Controlled Acid Jetting (CAJ) – A game changer for completion and stimulation of wells in carbonate reservoirs

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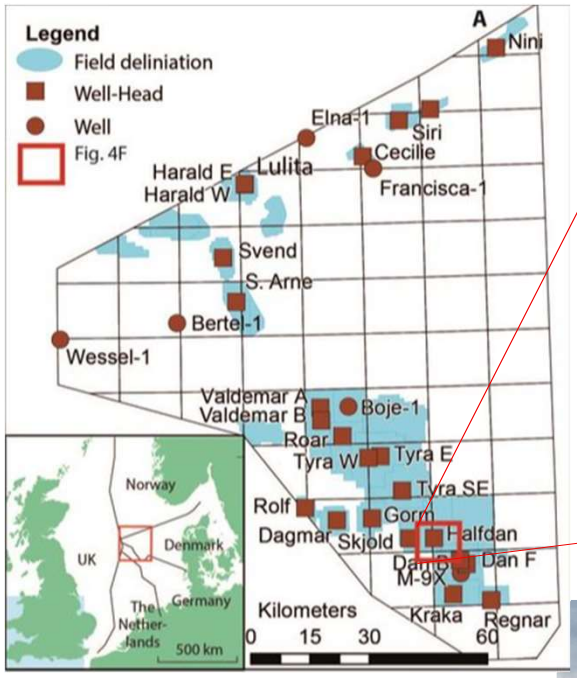
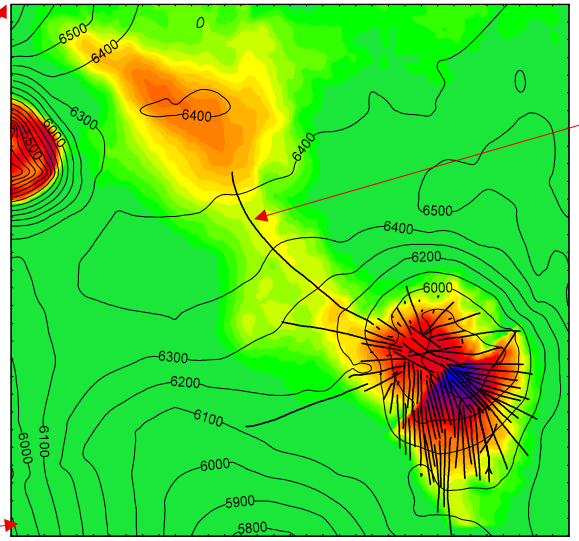
The Dan - Halfdan development challenge





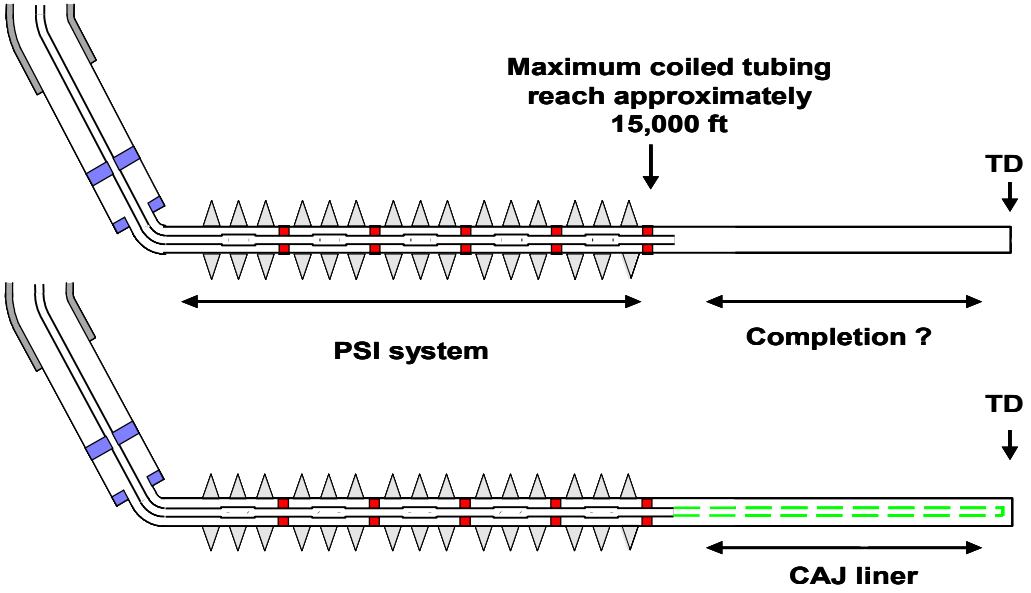
Halfdan discovery well:

- MD 29,600 ft - TVD 7,192 ft
- Reservoir section 20,749 ft
- Challenge: Completion and stimulation far beyond C/T reach (at reasonable cost!) => 1500 - 3000 tons hydrochloric acid optimally distributed along entire well accounting for reservoir properties

Reservoir description:

- 0.5 – 5 mD chalk / carbonates
- Homogeneous non-fractured reservoir
- Laterally extensive fields
- Offshore Denmark
- Depth 6000 – 7000 ft
- 50 – 300 ft pay zone

Typical horizontal well completion

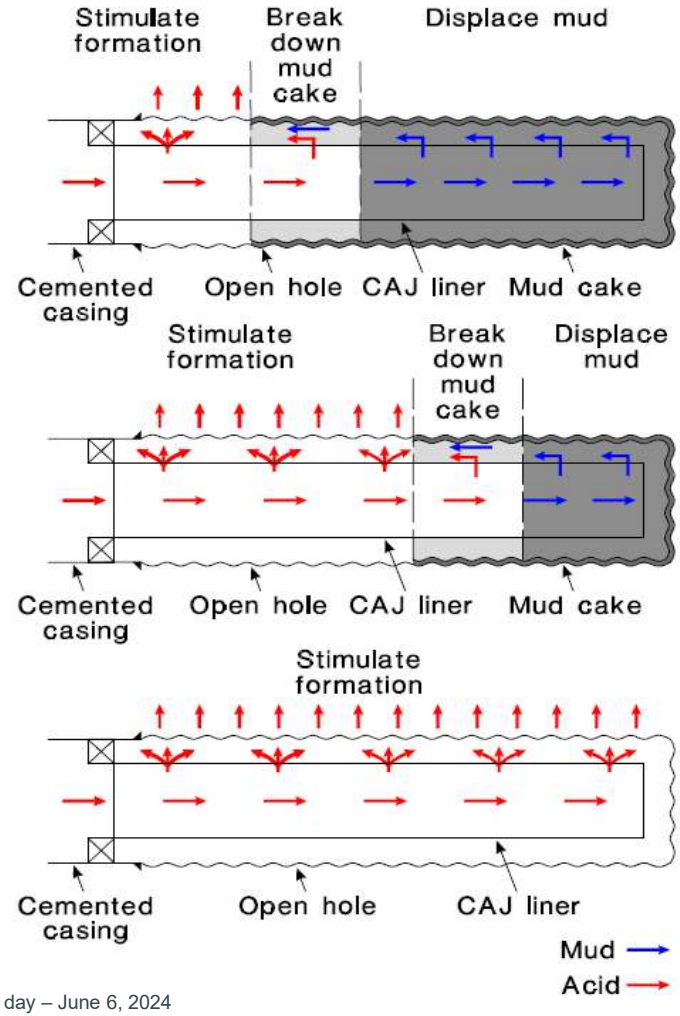


How to distibute 1000 – 3000 tonnes of 15% HCl beyond c/t reach?

Traditional completion characteristics:

- Requires c/t or tractor reach to shift sliding sleeves or alternative tractor runs or drop balls
- Zone length limited to 400-500 ft => many zones required
- Expensive for marginal fields
- Needs diverting chemicals and high pump rates
- Stimulation is suboptimal / non-uniform
- Often fractured instead of matrix stimulated

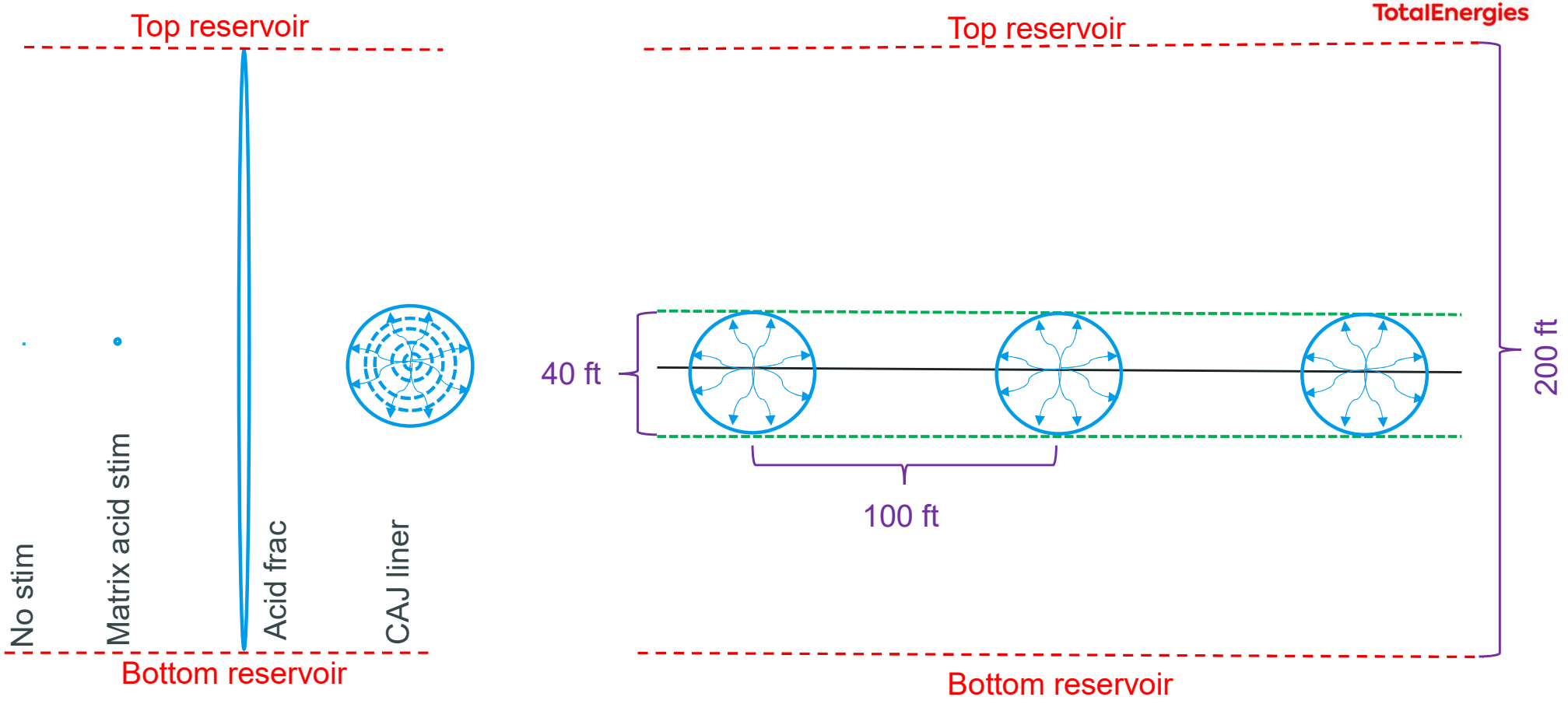
Controlled Acid Jet (CAJ) liner concept



Displacement mechanism of Controlled Acid Jet (CAJ)

- Holes act as diverters during acid stimulation
- Annual flow conduit ensures gradual displacement of the mud and stimulation of the full reservoir section
- Conventional perforation is 2 shots / ft but CAJ perforation is 0.02-0.01 perforation/ft
- Hole distribution reflects pump rate, liner size, mud type, hole size, pressure along well etc.
- More or larger holes needed in outer part of the well
- Hole size typically 3-6 mm
- Holes hand-drilled on the rig floor
- Friction reducing chemicals used to increase stimulation pressure at toe of well hence evening out the perforation spacing and diameter

Controlled Acid Jet - Effective wellbore radius



Design tally - example

CAJ liner perforation tally

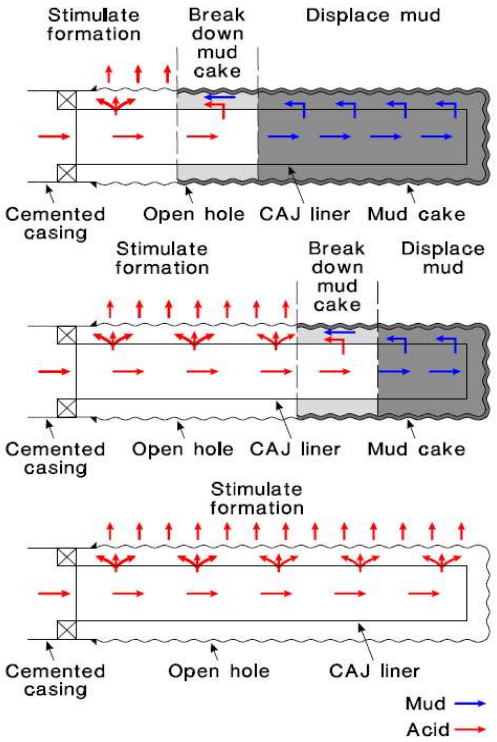
Report name: BU703 **Date:** 02.feb.21

FINAL RUNNING TALLY (TOP JOINTS TO BE RUN FIRST)

1 of 2

Number of Holes 92 **Setting Depth** 13.112 **Page** 1 of 1

Joint #	L	ID	Holes	Hole ID	Joint #	L	ID	Holes	Hole ID	Joint #	L	ID	Holes	Hole ID
1	30,0	4,0	1	0,197	51	30,0	4,0	1	0,197	101	30,0	4,0	1	0,158
2	30,0	4,0	0	0,197	52	30,0	4,0	0	0,197	102	30,0	4,0	0	0,158
3	30,0	4,0	1	0,197	53	30,0	4,0	1	0,197	103	30,0	4,0	1	0,158
4	30,0	4,0	1	0,197	54	30,0	4,0	0	0,197	104	30,0	4,0	1	0,158
5	30,0	4,0	0	0,197	55	30,0	4,0	1	0,197	105	30,0	4,0	1	0,158
6	30,0	4,0	1	0,197	56	30,0	4,0	1	0,197	106	30,0	4,0	0	0,158
7	30,0	4,0	1	0,197	57	30,0	4,0	0	0,197	107	30,0	4,0	1	0,158
8	30,0	4,0	0	0,197	58	30,0	4,0	1	0,197	108	30,0	4,0	1	0,158
9	30,0	4,0	1	0,197	59	30,0	4,0	0	0,197	109	30,0	4,0	0	0,158
10	30,0	4,0	1	0,197	60	30,0	4,0	1	0,197	110	30,0	4,0	1	0,158
11	30,0	4,0	0	0,197	61	30,0	4,0	1	0,197	111	30,0	4,0	1	0,158
12	30,0	4,0	1	0,197	62	30,0	4,0	0	0,197	112	30,0	4,0	1	0,158

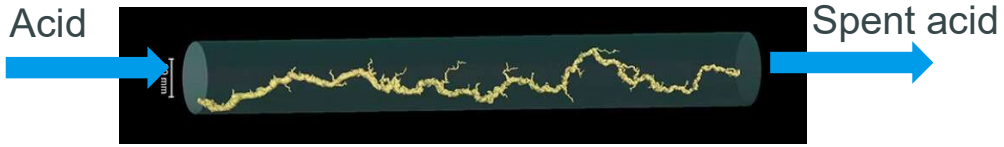


On the fly pre-drilling of 3-6 mm CAJ holes on the rig floor according to specified running tally

Important enablers to make it work

- The CAJ holes allows acid circulation for effective stimulation to the last foot of ultra long wells.
- Jetting onto formation creates an entry point by removing the mud and improves acid efficiency.
- Low treatment rate / pressure allows better use of the acid and growth of long wormholes
- Low acid concentration allows lower treatment pressure to avoid fracturing due to CO2 effects
- Large distance between the holes optimizes the use of the acid volume (clusters of wormholes)
- Friction reducing chemicals enables ultra long reach

Wormhole growth rate depends on acid flow rate



- Acid efficiency (pore volume to break through) strongly depends on the flow rate => Optimum rate gives much longer wormholes
- Too low rates or too high rates are inefficient
- Optimum injection rate can be defined in the laboratory
- What is the number of wormholes along a 20000 ft CAJ liner?

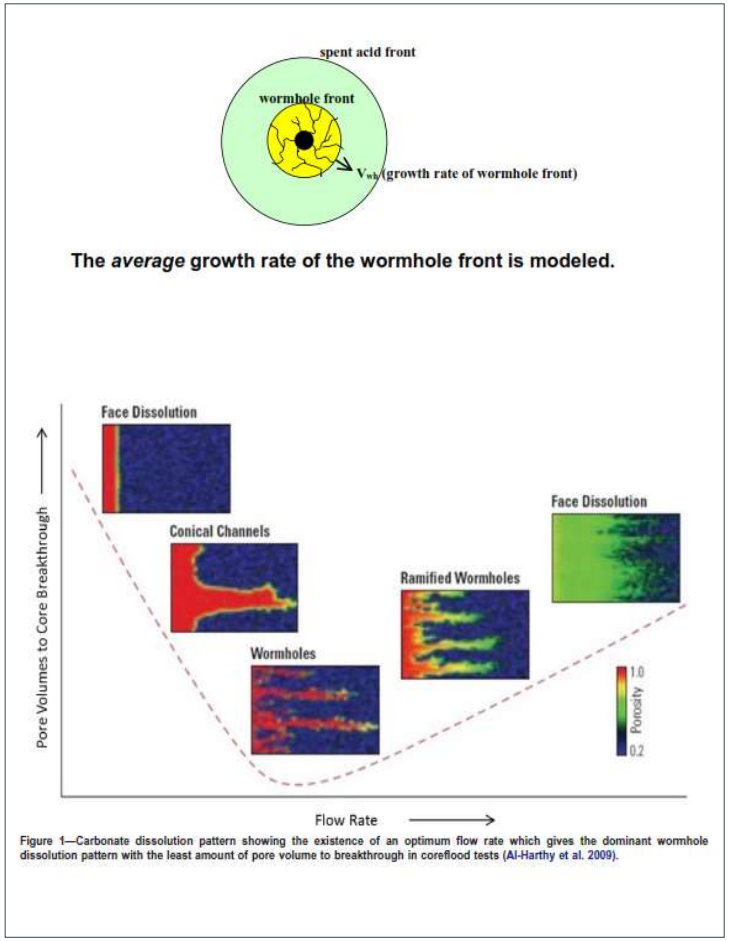
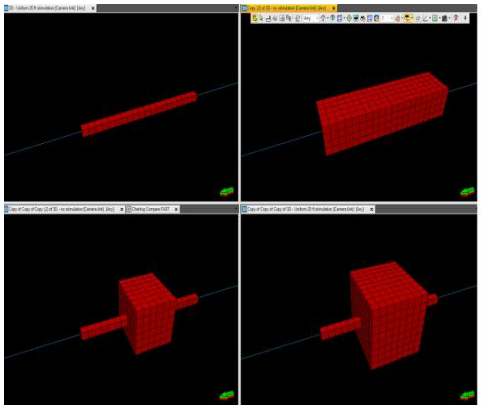
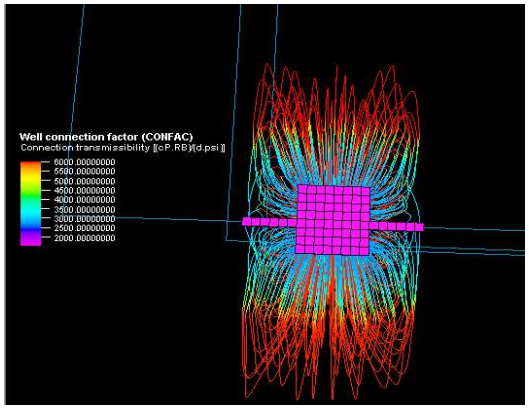
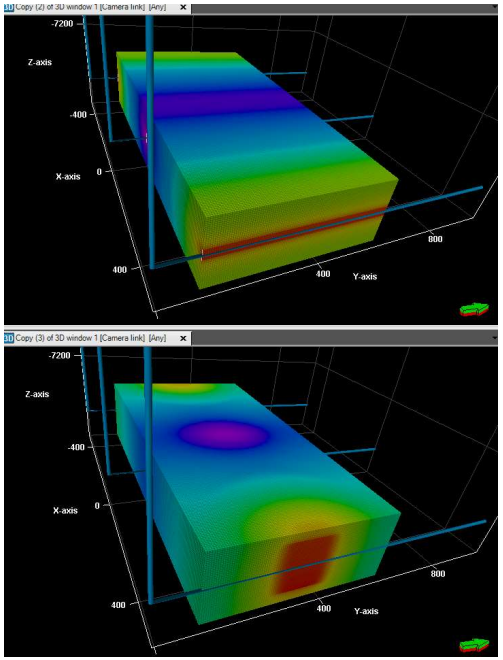


Figure 1—Carbonate dissolution pattern showing the existence of an optimum flow rate which gives the dominant wormhole dissolution pattern with the least amount of pore volume to breakthrough in coreflood tests (Al-Harthy et al. 2009).

Acid usage: CAJ liner & matrix acid stimulation



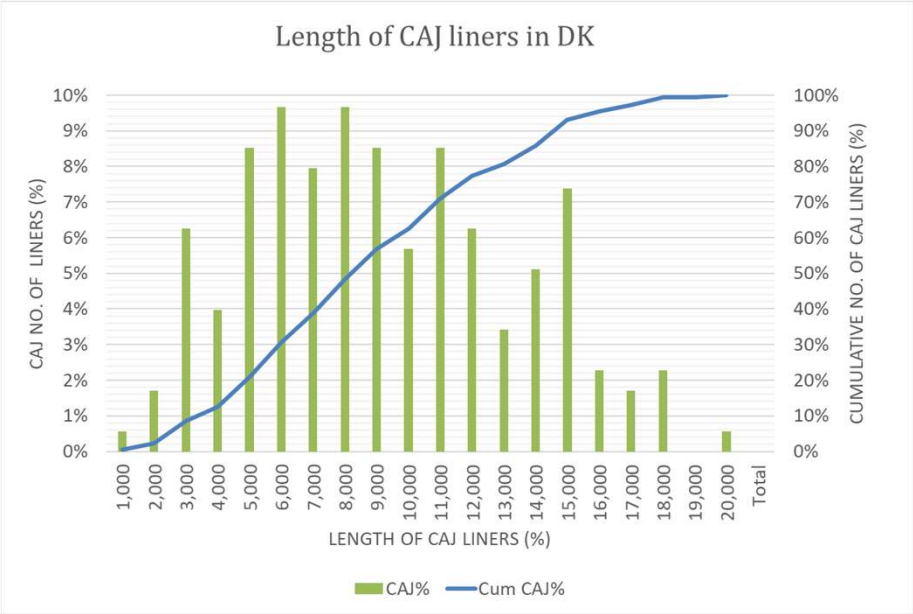




Surprising conclusions:

- For similar performance the uniform stimulation needs to stimulate 50% more rock volume than the wormhole cluster stimulation.
- The CAJ liner performs better than or similar to a fractured well for conventional spacing and kv/kh above 0.5.
- The limited number of small holes does not restrict production or injection.

Good experience with long and short CAJ liners



10 longest CAJ liners	
1	19205 ft
2	17582 ft
3	17268 ft
4	16246 ft
5	15491 ft
6	15288 ft
7	14990 ft
8	14918 ft
9	14860 ft
10	14780 ft

Experience since 1999:

- 1200+ km CAJ liner
- 300+ CAJ zones
- Long and short intervals handled successfully

Significant Cost and Rig Time Reduction in DK

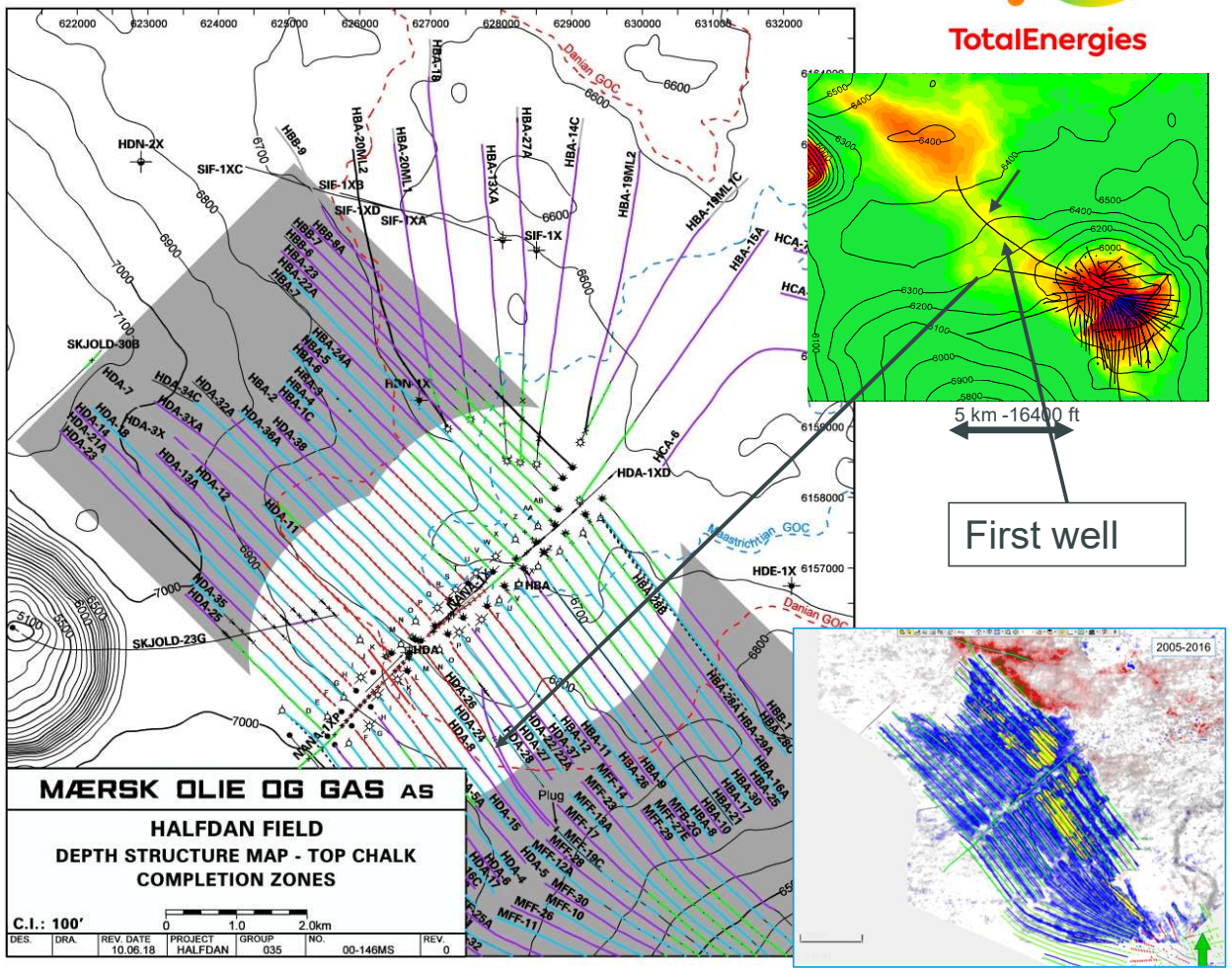
10,000 ft reservoir section within c/t reach		
Stimulation technique	Relative cost	Rig time (days)
Controlled Acid Jetting	13%	4.5
High Rate Matrix Stimulation	42%	18.7
Acid Fracturing	74%	32.4
Sand Propped Fracturing	100%	46.5

Impact of CAJ liner development:

- The well cost decreased
- The Dan – Halfdan area was developed with fewer wells, fewer platforms and fewer pipelines
- The time schedule accelerated substantially
- Additional reservoir flank areas became economic for development

Example of CAJ Liner application in the Dan & Halfdan fields offshore DK

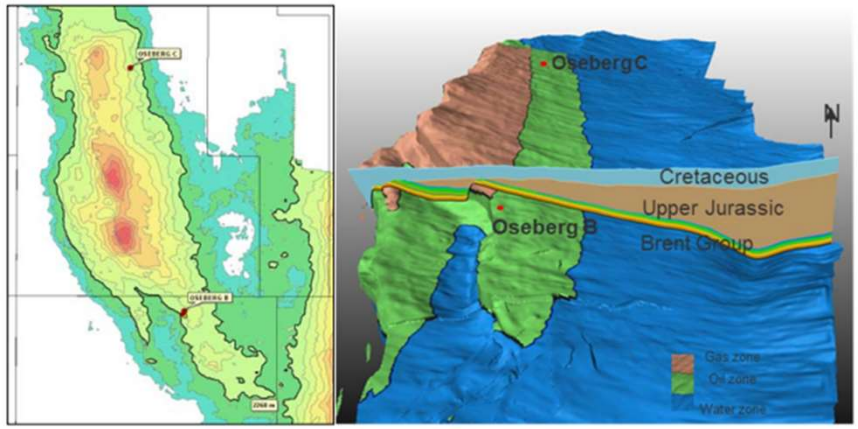
- 1200+ km CAJ liner in 300+ zones successfully installed and stimulated since 1999 (DK and Qatar)
- Productivity confirmed by well test, stimulation data analysis, 4D seismic, reservoir pressure, reservoir modelling, etc. including comparison of CAJ, matrix and fracture.
- Grey shaded areas located outside coiled tubing reach and would have required additional platforms, wells, pipelines etc. to develop.
- The flanks would not have been economically developed at all.
- CAJ liners now cover some 50% of all reservoir sections in Denmark
- Longest CAJ liner covers 19,200 ft / 6 km
- Denmark: Oil production 450 MM stb & water injection 1500 MMbbl (2018)

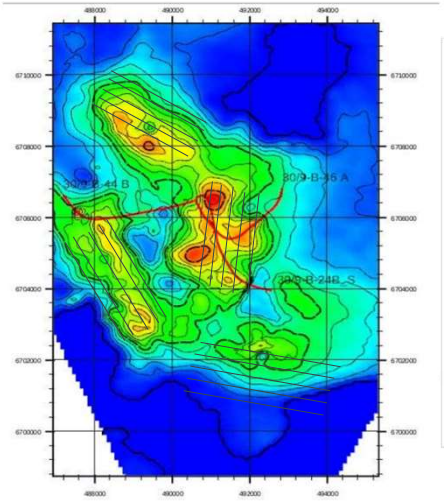


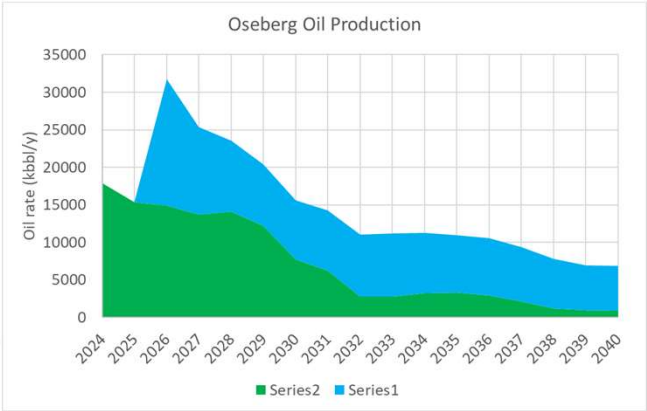
Potential Dev. of Stranded Oseberg Shetland Chalk

using Controlled Acid Jet (CAJ) technology

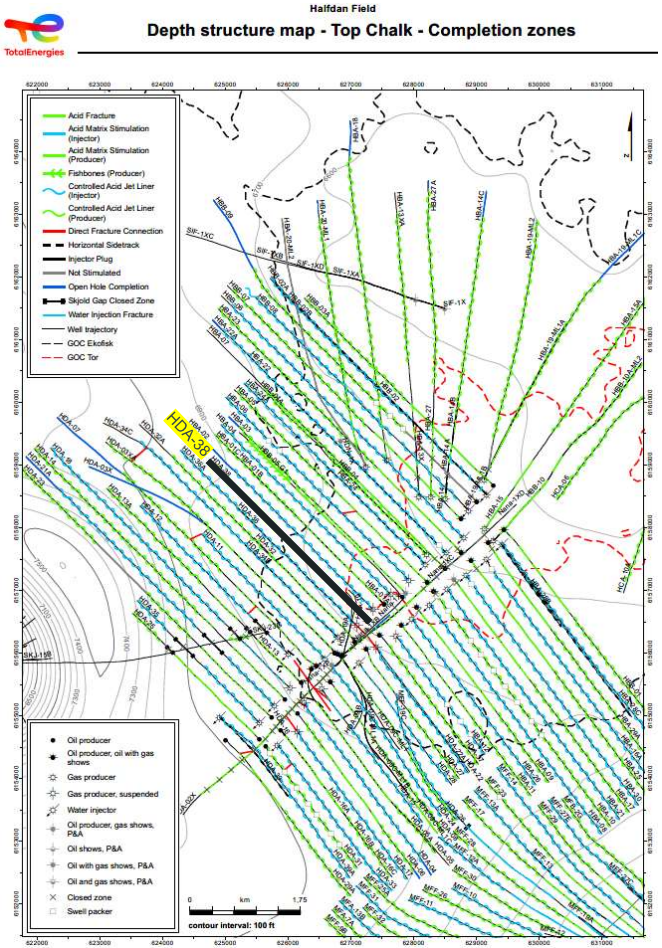
- Oseberg Shetland Fm is a low permatility (0.5 – 2 mD) laterally extensive chalk formation with ~200-400 Mboe STOOIP
- Oseberg Shetland chalk was deemed uneconomical due to high development cost and low production rates
- Controlled Acid Jet (CAJ) technology invented, developed and implemented by TotalEnergies & Maersk Oil in Denmark, Qatar, UAE to:
  - Lower well cost – typically 25% saving on total well cost
  - Longer and fewer wells – 20000 ft single operation stimulation
  - High well productivity similar to fractures
  - Less chemicals and no explosives
- Horizontal pilot well in Shetland fm (2007-2017), with classic fracturing technology, proved reservoir productivity but was not ecomomic due to well length, technology application and well design
- Compelling business case for first pilot and following development using CAJ outlined including field life extension

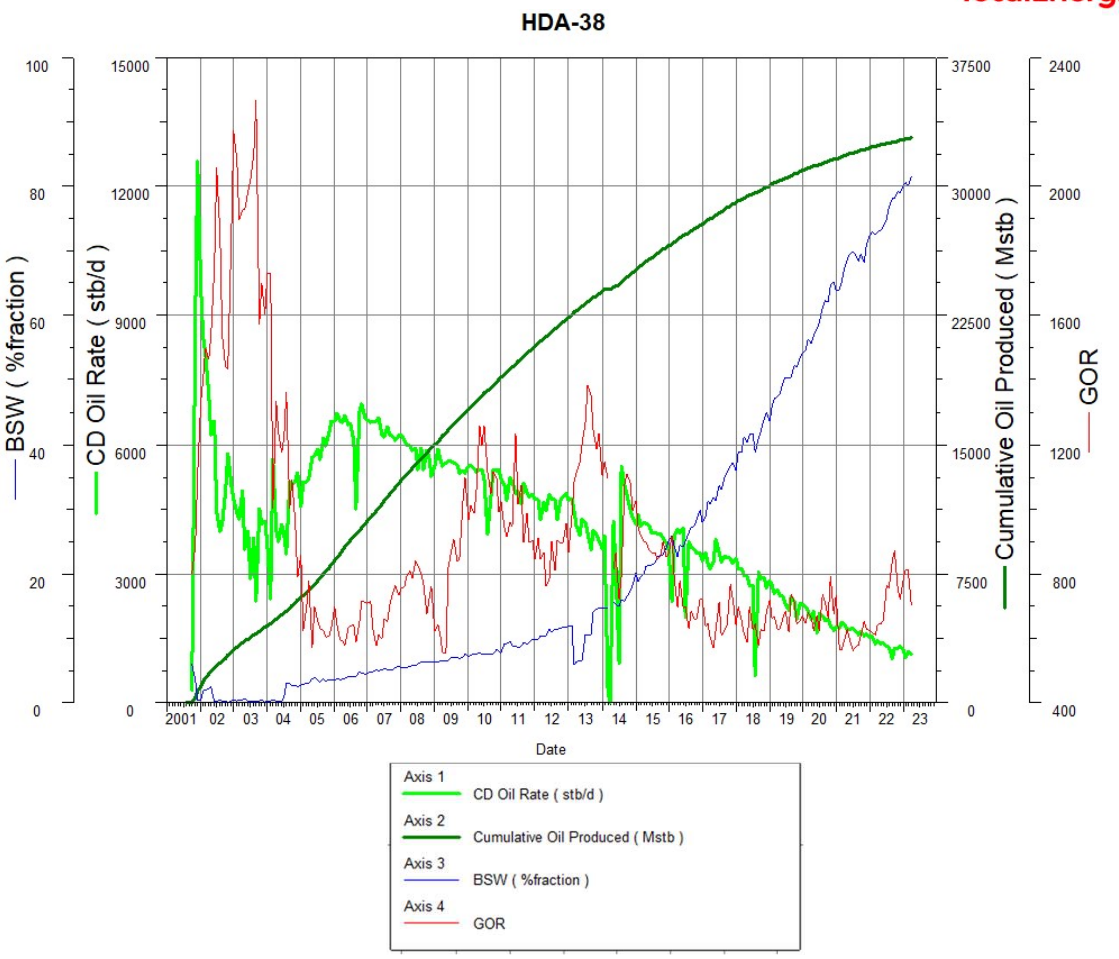




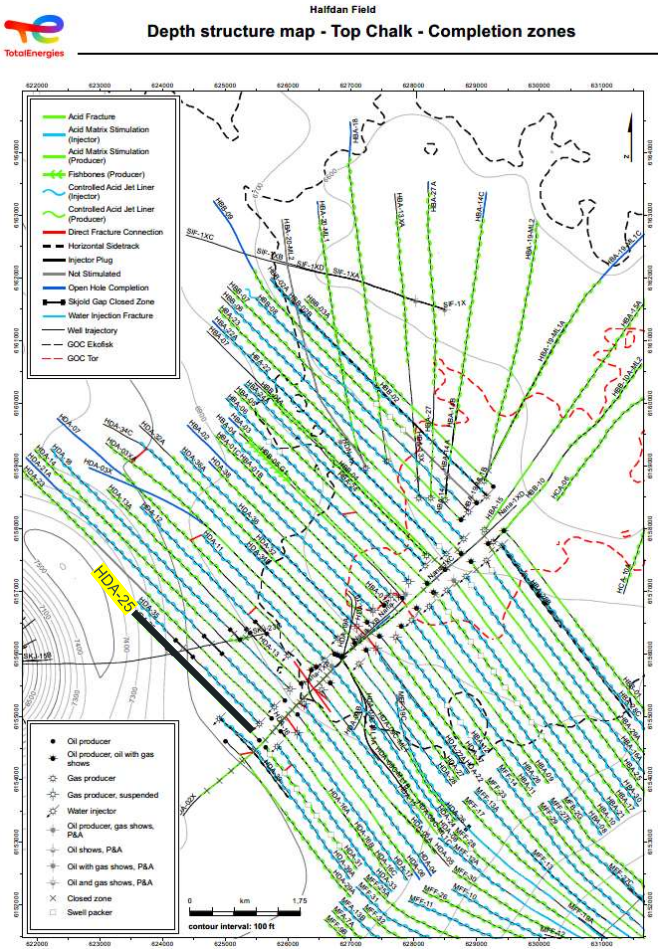


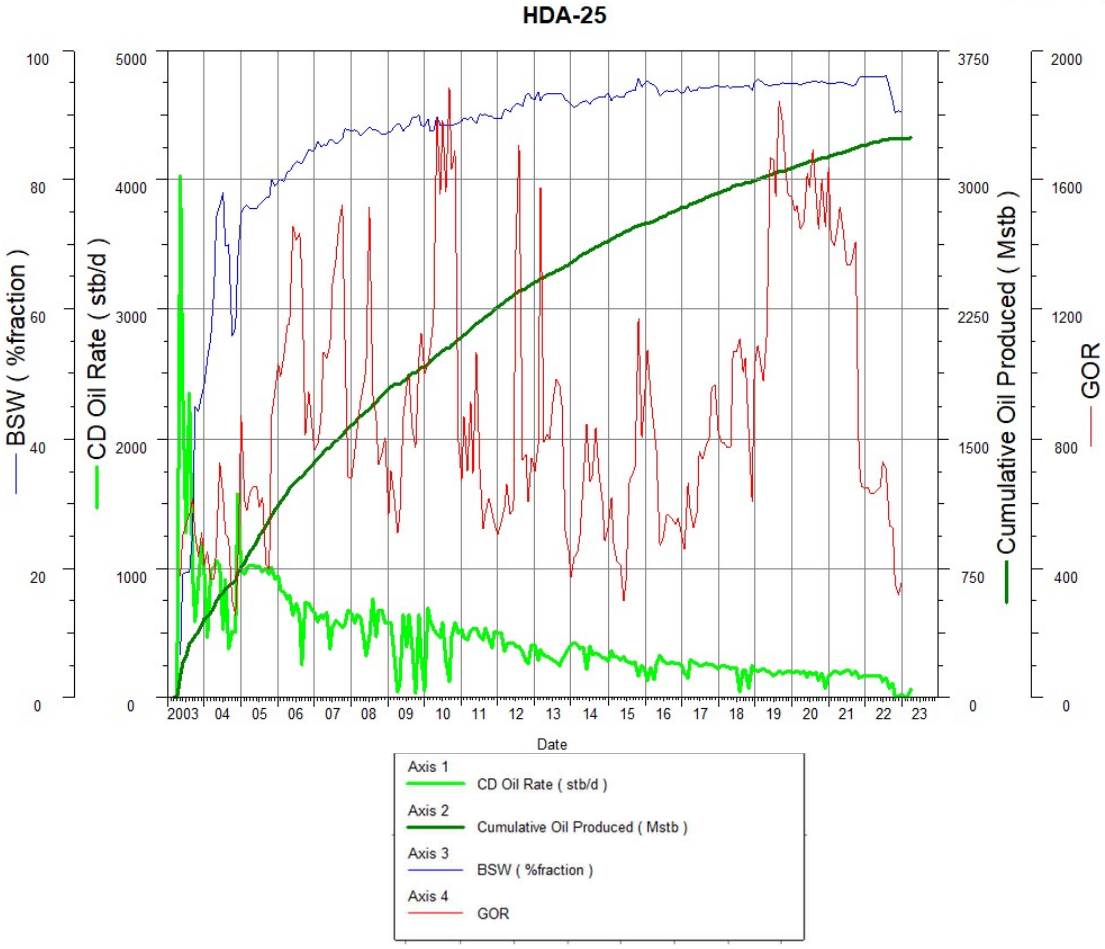
Halfdan Well Production Performance: HDA-38





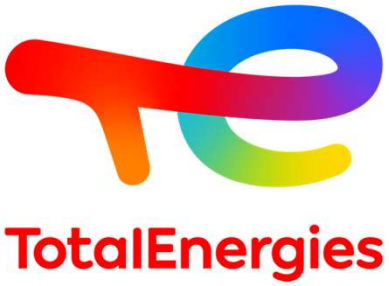
Halfdan Well Production Performance: HDA-25





Controlled Acid Jet (**CAJ**): Increasing recovery at **significantly reduced cost**

- **Application of CAJ liner technology**
  - For short or long wells in low permeability homogeneous carbonate reservoirs
- **Significant experience**
  - Invented, developed and implemented by TotalEnergies / Maersk Oil
  - CAJ liners in Denmark: Oil production 450 MM stb & water injection 1500 MMbbl (2018)
  - Successfully tested in 1200+ km reservoir section within TotalEnergies
  - Technology proved by well tests, 4D seismic, reservoir pressure, stimulation job analysis, reservoir modelling, etc.
- **Low cost**
  - Large rig time reduction on completion and stimulation (fast and simple installation) => Significant cost reduction
  - Longer wells => require fewer wells and fewer platforms for field development
  - Single operation stimulation of up to 20,000 ft (ca 6 km) zones! Rig not required
- **Efficiency**
  - Very high productivity / injectivity: Skin = -4 (Productivity is same as fracture stimulations)
  - No need to fracture the reservoir (additional cost, induced well connections, excessive water production, no additional production)
  - Full acid coverage in single zone length up to 20,000 ft (ca 6 km)
  - No need for diverters or mud displacement
  - Logging is more uncertain but due to flow in the annulus (adequate for reservoir mgt.)
  - Easy drilling of extended reach wells – formation impairment not a problem
- **HSE**
  - No perforation guns – CAJ holes are hand drilled on the rig floor
  - Fewer chemicals



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