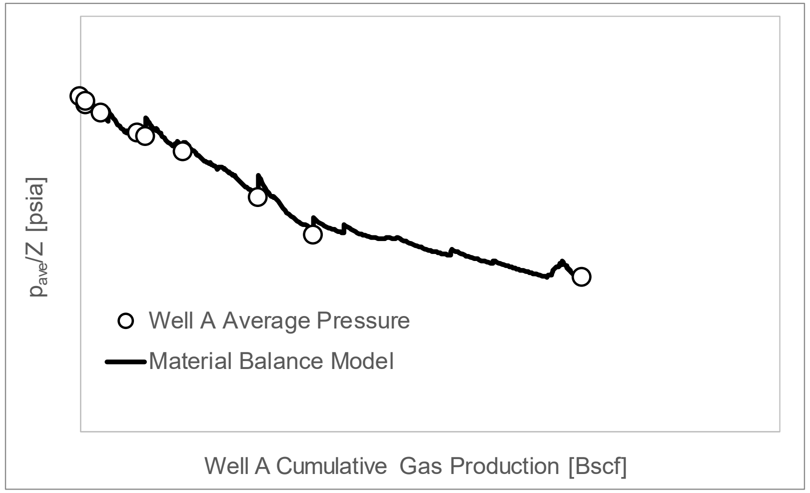
$$m(p_{ave}) - m(p_{wf}) = BQ_g + FQ_g^2$$

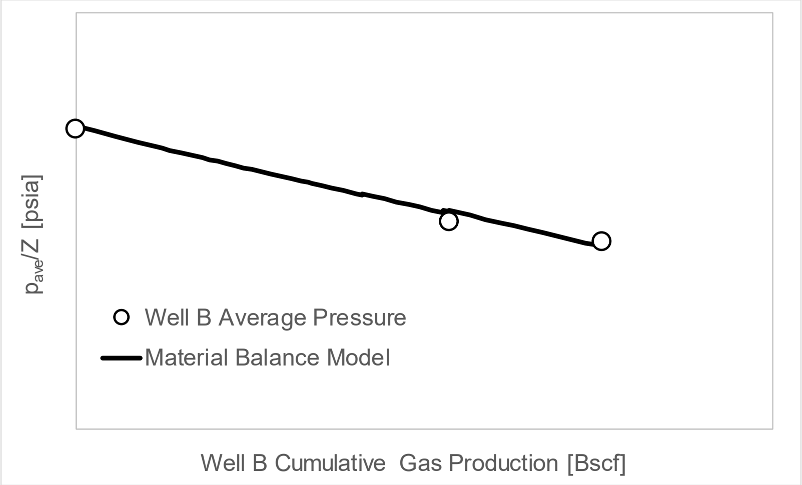
Material balance model



Adjust:
- Tank volume
- Inter-tank transmissibility

Reservoir pressure matching

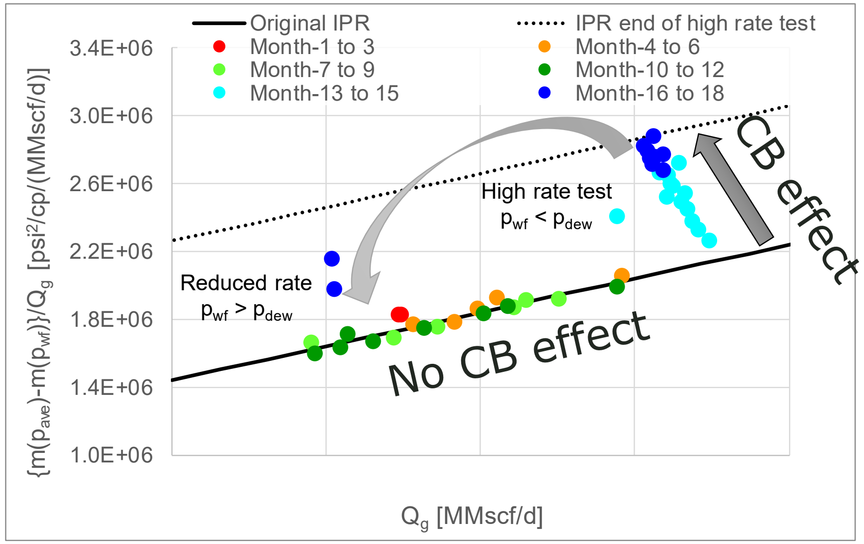




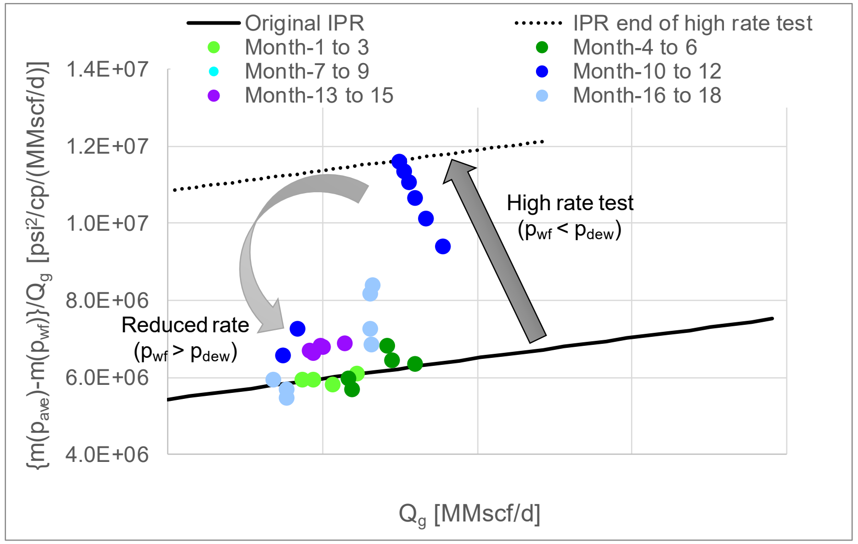
Condensate Banking Monitoring
Impact on Productivity

Deliverability

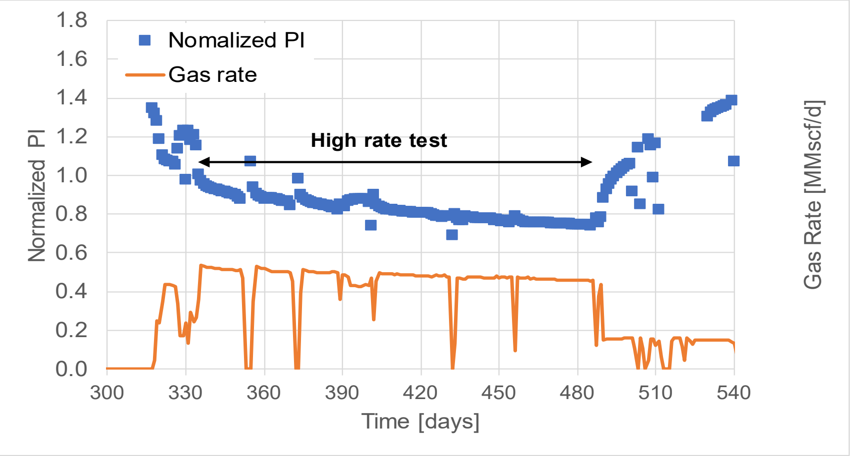
Well A

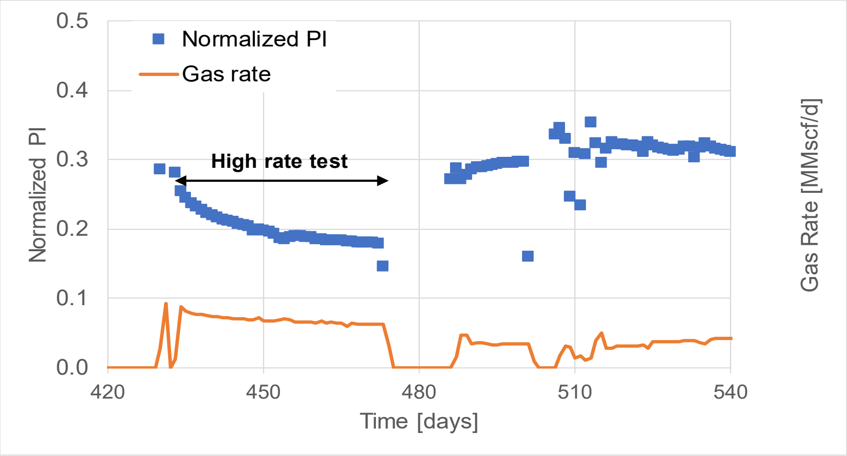


Well B



PI vs. Time





- Clear productivity deterioration once p_{wf} < p_d, while reverted closely to original after rate reduction.
- Productivity loss by 25% (Well A) / 40% (Well B) during the test

→ Larger impact on lower permeability well

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- ❑ Introduction
- ❑ Condensate banking monitoring
- ❑ **Well modelling for condensate banking effect**
  - **Workflow**
  - **Results**
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Well Modelling Options

Generalized Pseudo Pressure (GPP) option

Fevang and Whitson 1996

$$q_g = C \int_{p_{wf}}^{p_R} \left(\frac{k_{ro}}{B_o \mu_o} R_s + \frac{k_{rg}}{B_{gd} \mu_g} \right) dp$$

- Available in commercial reservoir simulator
- Takes account of CB effect even with coarse grid
- Requires relative permeability to be tuned for history matching

Local Grid Refinement (LGR) near wellbore with Velocity Dependent Relative Permeability (VDRP)

- Most accurate approach to account for CB effect
- Impractical to apply to full-field model due to prohibitive computing time

Skin correlation to mimic CB effect

- Practical method to be implemented in full-field model
- Flexible to tune when simulated flowing bottomhole pressure (FBHP) is deviated from observation

Well Modelling Workflow

Compositional Sector Modelling

- LGR
- Velocity Dependent Relative Permeability (VDRP)

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Condensate Banking Skin Correlation

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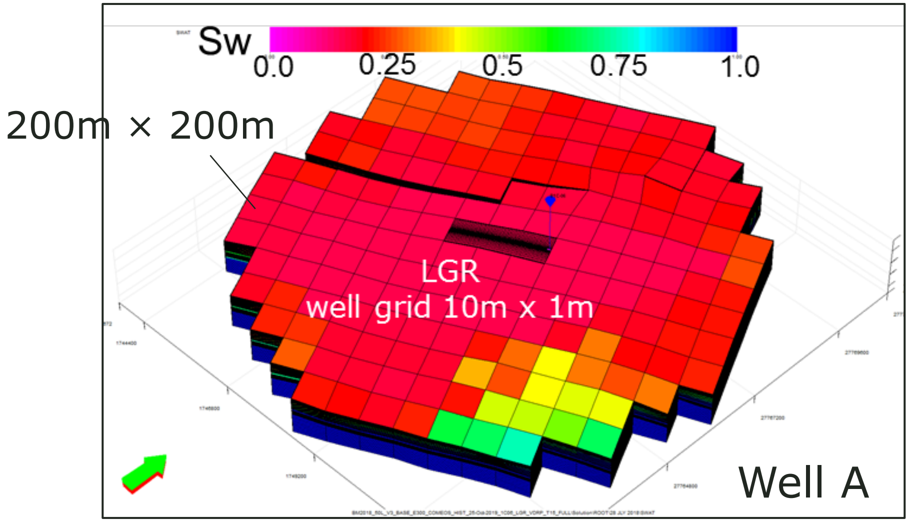
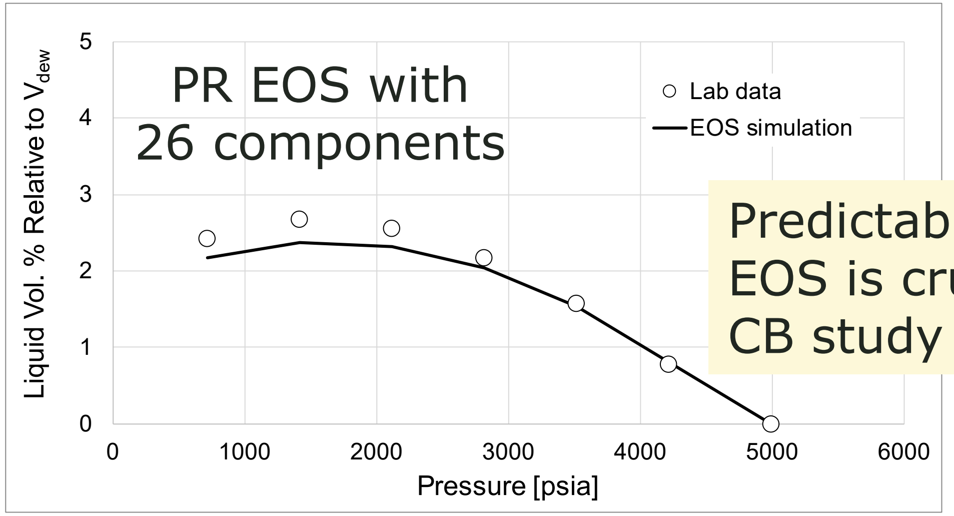
Application of Correlation to Full-Field Black-Oil Model

Compositional Sector Modelling

LGR applied to well grids



EOS modelling



Predictability of EOS is crucial for CB study

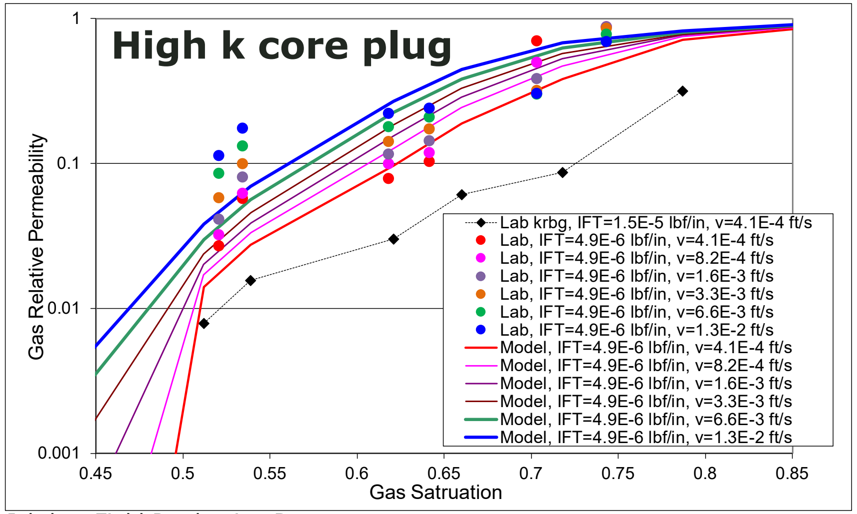
VDRP correlation

$$N_c = \frac{v_g \mu_g}{\sigma}$$

$$k_{rvp} = N_{cn}^{1/n_p} k_{rbp} + \left(1 - N_{cn}^{1/n_p}\right) k_{rmp}$$

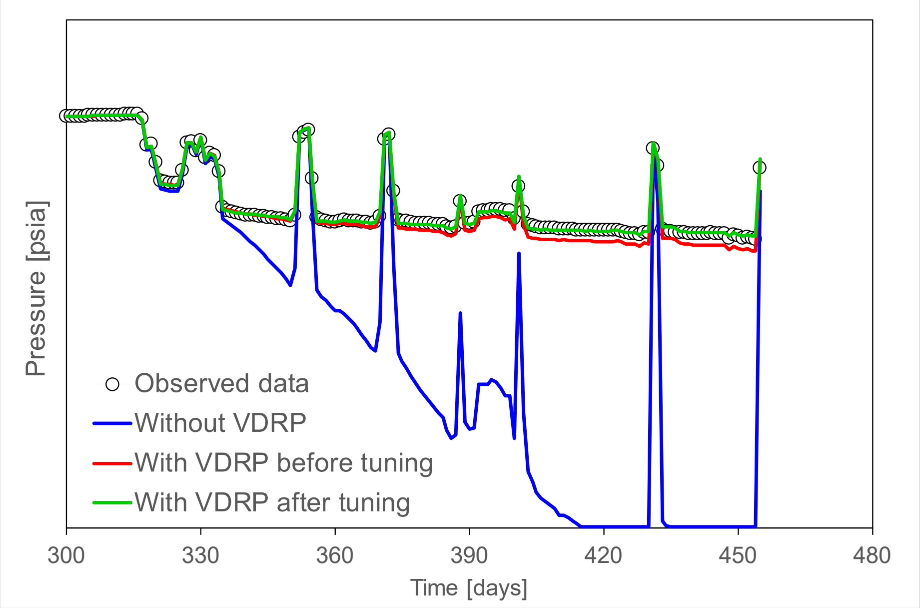
$$n_p = n_{1p} S_p^{n_{2p}}$$

Coefficients based on lab measurements

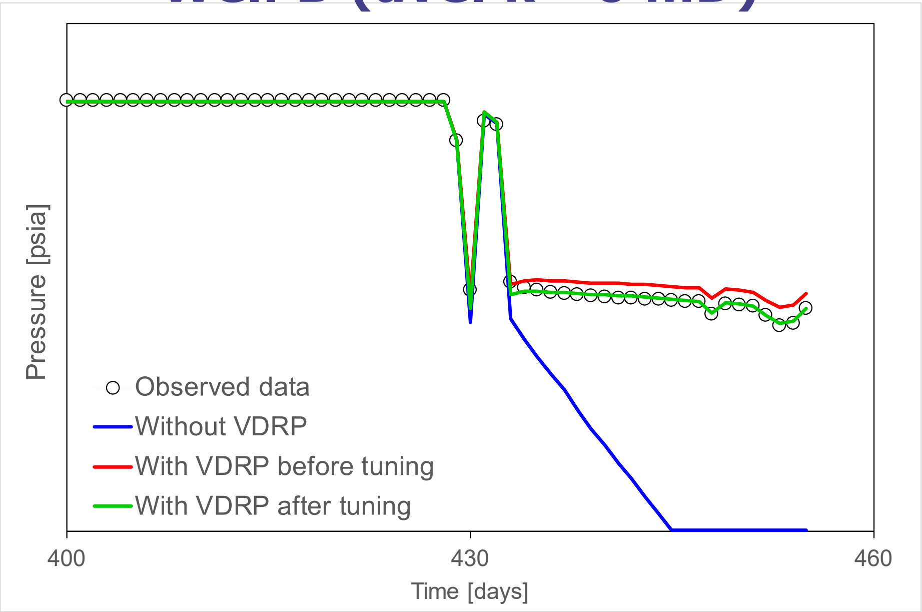


Compositional Sector Modelling

Well A (ave. k ~20 mD)



Well B (ave. k ~6 mD)



Tuned VDRP parameters

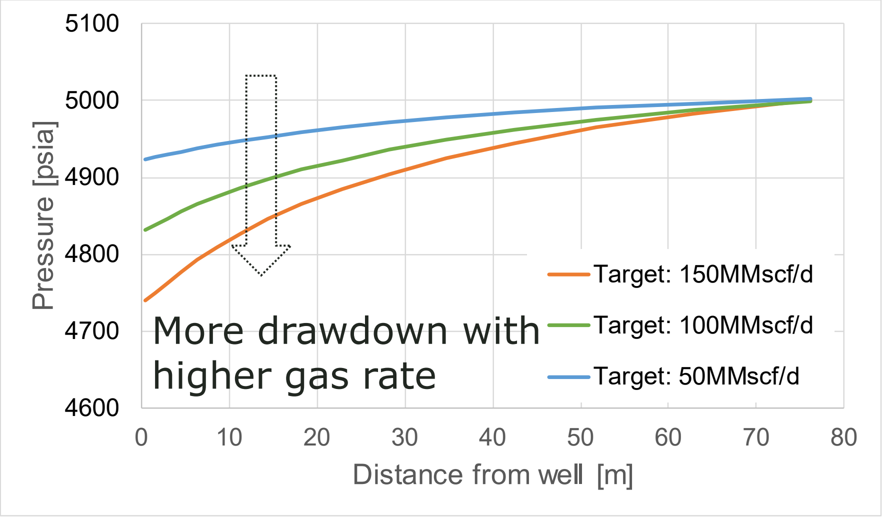
Saturation Table Region	Permeability Range	m_g	n_{1g}	n_{2g}	m_o	n_{1o}	n_{2o}	N_{cb}
1	> 50 mD	100	3.00	-5.00	1.86	0.526	-3.71	2.00E-8
2	10 – 50 mD	100	3.00	-5.00	1.60	0.367	-3.84	2.00E-8
3	2 – 10 mD	47.6	33.4	-0.146	13.4	0.171	-14.7	2.00E-8
4	0.5 – 2 mD	100	100	-0.104	13.4	0.116	-15.3	2.00E-8

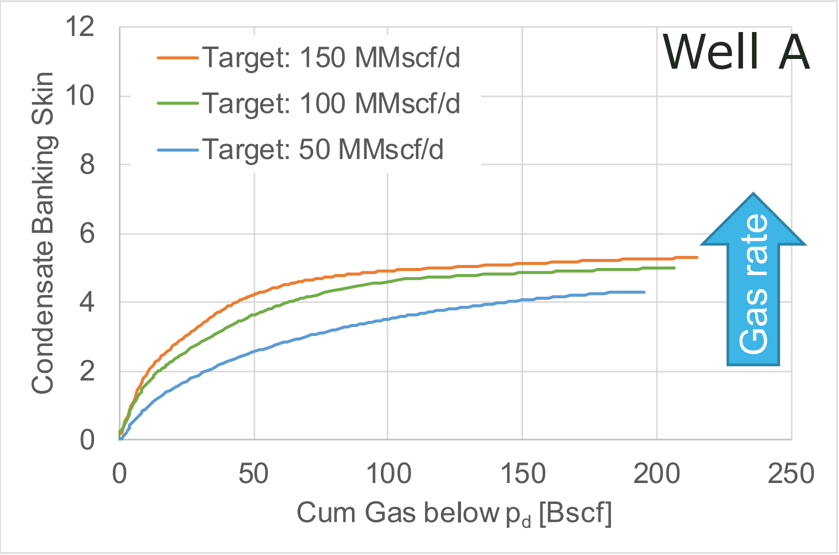
Saturation table region	Permeability range	m_g	n_{1g}	n_{2g}	m_o	n_{1o}	n_{2o}	N_{cb}
1	> 50 mD	100	0.146	-10.6	1.86	0.526	-3.71	5.00E-7
2	10 – 50 mD	100	3.00	-10.0	13.4	0.171	-5.00	5.00E-7
3	2 – 10 mD	100	3.00	-10.0	13.4	0.171	-5.00	5.00E-7
4	0.5 – 2 mD	100	3.00	-10.0	13.4	0.171	-5.00	5.00E-7

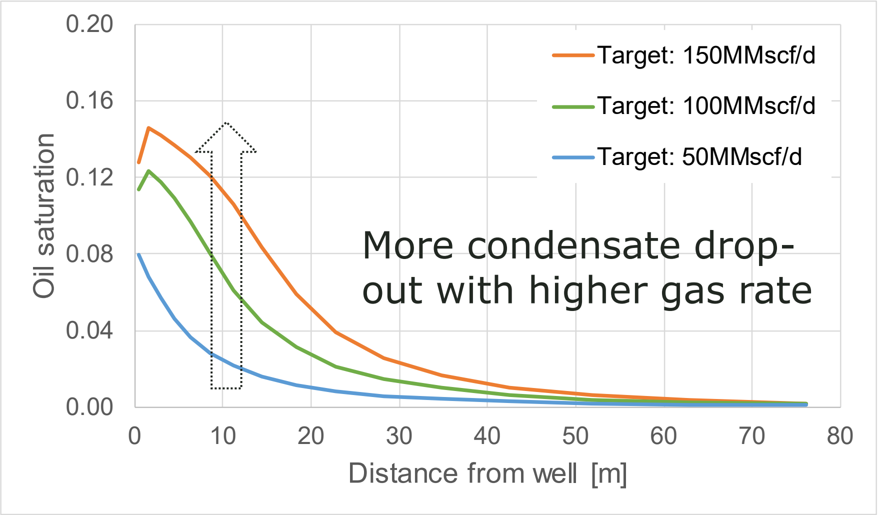
Reasonable history match with VDRP after tuning lab-derived parameters.

Condensate Banking Skin Correlation

- Use matched compositional sector model to investigate skin increment below p_d with a different target gas rate.
- **Higher gas rate leads to quicker skin increment.**
  - Higher the gas rate is, larger pressure drawdown near the wellbore is, dropping more condensate.







Condensate Banking Skin Correlation

CB Skin Correlation

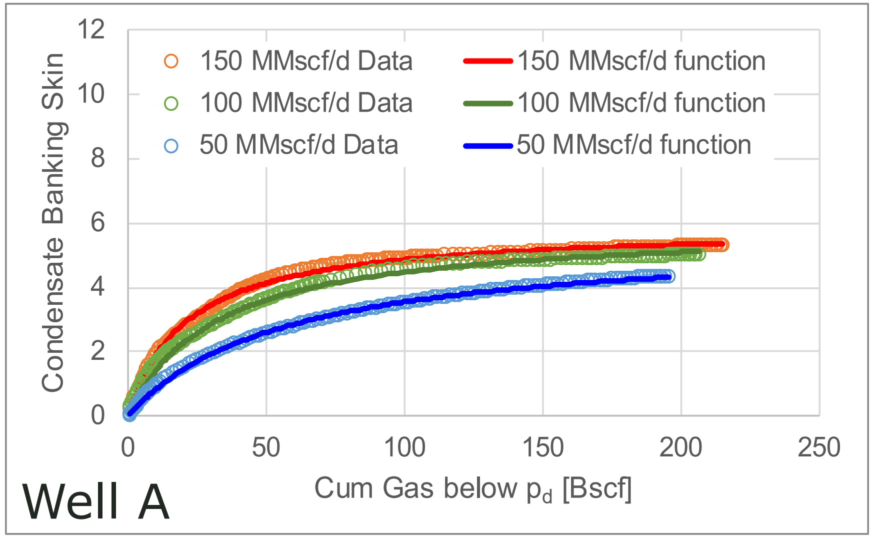
$$s_{CB} = \frac{bG_p}{1 + aG_p}$$

$$a = a_1 Q_g + a_2$$
$$b = b_1 Q_g + b_2$$

} Dependent on gas rate

G_p: Cumulative gas production below p_d

accounts for depletion and time dependency

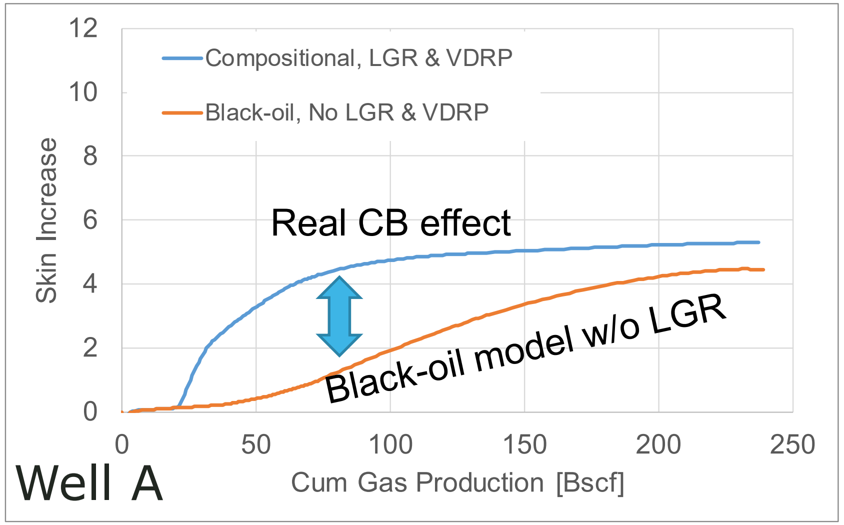


Pseudo-skin for CB effect in black-oil model w/o LGR

$$s_{BO} = \frac{d}{1 + e^{-c(G_p - f)}} - s_{BO}(0)$$

$$s_{PCB} = s_{CB} - s_{BO}$$

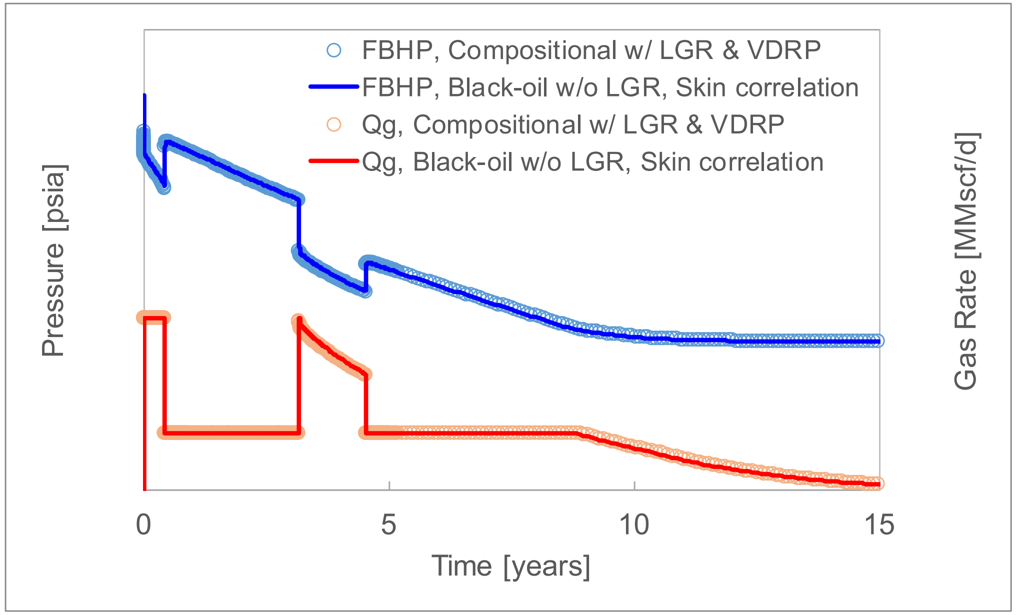
To avoid double count of condensate blockage in black-oil model w/o LGR



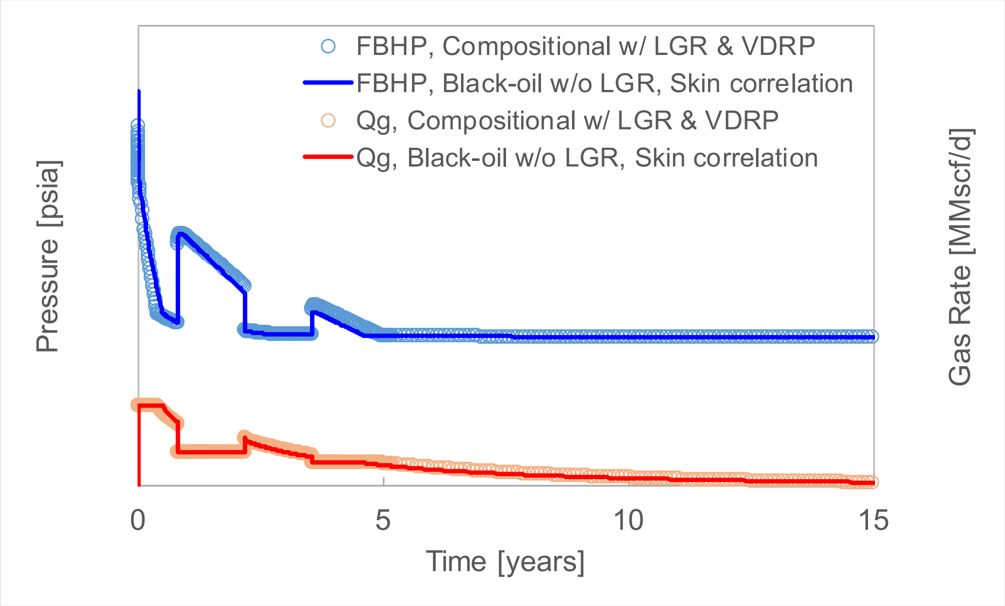
Condensate Banking Skin Correlation

- Compare black-oil simulation with skin correlation to compositional simulation with LGR and VDRP (single well sector model)
  - Use test schedule for validation of skin correlation

Well A (ave. k ~20 mD)



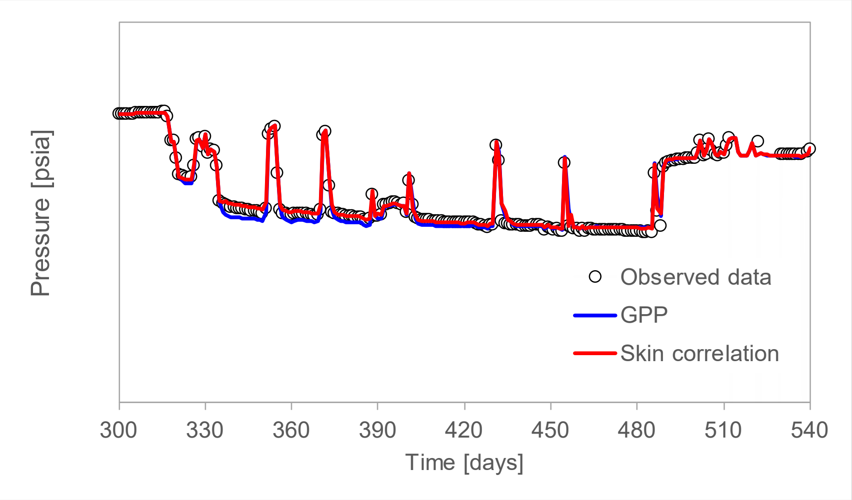
Well B (ave. k ~6 mD)

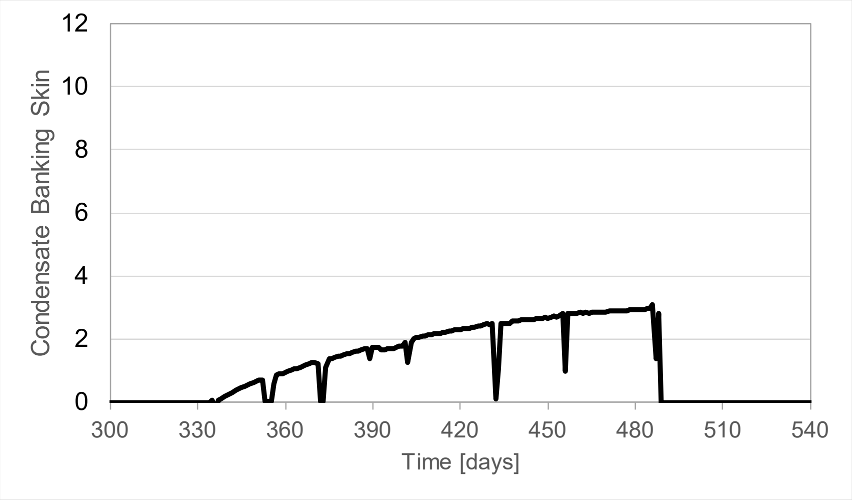


Skin correlation reasonably mimics the condensate blockage simulated by compositional model with LGR and VDRP.

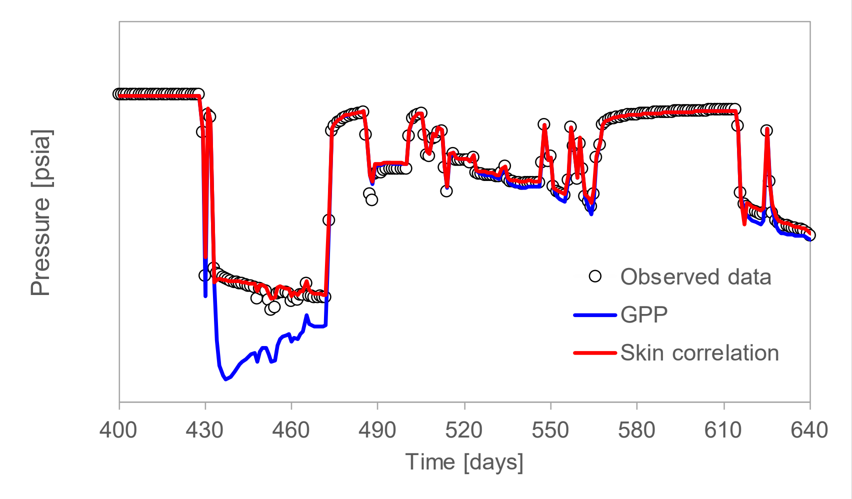
Application of Correlation to Full-Field Black-Oil Model

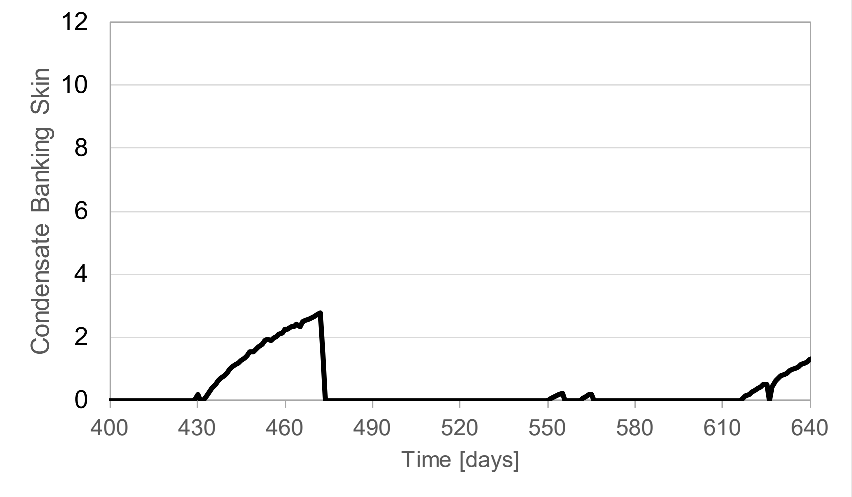
Well A





Well B





- Skin correlation accurately replicates the observed data.
- It is difficult to history-match for well B with GPP option.

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Conclusions

- Monitored productivity impairment by condensate banking during high rate test.
  - Clear deterioration once p_{wf} < dew point, while reverted closely to original productivity after rate reduction.
  - Loss of productivity during the test by 25%-40%, larger impact on lower permeability well.

- Established well modelling method to incorporate CB effect in full-field black-oil model.
  - Created skin correlations as function of cumulative gas production below dew point and gas rate. Confirmed the correlations accurately replicated CB effect.
  - Will investigate whether the correlations for specific wells are applicable to other wells in the field.

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Thank you

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Q&A