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Effect of Soaking Process on Shale Gas Well Performance

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KFUPM University

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Outline

- Introduction
- Observations
- Well performance Analysis
- Experimental Investigation
- Well Screening for soaking
- Conclusions

Introduction

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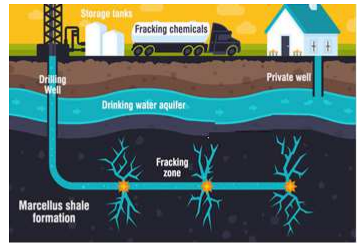
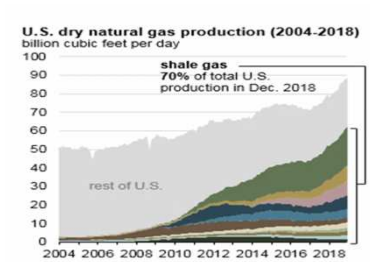
- Hydraulic fracturing is a well stimulation technique usually on shale and tight sandstone formations.
- Different fracturing fluids have been used including slick water, polymer-based, and foam-based fluids
- Fracturing fluid leak-off occurs, and it can exceed 70% of the injected volume





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Introduction

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- In shale wells, small percent of the injected Frac fluid is recovered

Injection Volume (bbl)	Flowback Recovery	Shut-In Duration (days)	Formation
37,740-157,250	5%	N/A	Haynesville
484,330 (mean)	13%	60 (18 wells)	Horn River
100,640-163,540	1-50%	0-144 (189 wells)	Marcellus
69,190-144,670	65% (1st year)	N/A	Barnett

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Well Life Stages

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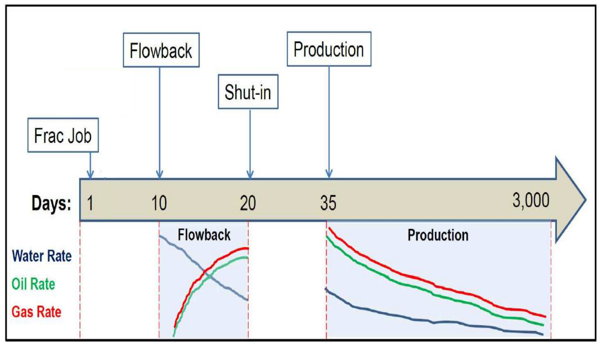
- Frac job stage, This process involves pumping large volumes of water with different types of proppant
- Well flowback removes most of the movable water
- Shut in due to pipeline restrictions.
- Then the production stage

The sequence of events during the production life of a well from hydraulic fracturing to production stage



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Field Observations

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- Recently, in some shale formations, operators have observed improved well performance after an extended shut-in period following the initial flowback of a well.
- The time between flowback shut-in to first production has an impact on early production rate and ultimate performance, sometimes adversely, sometimes beneficially, Crafton (2010)
- The flowback water tends to be highly saline compared with actual injected fluid.
- Then the industry called Soaking

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WELL PERFORMANCE INVESTIGATION

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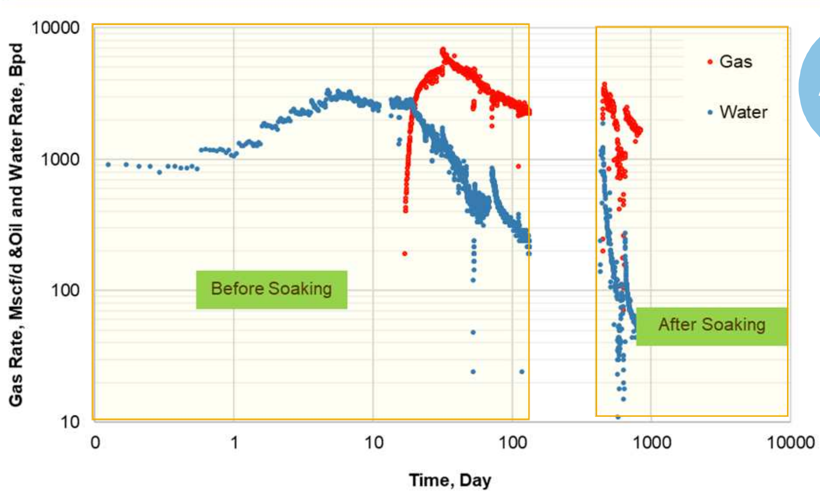
Production Analysis



Analysis

RTA

DCA

Analysis

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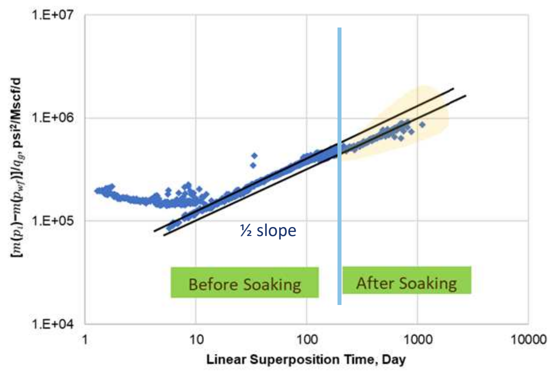
- Rate transient analysis (RTA) was conducted in the production data before and after the soaking process to estimate the change in the stimulated area.

$$\frac{\Delta m(p)}{q} = \frac{1261.7308\,T}{\sqrt{k}\;A_C\,\sqrt{(\phi\mu c_t)_i}}\ \sup\left(\sqrt{t}\right)\ + Const * s_f$$

$$A_C = 4N_f x_f h_f$$



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Analysis

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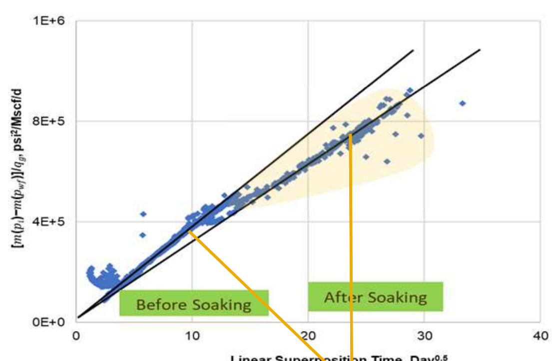
- Rate transient analysis (RTA) was conducted in the production data before and after the soaking process to estimate the change in the stimulated area.

$$\left[m(p_i) - m(p_{wf})\right]/q_g\ vs.\sqrt{t}$$

$$\sqrt{k}A_C = \frac{1261.7308}{\sqrt{(\phi\mu c_t)_i}}\left\{\frac{T}{m_{CP}}\right\}$$



$$(\sqrt{k}A_C)_r = \frac{m\ before\ soaking}{m\ after\ soaking}$$

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Analysis

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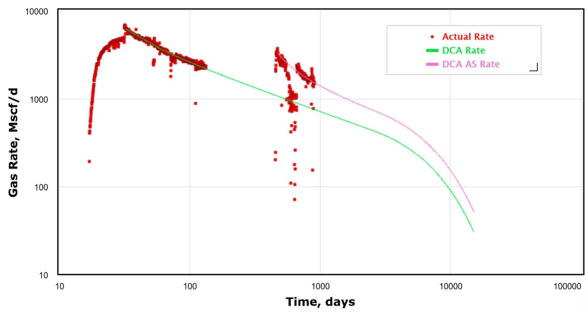
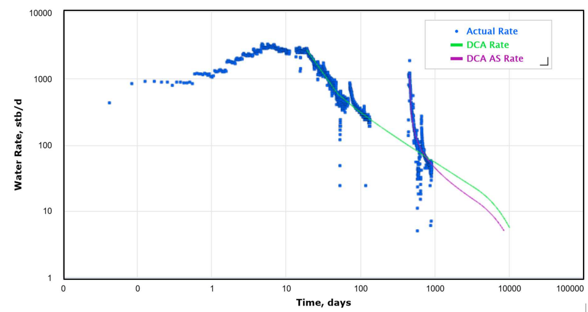
- Decline curve analysis for the gas and water rates was conducted for the production data before and after the soaking time.





$$EUR_{rg} = \frac{EUR_{gAS}}{EUR_{gBS}}$$

$$EUR_{w}\ reduction = \frac{EUR_{wAS}}{EUR_{wBS}}$$

Results

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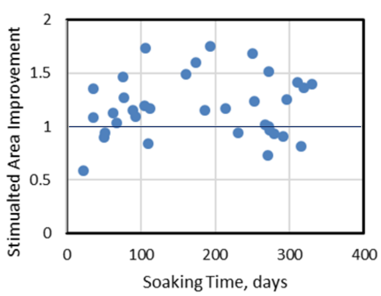
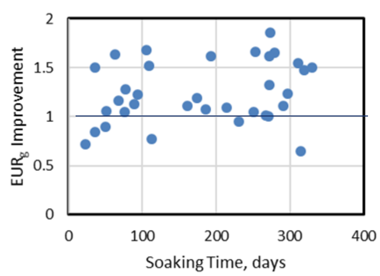
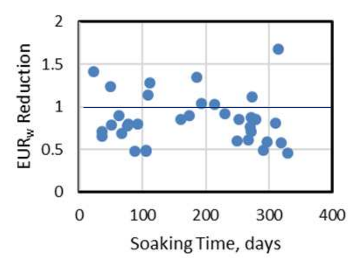






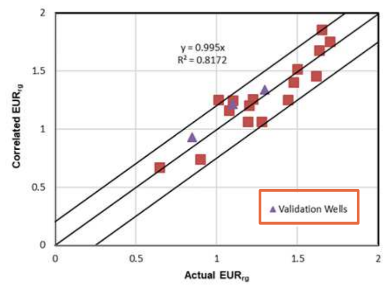
- Most of the wells show an increase in the stimulated area and EURg associated with a reduction in water recovery after well shut in.

12/6/2021

Correlation Development

Genetic optimization algorithm was used to generate a correlation for the change of EUR_g with soaking process.

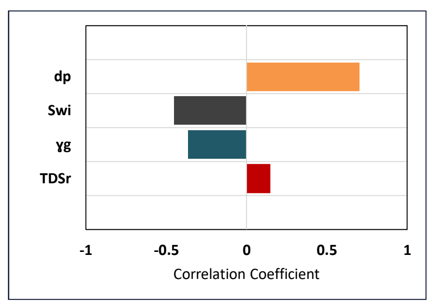
$$EUR_{rg} = \left(-0.6104\, S_{Wi}^{\,dp_G} + 0.0045\, TDS_r + \frac{0.5254}{\gamma_g}\right) \times dp_G \times (t)^{0.183}$$



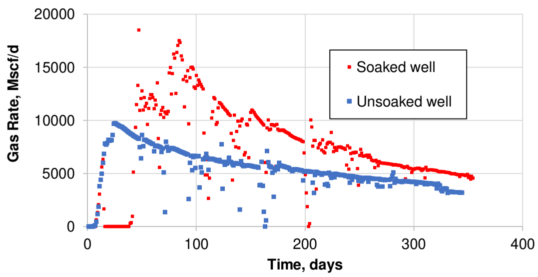
- S_{Wi} is initial water saturation (volume fraction)
- TDS_r is the salinity ratio between the formation water and the frac fluid
- γ_g is the gas specific gravity
- dp_G is the formation pressure gradient divided by the normal hydrostatic pressure gradient for freshwater (0.433 psi/ft)

Sensitivity Analysis

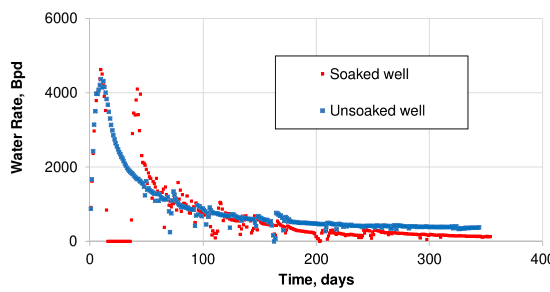
- Formation pressure gradient is the more effective parameter on the well performance after soaking, followed by water saturation and gas specific gravity which is an indication for the thermal maturity for the formation.
- Salinity difference between the injected fluid and the formation water has the lowest effect on the well performance with soaking.



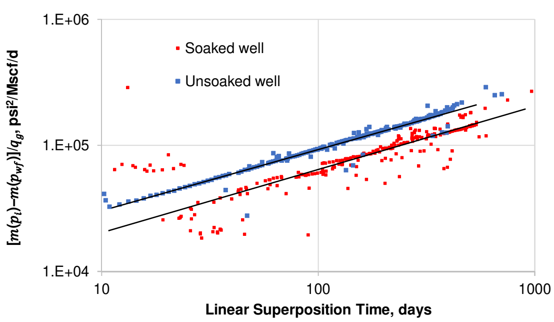
Comparison Between Soaked and Unsoaked Well Performance

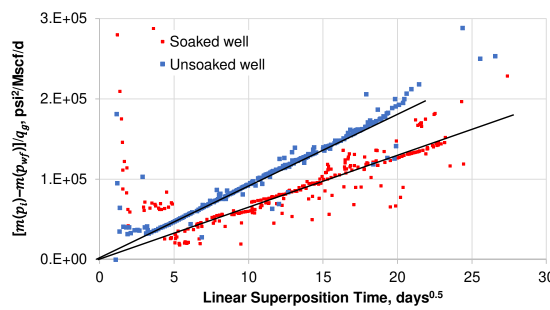


	Unsoaked Well	Soaked Well
# of stages	35.0	39.0
Water: gal/ft	1,675.7	1,766.7
proppant: lb/ft	1,500.2	1,439.0
Cluster Spacing, ft	23.0	25.0
Injection rate, BPM	79.0	77.0
Stage Length, ft	160.0	170.0



Comparison Between Soaked and Unsoaked Well Performance

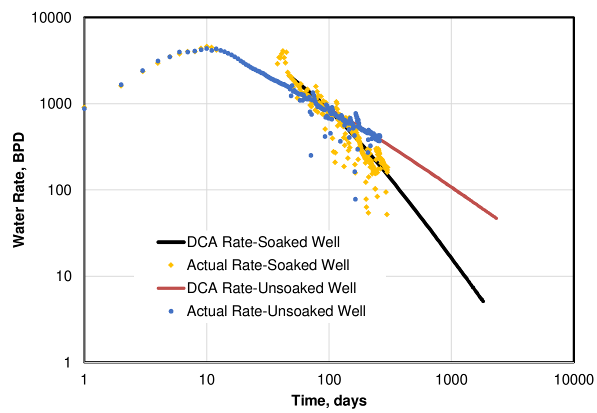




- By normalizing the stimulated area to a number of stages, Ac per stage ratio between the soaked and the unsoaked well was found to be 1.28

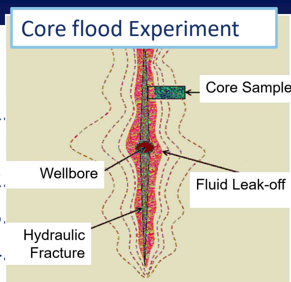
Comparison Between Soaked and Unsoaked Well Performance

- The water decline faster in the soaked well compared to the unsoaked well

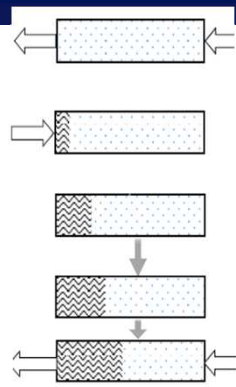


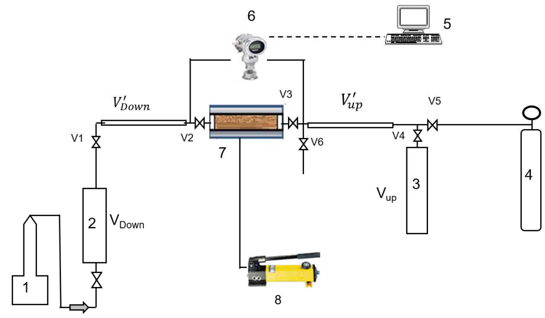
EXPERIMENTAL INVESTIGATION

Soaking Process Mechanism



1. ...urement
...od (CT)
2.
3.
4. ...ent (CT)



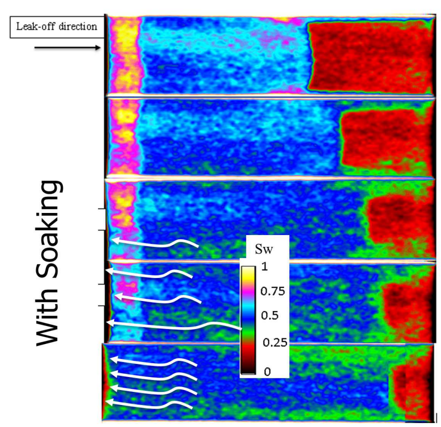


A schematic of the coreflood setup. 1 = syringe pump, 2&3 = accumulators, 4 = N_2 cylinder, 5 = PC recorder, 6 = pressure transducer, 7 = core holder, 8 = hand pump for overburden pressure.

Ibrahim and Nasreldin 2019

Soaking Process Mechanism

- During shut in, the length of the invaded area increases with time and the water saturation at the fracture interface reduces that opens paths for gas flowing



Ibrahim and Nasr-El-Din 2019

Soaking Process Mechanism

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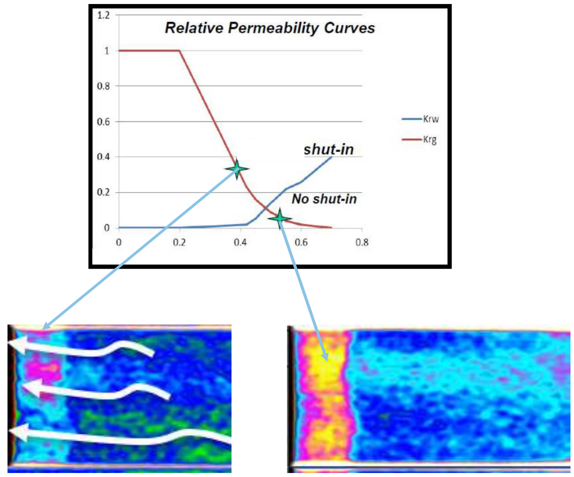
- Shale is a very tight formation and it has depressed (concave) relative permeability curves.
- As a result, a small decrease in water saturation will cause a large increase in the relative permeability to gas



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Soaking Process Mechanism

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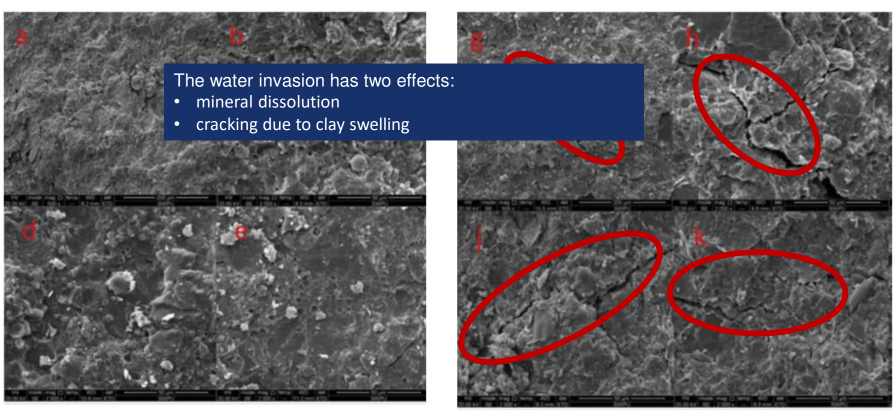

Liu et al. 2016

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Soaking Process Mechanism

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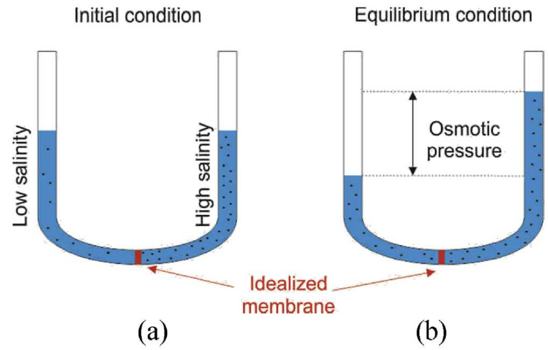
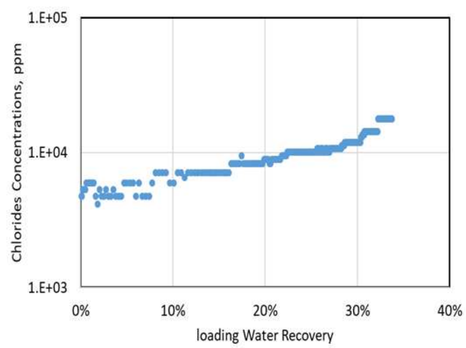
- Another possible reason for this behavior is triggering osmotic forces and changing the formation wettability.



After Vengosh et al. 2017



Ibrahim et al. 2020

Soaking Process Mechanism

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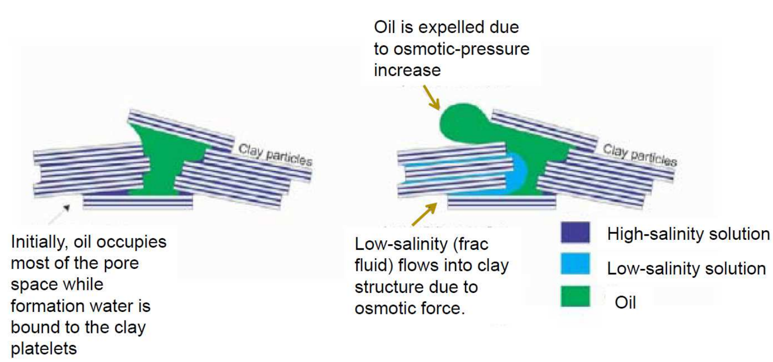

Formation wettability changes by low water salinity.

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QUICK SCREENING

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Screening based on flow back analysis

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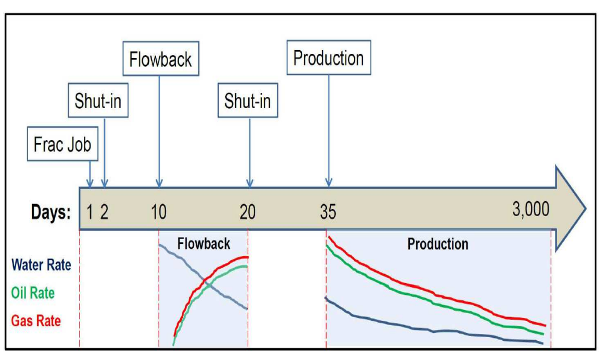

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Water RTA

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- Water RTA was conducted for water production.
- The log-log diagnostic plots of $\frac{[p_i - p_{wf}]}{q_w}$ and the drop-pressure/water rate derivative function, $t\left[\frac{\Delta(p)}{q_w}\right]'$, versus time were used for flow regime diagnosis.
- Water material balance time (tmBw = Qw/qw) was used to account for the production at varying flowrate:

$$OWIP = \frac{5.615\ S_{wi}}{c_{t_i}}\left(\frac{1}{m_{PSS}}\right)$$

$$\sqrt{k}A_c = \frac{79.65 B_w \mu_w}{\sqrt{(\varphi \mu_w c_t)_i}}\left(\frac{1}{m_{CRL}}\right)$$

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Log-Log Diagnostic Plot for Water RTA - Case 1 (BDF Regime)

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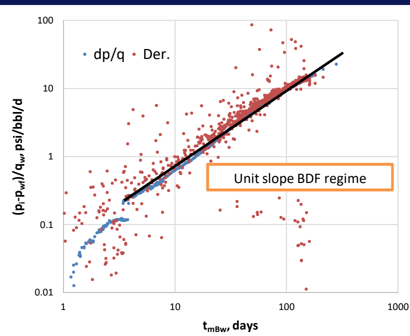

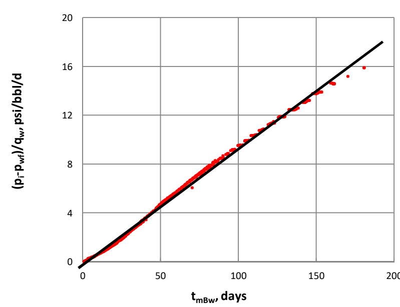

- RTA analysis shows unit slope line that defines the BDF regime with no transient flow
- An indication of the absence of movable formation water

Water Loading 9% at gas kickoff

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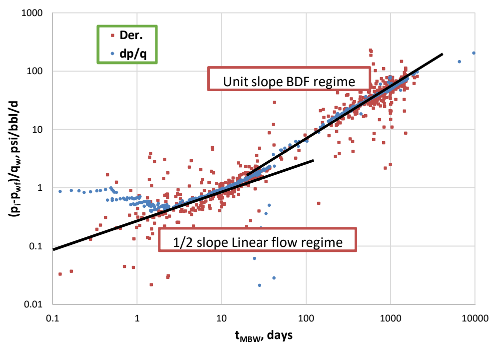
Log-log Diagnostic Plot for Water RTA - Case 2

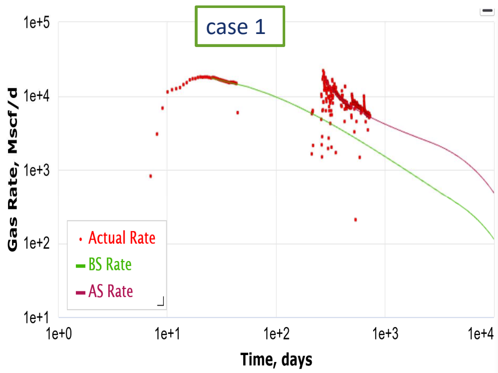


- Two flow regimes:
  - A half slope defined the linear flow regime in the early production data
  - The late production data showed the BDF regime
- Presence of transient flow regime gave an indication of movable water saturation

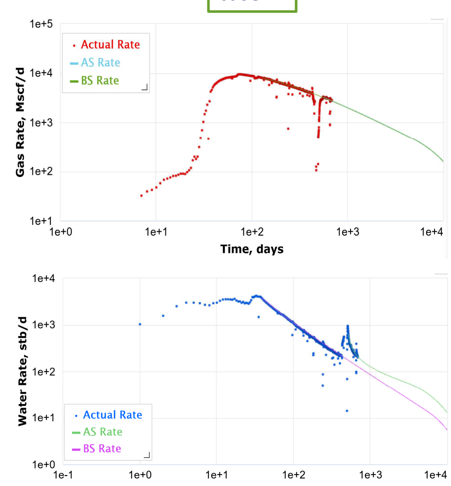
Water Loading 32% at gas kickoff)

Soaking Effect

case 1



case 2



Confirmation

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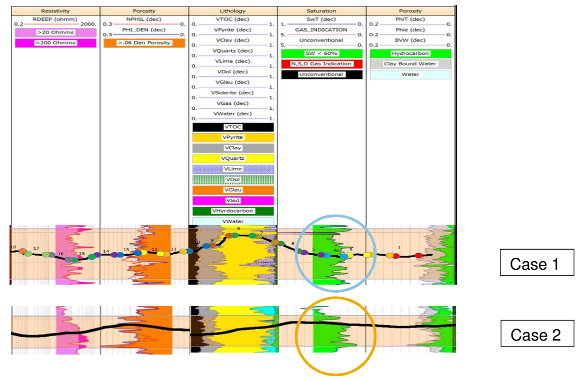
- The initial water saturation in case 1 was found to be around 0.35 which was slightly higher than the initial water saturation (0.30) in case 2.
- higher clay content in case 1 compared to case 2 (32% higher). As a result, the CBW saturation increased and the movable water saturation decreased.



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Water Saturation Effect

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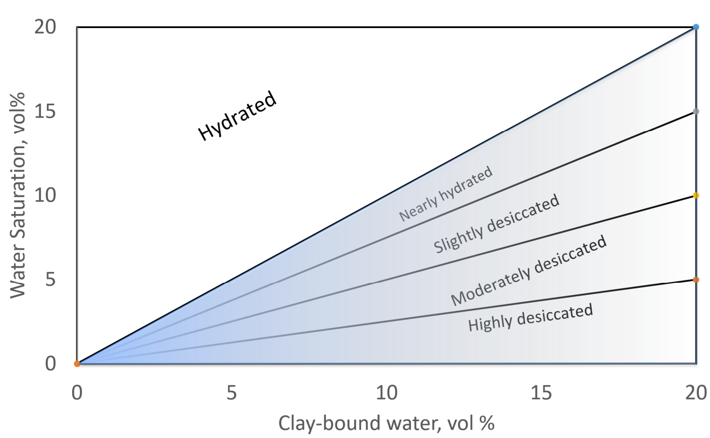

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Conclusions

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- Shut in the well after flowback increases the gas productivity and decreases the water production.
- Higher potential benefits from the soaking process can be expected for low water saturation, high-pressure gradient, and high thermal maturity formations.
- Water flowback analysis can be used to rank the shale formation for soaking process

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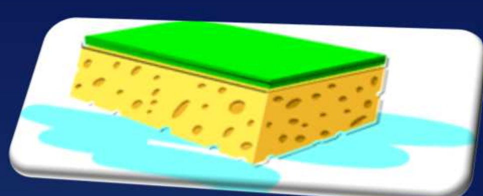
THANK YOU



Let it soak and let's talk in a few weeks...

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