Using Tracers for Monitoring EOR Performace. Study Case of Snorre Field (Paper SPE 129877)

Outline

- SWCTT
- Background
- Operation
- Results
- Analysis
- Conclusion

Statoil

Workflow of an EOR project

ΔSo ?

ΔSo ?

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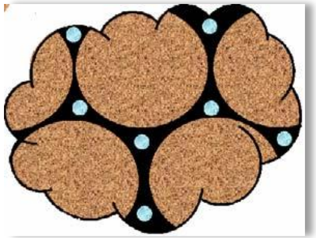
SWCTT

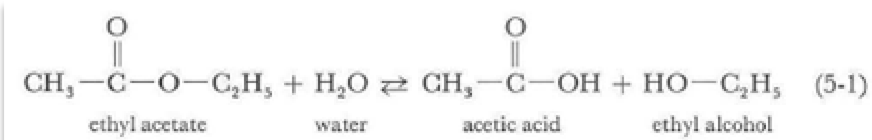
SWCTT

- SWCTT stands for single well chemical tracer test
- Estimating residual oil saturation
  - Immobile oil saturation
- A commonly used tracer is ester.



Key concepts

- Hydrolisis

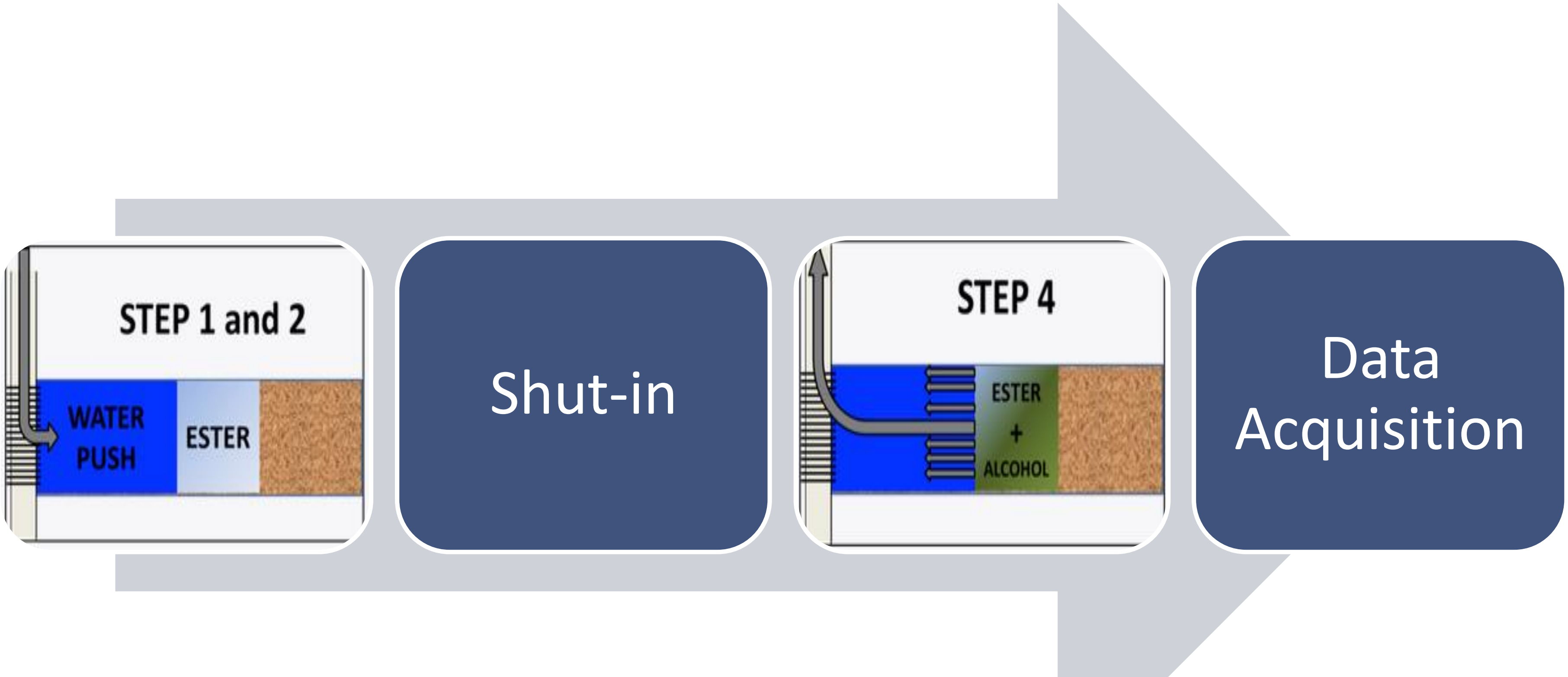


- Partitioning

$$K_d = \frac{C_0}{C_w}$$

Source: Wikipedia

How it works

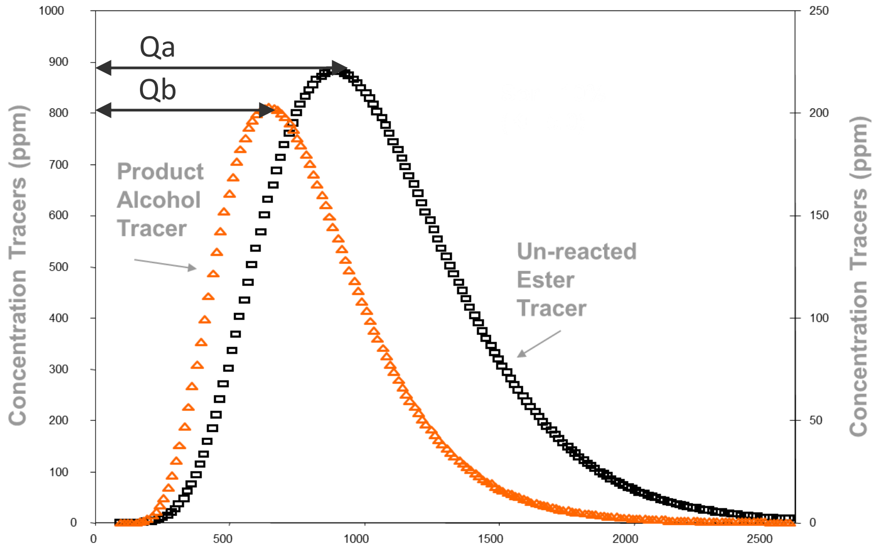


Source: http://chemicalfloodingtechnologies.com

Determination of oil saturation

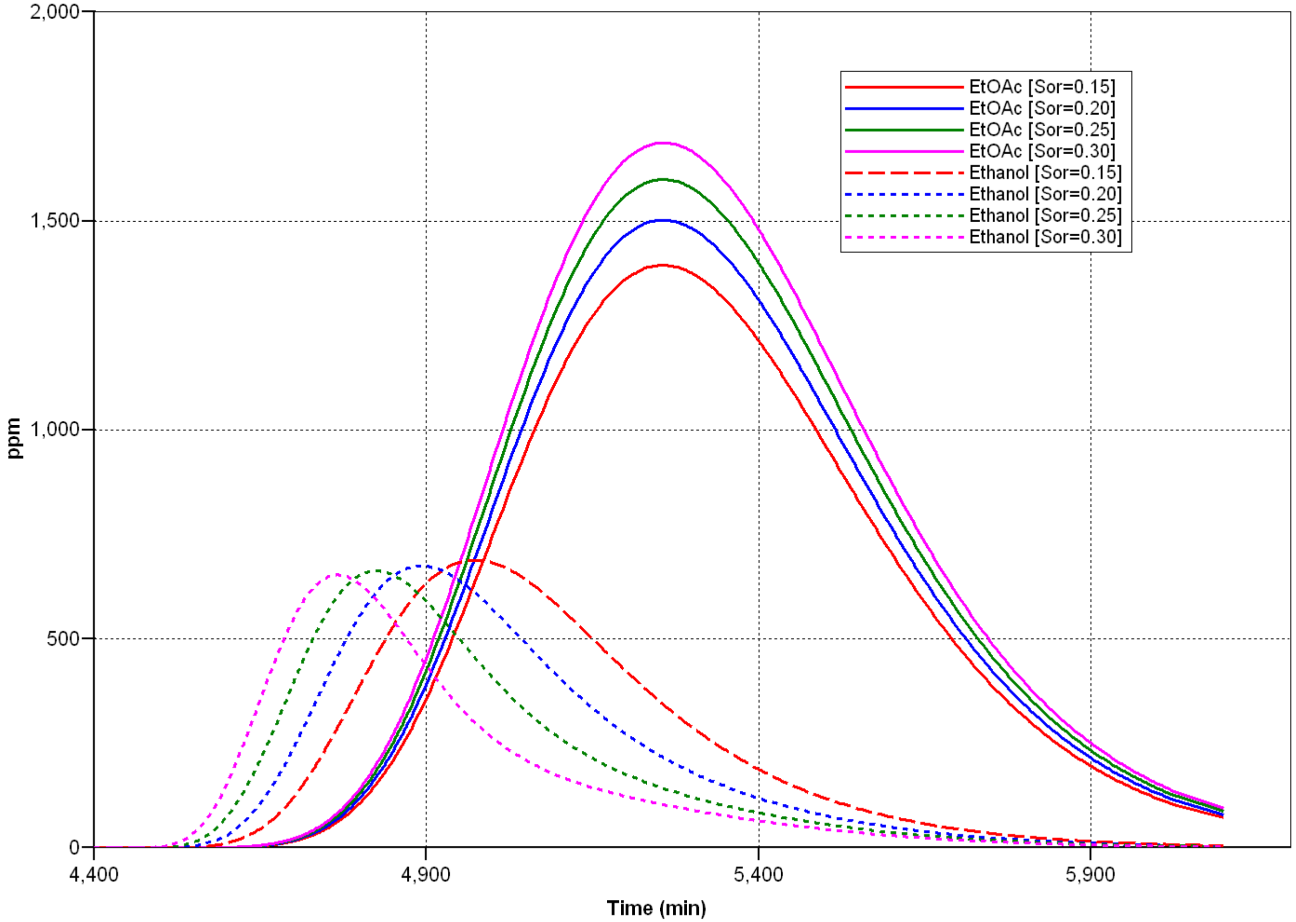
- Parameters required
  - Partitioning coefficient
  - Tracer concentration curves

$$S_o = \frac{\frac{Q_a}{Q_b} - 1}{\frac{Q_a}{Q_b} - 1 + K}$$



Source: CTI presentation

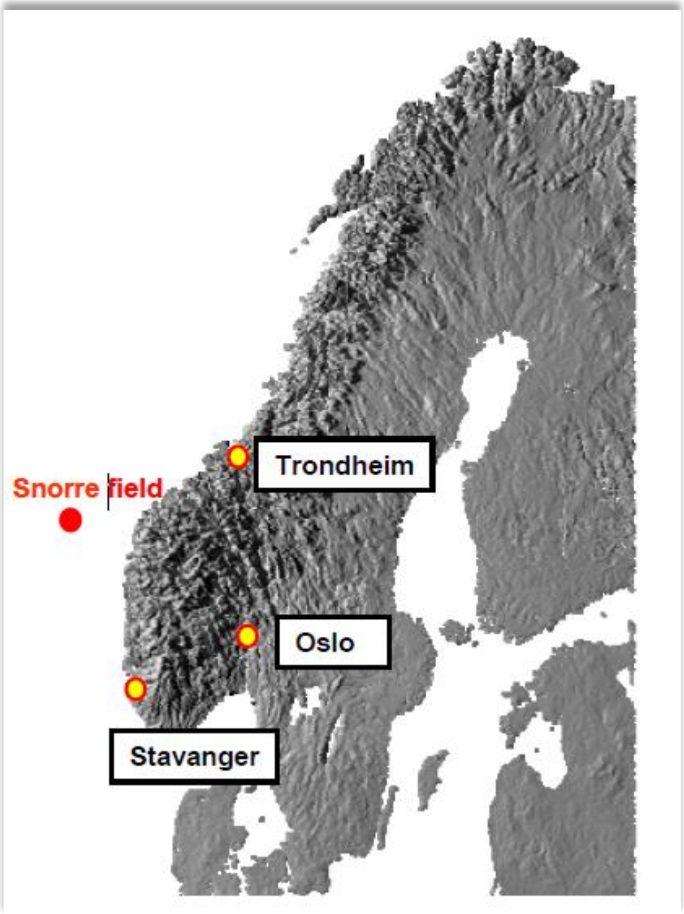
Impact of Sor changes



Background

Data and facts

- OOIP : 513 MSm3
- Current expected RF : 46%
- Ultimate goal with IOR : 55%
- Porosity : 14 – 32 %
- Permeability : 0.1 – 4 D
- Upper /lower Statfjord and Lunde formations
- Potential IOR : low salinity water injection



Source: SPE 129877

Workflow of an EOR project

ΔSo ?

ΔSo ?

Core flooding experiment

Table 5. Average oil recovery/incremental oil recovery (% OOIP).

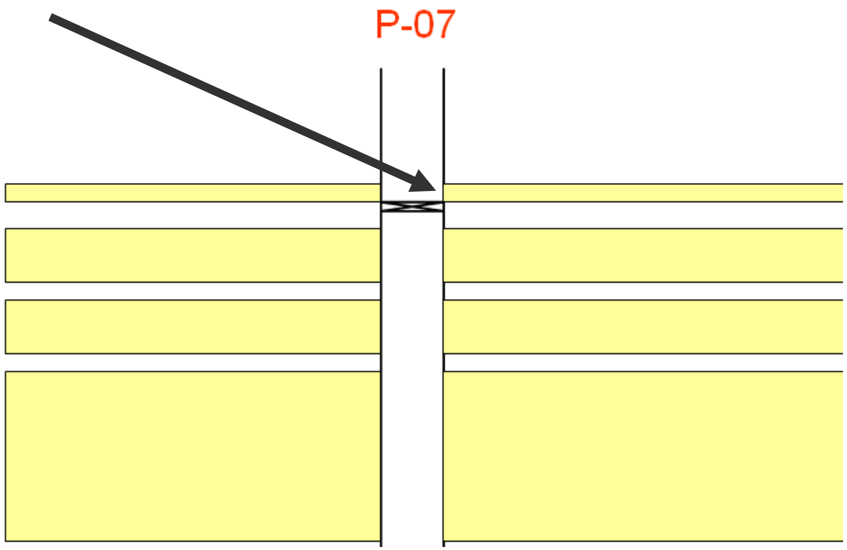
Formation	After flooding stage	lp	hp	all
Upper Statfjord	• sea water	37.5	63.7	45.0
	• low salinity sea water	1.8	3.3	2.2
	• low salinity NaCl brine	2.8	0.2	2.1
	• alkaline	0.3	0.0	0.2
Lower Statfjord	• sea water	51.1	58.1	54.6
	• low salinity sea water	0.4	4.9	2.6
	• low salinity NaCl brine	0.6	1.3	0.9
	• alkaline	2.8	0.5	1.6
Lunde	• sea water	65.5	66.5	65.9
	• low salinity sea water	0.5	0.5	0.5
	• low salinity NaCl brine	0.0	0.8	0.3
	• alkaline	0.0	0.0	0.0

Source: SPE 129877

Operation

SWCTT in Snorre

- SWCTT is performed in well P-7 in a single zone upper statfjord (1.5 meters)



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Details of the operation

Table 7. Injected and produced volumes, and rates throughout the SWCTTs (incl. 50 m^3 well bore volume)

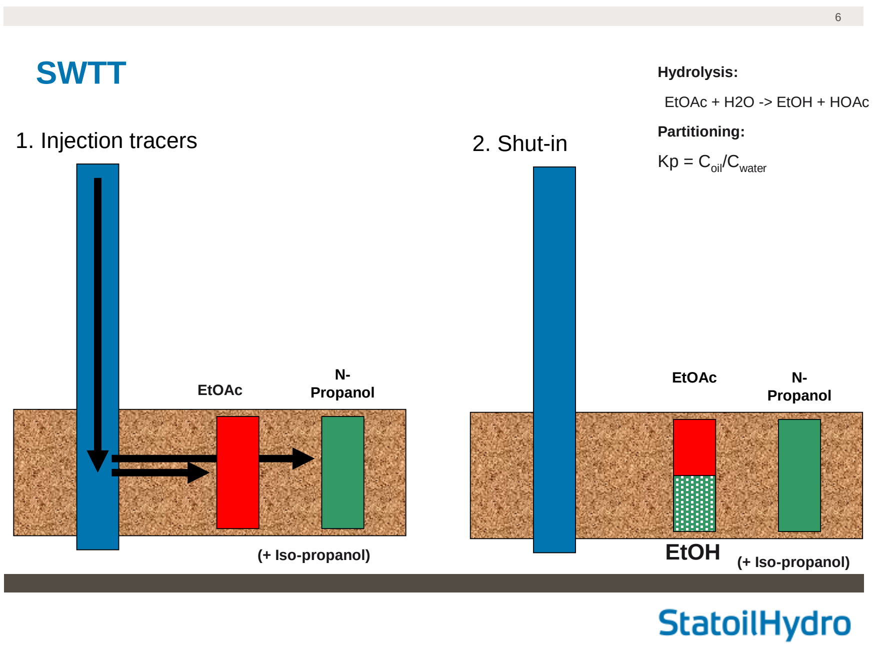
Stage	Start date (2008)	End date (2008)	Operation	Vol. inj. (m^3)	Inj. rate (m^3/h)	Vol. prod.(m^3)	Prod. rate (m^3/h)
1	14 Nov.	20 Nov.	Production for clean up of well				
2	20 Nov.	23 Nov.	**Sea water injection**	1100	15-16		
3	23 Nov.	24 Nov.	Back-production of sea water			109	16-17
4	24 Nov.	24 Nov.	Sea water injection	110	15-16		
5	24 Nov.	24 Nov.	SWCTT-1 injection	255	17		
6	24 Nov.	28 Nov.	Shut-in SWCTT-1				
7	28 Nov.	29 Nov.	SWCTT-1 back-production			412	19
8	29 Nov.	30 Nov.	**Low salinity water injection**	225	17		
9	30 Nov.	01 Dec.	Sea water inj. to displace lowsal	180	17		
10	01 Dec.	02 Dec.	SWCTT-2 injection	252			
11	02 Dec.	05 Dec.	Shut-in SWCTT-2				
12	05 Dec.	06 Dec.	SWCTT-2 back-production			408	20-16
13	06 Dec.	07 Dec.	**Sea water injection**	366	17-16		
14	07 Dec.	08 Dec.	SWCTT-3 injection	251	17-16		
15	08 Dec.	11 Dec.	Shut-in SWCTT-3				
16	11 Dec.	12 Dec.	SWCTT-3 back-production			390	16

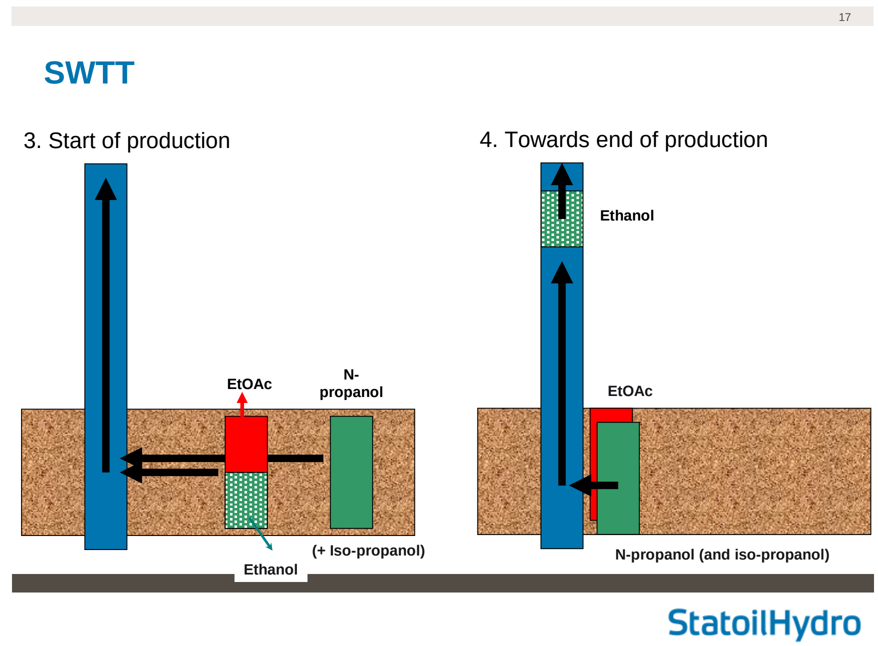
Source: SPE 129877

Sequence in each SWCTT

- 3 tracers are being used:
  - Ethylacetate : the main tracer
  - N-propanol : material balance tracer
  - Iso-propanol : material balance tracer
- The sequence
  - 40 Sm^3 sea water + ethylacetate + n-propanol + iso-propanol
  - Displaced with 211-215 Sm^3 sea water with iso-propanol

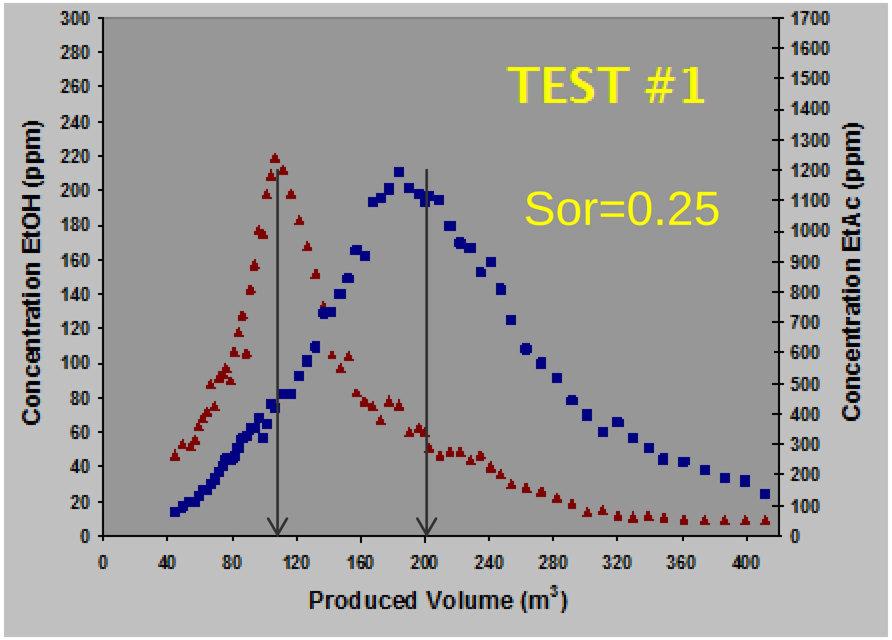
The process

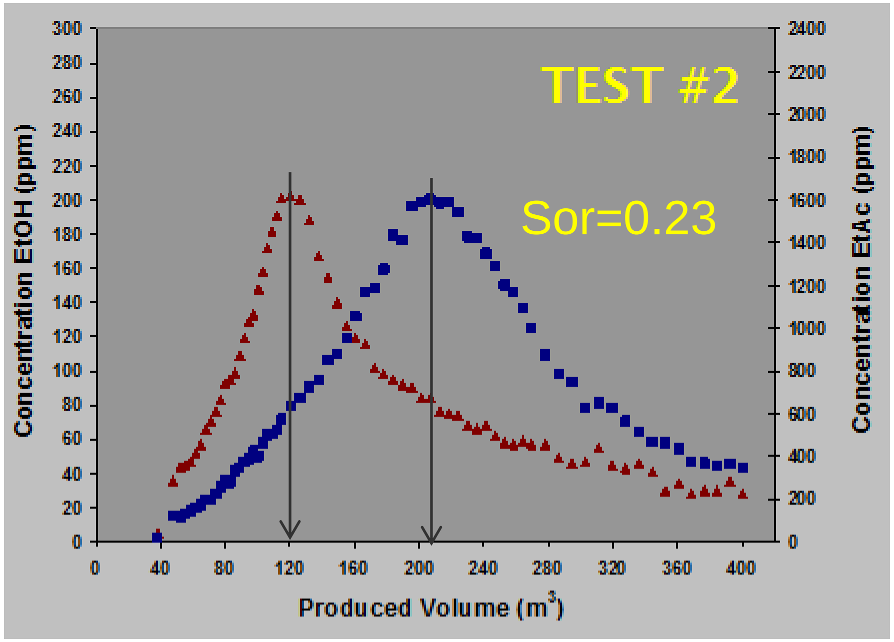


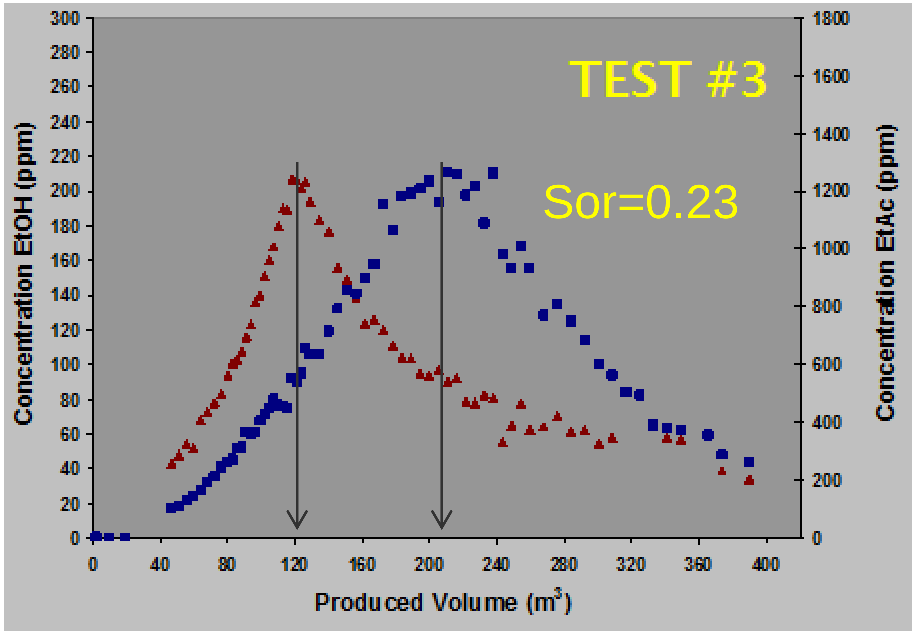


Source: Sjevrak and Ibatullin

Results

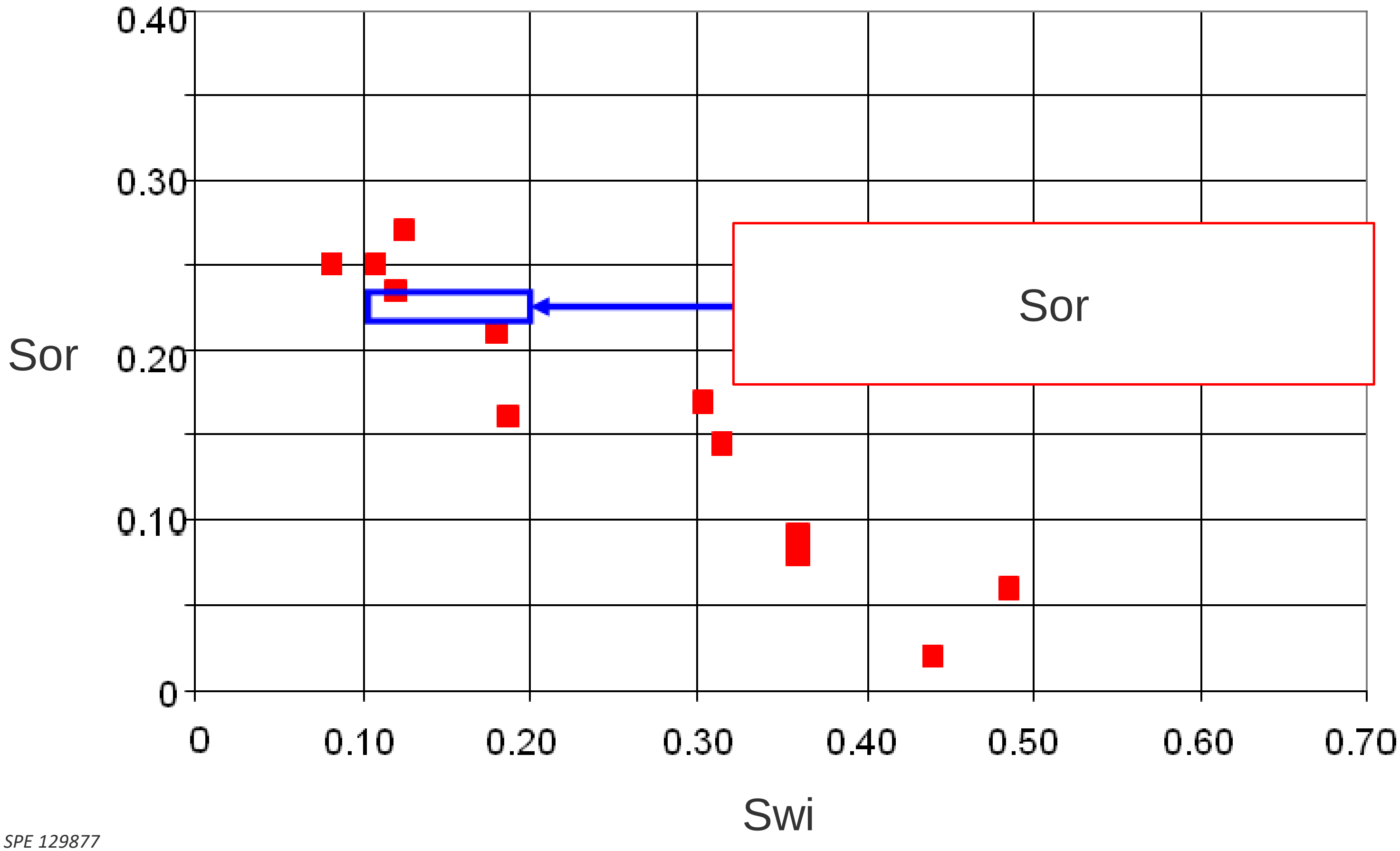






Source: Sjevrak and Ibatullin

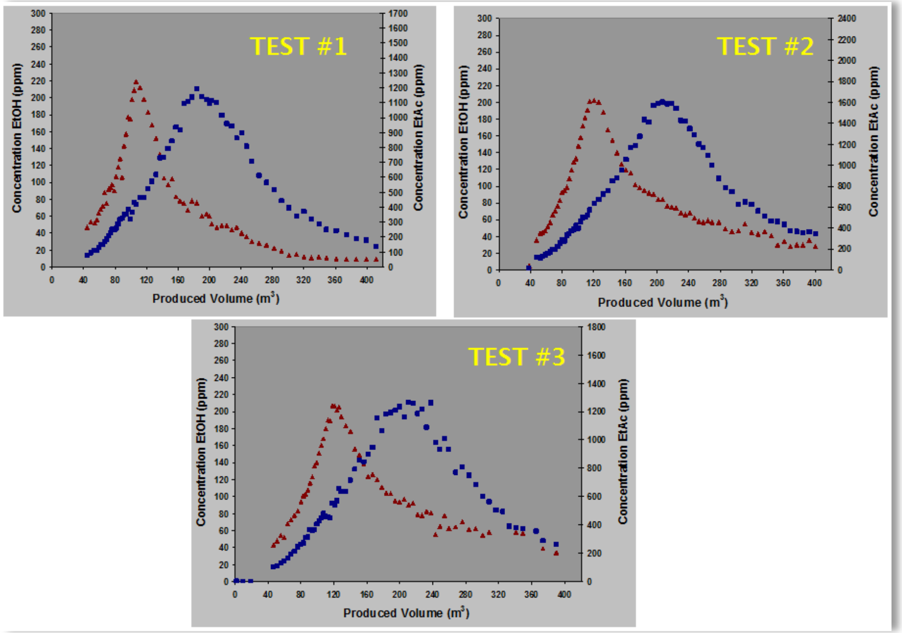
Sor from SCAL vs. SWCTT



Source: SPE 129877

The big question

- Does the difference of the curve separation come from Sor reduction?



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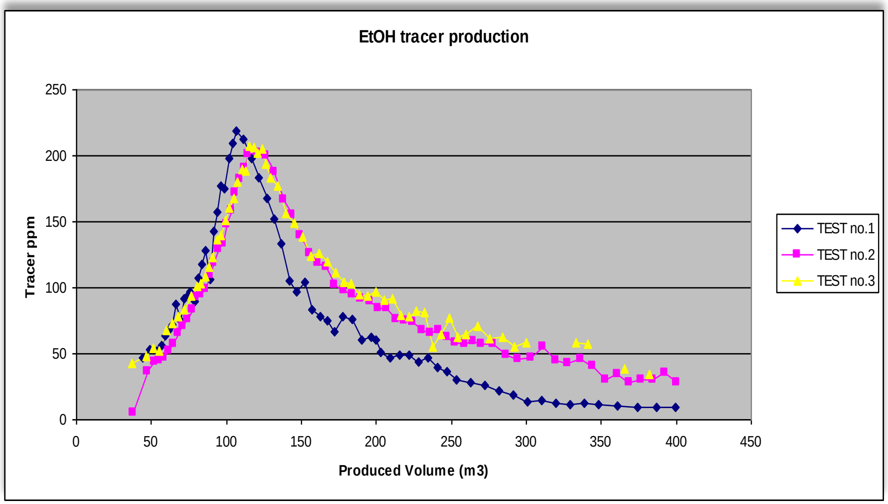
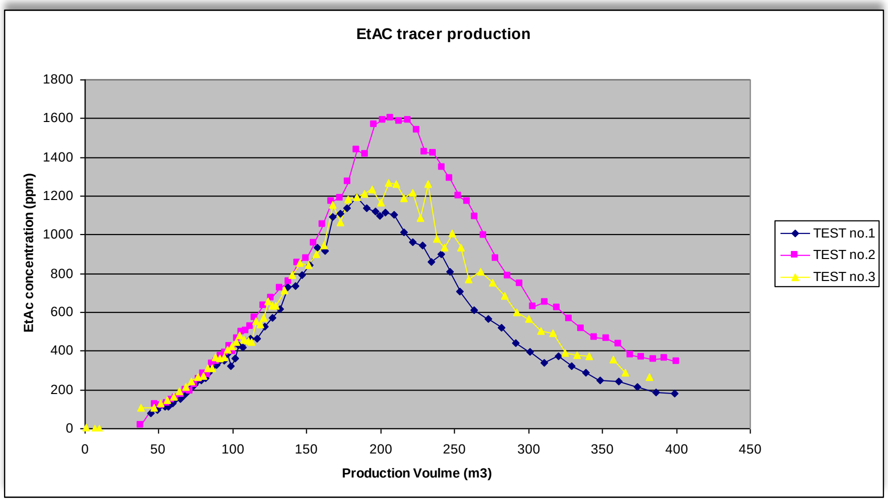
Analysis

Details of the alcohol and ester production

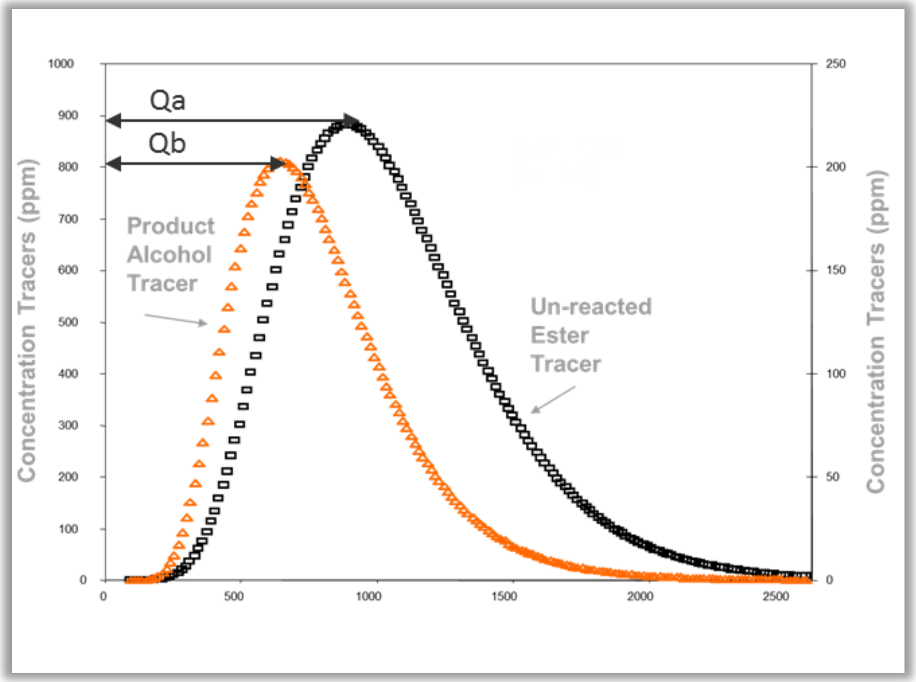




Source: Sjevrak and Ibatullin

Uncertainty analysis

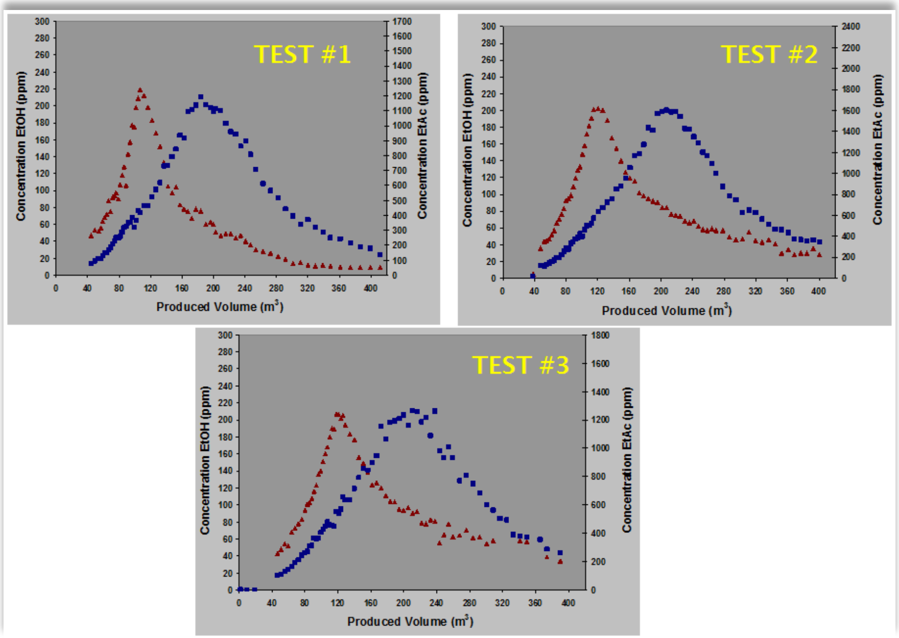
- Tracer concentration
- Partitioning coefficient
- Rate measurement



$$S_o = \frac{\frac{Q_a}{Q_b} - 1}{\frac{Q_a}{Q_b} - 1 + K}$$

Tracer concentration

- Common uncertainty of the analytical data from laboratory experiment is ±3%
  - But it doesn't change the curve separation

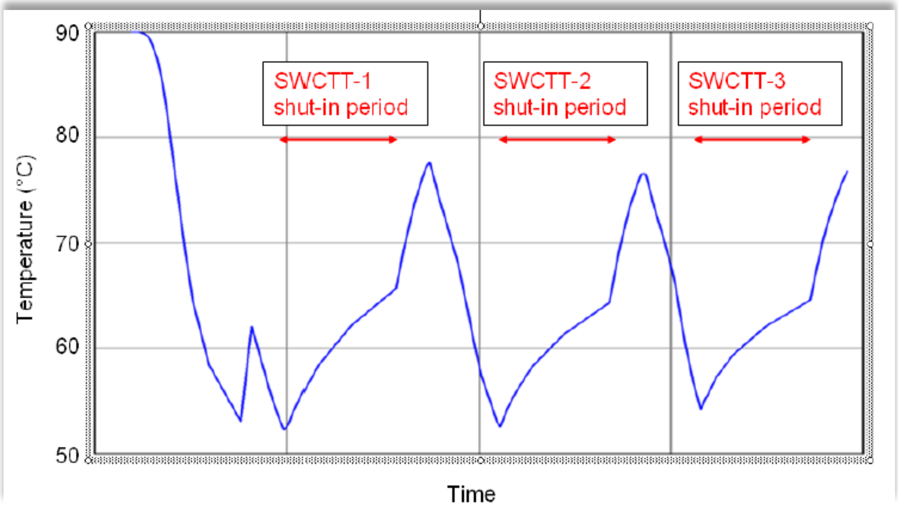


This is not the factor!!

Partitioning coefficient

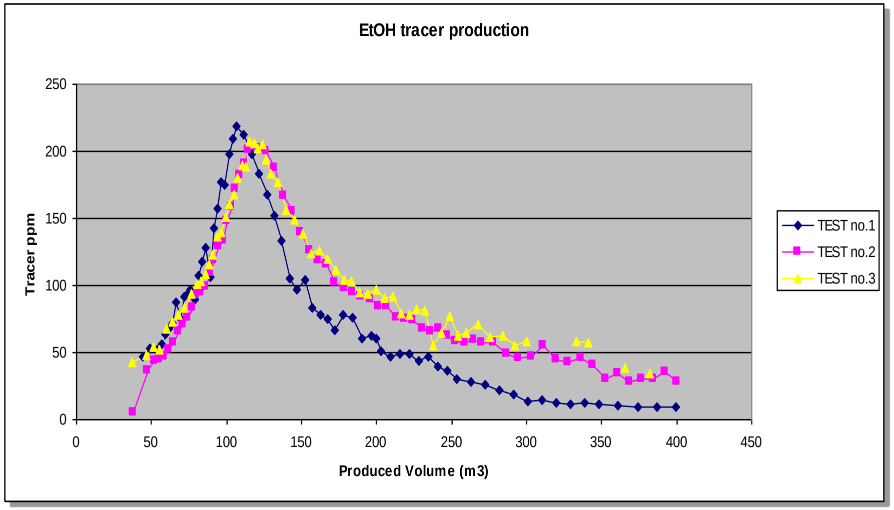
- K is sensitive to temperature changes
  - Variation of ±20ºC → ±20% deviation in partitioning coefficient (K) → ±2% Sor
  - But the temperature changes between the SWCTTs are far less than 20ºC

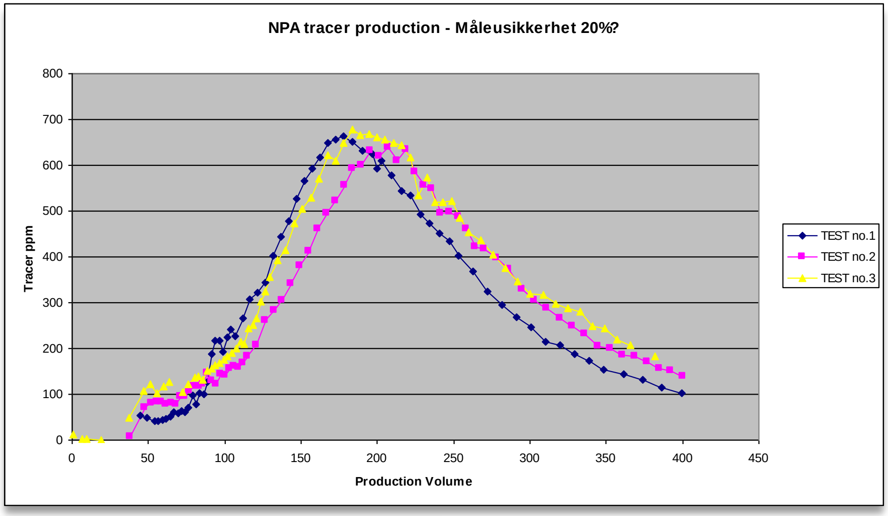
This is not the factor either!!

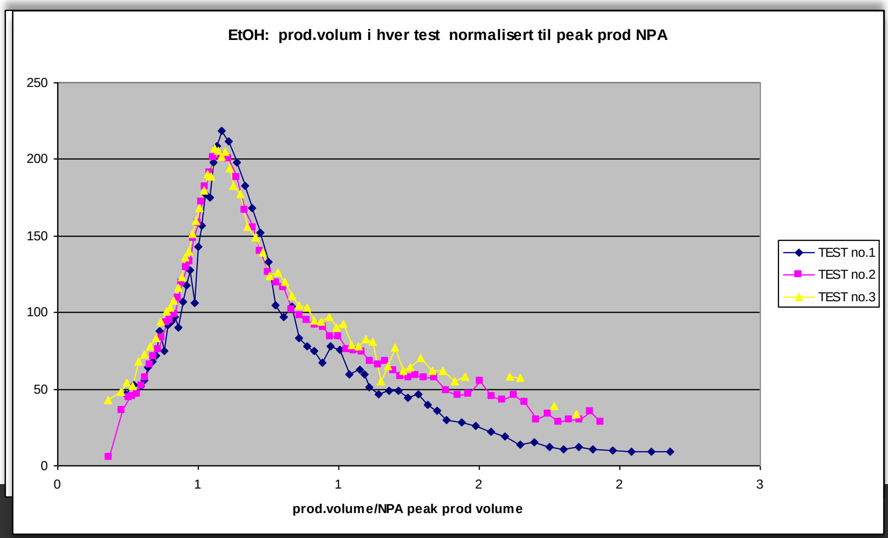


Source: SPE 129877

Rate measurement







This is the factor

Source: Sjevrak and Ibatullin

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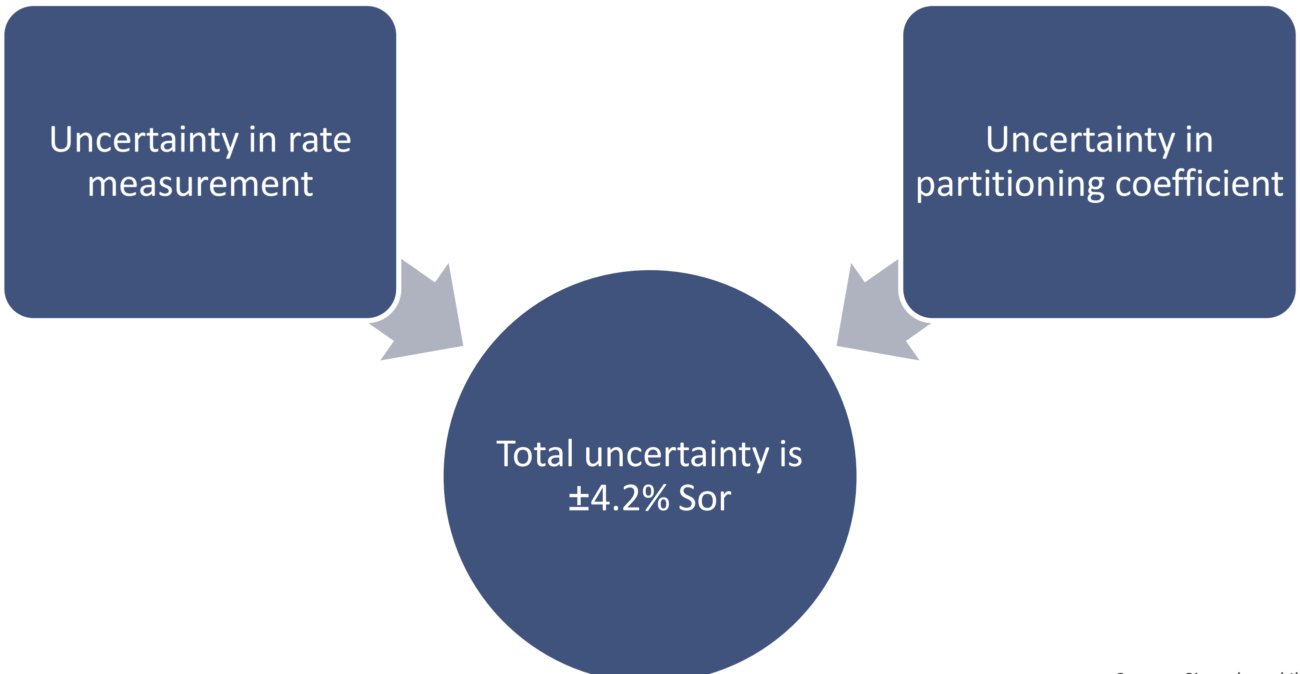
Therefore…

- The drift of the alcohol curves is due to the inconsistency of the rate measurement
- No significant reduction in the remaining oil saturation had taken place during the low salinity water injection

Uncertainty evaluation

$$\frac{\Delta S_o}{S_o} = \frac{1}{\left(\frac{Q_a}{Q_b}-1\right)\left(\frac{Q_a}{Q_b}-1+K\right)} \sqrt{\left(\frac{K}{Q_b}\right)^2(\Delta Q_a)^2+\left(\frac{KQ_a}{Q_b^2}\right)^2(\Delta Q_b)^2+\left(\frac{Q_a}{Q_b}-1\right)^2(\Delta K)^2}$$



Source: Sjevrak and Ibatullin

Conclusion

Conclusion

- SWCTT has a potential for measurement of relative changes in Sor due to an EOR activity including MEOR
- In Snorre case
  - Sor obtained from SWCTT is in line with the SCAL data
  - No significant reduction of Sor identified from both core flooding and SWCTT
  - Rate measurement is the main error source followed by partitioning coefficient
  - Repeated measurements are necessary
  - Injection of mass balance tracer is critical for additional control
  - It is beneficial to have a relationship of partitioning coefficient and temperature from laboratory test
  - Potential uncertainties should be assessed prior to the test
    - Reservoir fluid drift, irreversible flow, crossflow, thief zone, etc.

There's never been a better time for good ideas

Presentation title

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Test conditions (Reference CTI)

Variable	Range
Interval Height	8 to 104 feet
Porosity	7 to 34 %
Reservoir Temperature	80 to 249 Deg. F.
Brine Salinity	1,200 to 270,000 ppm TDS
Permeability	4.5 to 6,000 md
Oil Gravity	12 to 49 API
Sor (PV)	7 to 45%

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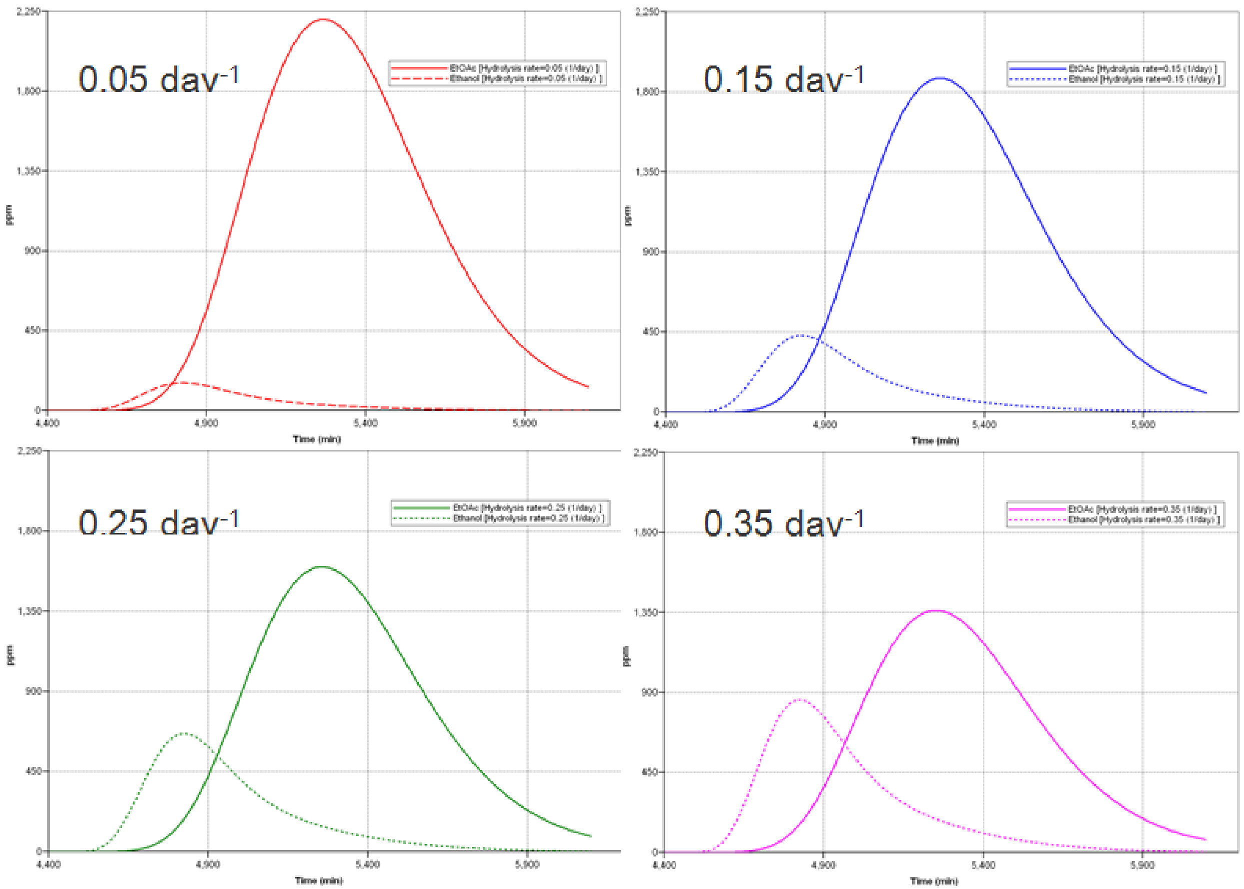
Impact of hydrolysis rate



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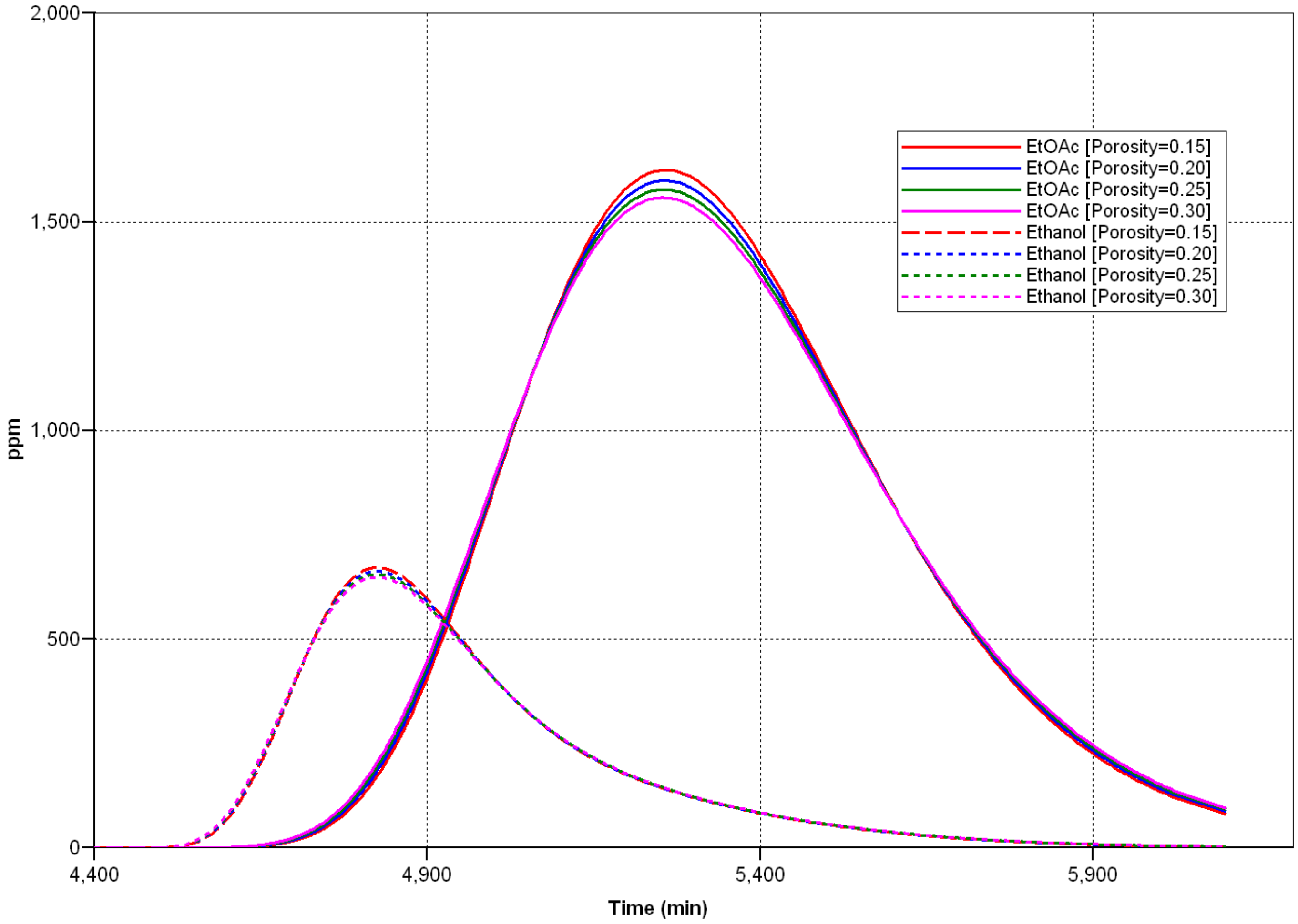
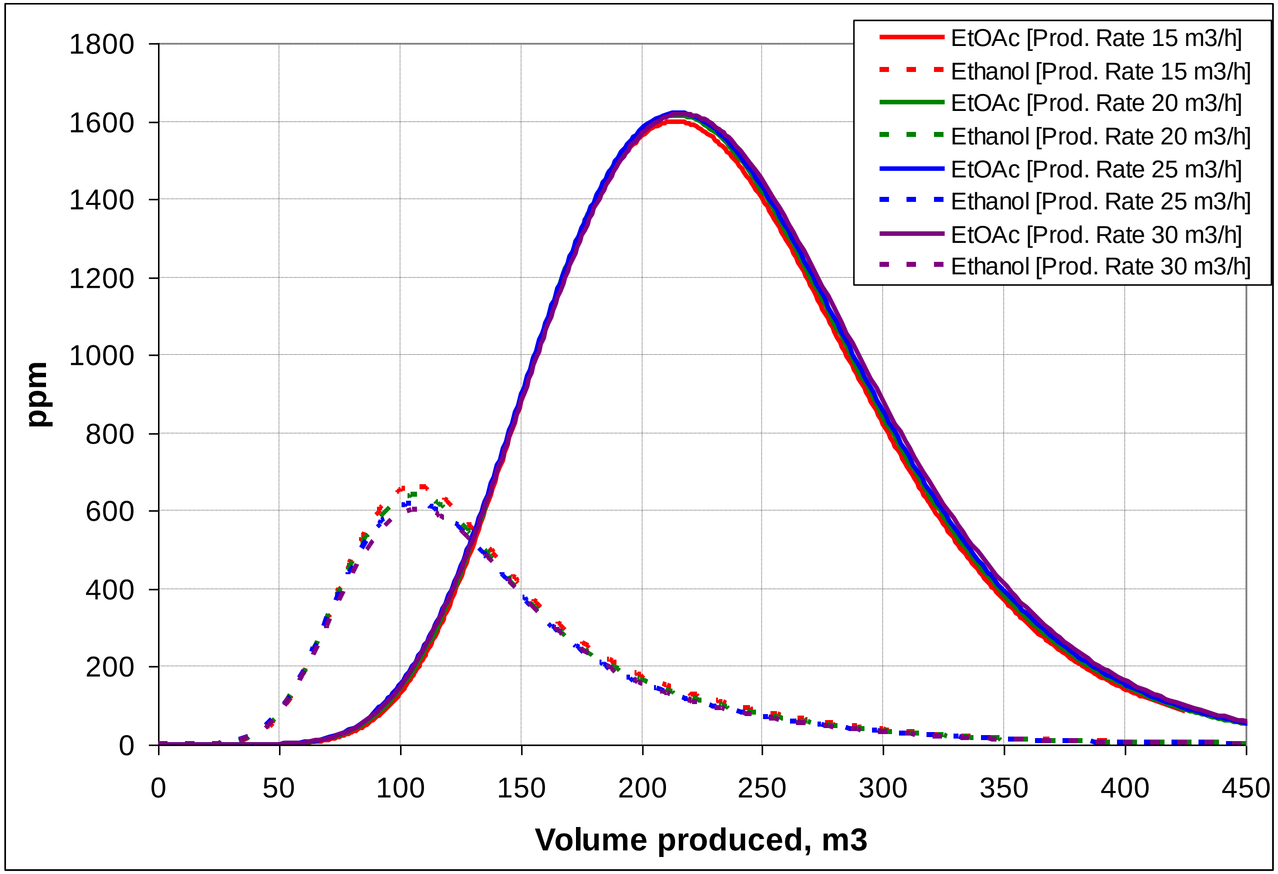
Impacts of porosity



Impacts of back production rate



Impact of partitioning coefficient