A Closed Loop System Using a Brine Reservoir to Replace Fresh Water as the Frac Fluid Source

Minimization of Fresh Water Use: The Use and Reuse of 35000 ppm Brine from a Dedicated Deep Reservoir as a Fracture Fluid For Shale

George E. King
Apache Corporation
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Acknowledgements

• EnCana – water plant operator and lead company on testing of Debolt water.
• Dave Sherman (formerly Apache facilities) – plant design, water handling solutions, emissions reduction, natural gas substitution for Diesel fired engines in pad operations.
Minimizing Fresh Water Usage, George E. King, EPA 29/30 March 2011

Figure 1 Aerial Photo of the Horn River 70-K pad
A Unique Frac Water Source

• Debolt formation, above the Horn River Play (British Colombia, Canada)

• Water
  – 35,000 ppm TDS
  – H2S (10 to 30 ppm?) removed prior to use
  – Temperature of 60C (140F) (useful for cold weather operations)

• Minimizes water storage needs
• Minimizes fresh water requirements
• Flow back returned to the Debolt formation.
Cold Weather Water Pumping

Water at high rates has enormous specific heat capacity. If water is kept moving it can be pumped long distances in cold weather without freezing or heat input.

Intrinsic Heat Load for 10" Thin Wall Aluminum Pipe, -25 C

| Daily Water Volume Transferred | 16000 m³ |
| Tm | 5 Deg C |
| Water Vel | 3.6 m/s |
| ID | 25.4 m |
| Tamb | -25 Deg C |
| Air Vel | 1.4 m/s |
| Water Kin Vis | 0.000001519 m²/s |
| k | 0.609 W/(m Deg C) |
| Pr | 11.57 |
| Reynolds Number | 601974.9835 |
| Inside Film Coefficient hi |=((Nu)*k/ID) |
| Outside Film Coefficient ho | =NU*k/Do |
| Overall Heat Transfer Coefficient U | =1/(1/hi+1/ho) |

| Intrinsic Heat load | Heat Loss Per Meter Pipe Q | 334.8639279 W/m |

Water specific heat capacity at 16,000 m³/day, 2 Degrees C

| Water Specific Heat Capacity | 4.21 kJ/kg*K |
| Delta T | 2 Deg C |
| Mass Flow | 11000 kg/min |
| Meters to Freezing | 4609.83 m |

What happens when the water stops moving?

| 6" AL Pipe | 10" AL Pipe | 12" AL Pipe |
| 1.0 Length m | 1.0 Length m | 1.0 Length m |
| 18.2 kg water | 50.7 kg water | 73.0 kg water |
| 2.0 Temp Water | 2.0 Temp Water | 2.0 Temp Water |
| -10.3 minutes | -21.2 minutes | -27.5 minutes |

Large diameter water piping is a must for cold climate water pumping! Large diameter piping makes it possible to address equipment failures prior to piping freeze offs.
Before: Off lease Remote Water Heating 8° C @ 100 bbl/min – > 30 MMBTU/hr

Tight lease space on the d-70-K Pad and LPG fuel storage regulations required an off lease water heating solution creating the following special challenges:

Conventional methods were to heat bulk water storage reservoirs typically on lease, not provide instantaneous energy input for 8 C water heat rise at 100 BBL / min

| Water Specific Heat Capacity | 4.21 | kW/kg*K |
| Delta T | 8 | Deg C |
| Mass Flow | 16000 | kg/min |
| Specific Heat | 538880 | =kJ/min |
| | 30,645,580.01 | =BTU/HOUR |

Size and type of heat exchanger required for water flows at 100 – 125 bbl

| Q=mCp(DeltaT) | Q=266.7 kg/sec X 4210 J/Kg*K X 8 Deg C | =896133.3 Watts |
| Area = Q/(U X DeltaTLMTD) | Hex Area = 260.4 m² |
| Length 3 inch = 1087.8 m |

Heat losses in 1,000 m of 12” piping at -25 C

| Daily Water Volume Transferred | 16000 | m³ |
| Tamb | -25 | Deg C |
| Overall Heat Transfer Coefficient U | =1/(1/hi+1/ho) |
| Heat Loss Per Meter Pipe Q | -A*U*Delta T |
| DeltaT = Q/(m X Cp) | -0.331466002 Deg C |

Slipstream and Mix Flows Apache Solution to Enable Compact Portable Heat Exchange of 30,645,580 BTU / Hour
Water Management

• Large volumes of fresh water not required.
• Recycling frac & produced waters
• Higher salinity sources are now usable.
• Chemical Management is Essential
  – Biocides under the microscope
    • Greener (bio-degradable and no bioaccumulation)
  – Lower vol. of chemicals (what’s really needed?)
Brackish Water Source for Fracs

• High perm sand w/ 35,000 ppm, sour (H₂S) brine is present ~ 2,000’ above gas shale target zone.
• Brine can be supplied at high rate to the treating facility for sweetening and then to the frac spread for pumping.
• Flowback water is cleaned and re-injected.
• Advantages:
  – Fresh water use is cut to a minimum.
  – High Cl⁻ brine eliminates or reduces many chemicals
  – Surface storage of frac brine is <<5% of job volume.
  – Higher salinity brine stabilizes shale?
  – The hot water from the reservoir eliminates very expensive water heating need and eliminates air emissions from the heater
  – Cheaper than fresh water for development of multi-well pads
  – Lowest Environmental Impact and Smallest Foot Print
Moderate Salinity Brine Supply for Frac Water

• 2009 Capital spending to be minimized where possible
• Apache completions to begin October 2009
• Design for average of 3 Fracs a day with enough water for goal of 4 ~ 4,000 m³ fracs per day
• Lowest environmental impact and smallest footprint possible
• Repairs to water system can be performed in a timely fashion using local stock parts
• Follow all of Apache and Encana’s EH&S regulations, ensure safe handling of water
Getting away from fresh water use – Saline Water Supply Schematic

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77-K Non Potable Water Source Well

67-K Non Potable Water Source Well

Mercaptan Scavenger & PH Buffer

Treated Non Potable Source Water for Fracture Stimulations

ACL d-70-K Well Pad

ACL d-52-L Well Pad

Produced Shale Gas & Fracture Stimulation Flowback Water

Separator Vessels & Treated Water Storage Tanks

C-67-K/94-O-08 Etsho Compressor Station & Water Plant Site

67-K Plant Inlet Separator

Produced Natural Gas to Spectra Sales Tie-In

Produced Fracture Stimulation Flowback Water

Debolt Reservoir (ASR) Non-Potable Aquifer Storage Reservoir

Borrow Pits For Freshwater Storage Only

Fresh Water Lake

Mineral Production Wells to Source Water

Water Compatibility Review

* Water Recycle Line, Stimulation Flowback Water Compatibility Under Review

* Closed system, no storage of treated water in un-lined burrow pits.
Debolt Water Analysis

WATER ANALYSIS

CONTAINER IDENTITY: EnCana Oil & Gas Partnership
LOCATION [WGS]: ECA Elsho C-67-K/94-O-8
STOCK: Debolt
TEST TYPE AND NO.: WELLHEAD - 732.0 - 735.0
POINT OF SAMPLE: PUMPING
SAMPLE POINT NO.: 12:00 Hrs
Pressures, kPa (gauge): 2006 11 30
Date Sampled [WMD]: 2006 12 01
DATE ANALYZED [WMD]: 2006 12 03
CONTAINER [WMD]: SWAB
EPD: C-67-K/94-O-8
WELL NAME: Silverlip Production
OPERATOR: 690.2
LABORATORY FILE NUMBER: 62134-2000-0604
LABORATORY: PAGE
GHI: 695.0

TEST INTERVAL [FT (meters)]:
732.0 - 735.0
736.0 - 739.0
945.0 - 948.0

PHYSICAL DATA:

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LOGARITHMIC PATTERNS OF DISSOLVED IONS
meq/L

Remarks:
- Analyte Present: Total Fe (mg/L) = 11.0  Total Mn (mg/L) = 1.3
- Total Suspended Solids (mg/L) = 94.5  Conductivity @ 25°C (mS/cm) = 46.6
- Total Hardness as CaCO3 (mg/L) = 11067  Total Alkalinity (mg/L) = 2394.8
Flow Back vs. Time

Horizontal Shale Flowback Rates

3 bbls/minute
Flowback water from a shale frac. The yellow color is from iron in contact with oxygen from the air.

Slight adjustment to pH results in a clear solution.

Background salinity varies with the shale.
Ion variation in the backflow
Conclusions

• Debolt source water is from a regional sour aquifer with a TDS level unsuitable for either agriculture or drinking water.

• Use of Debolt water required a series of tests focused on water treatment, formation interaction and disposal potential.

• Environmental impact improvements are seen in a number of areas:
  – Closed loop system – no oxygen and minimal flare/venting.
  – Minimize water heater emissions using hot Debolt water (~140F/60C) to prevent freezing in the -20C operations.
  – Minimize fresh water usage - still used in surface drill & cementing.
  – Possible reduction of biocides & elimination of some other chemicals.
  – Reduce surface frac water storage to <<5% of total needed
  – Reduction of surface pipe & draw from lakes.
  – Reduction of truck traffic and roads by using the closed-loop system.

• Pad design (16 wells on 6.3 acres drains >2500 acres). Sharp reduction in roads, pipelines, facilities and traffic.

• Possible shale stability improvements with more saline water.
Support Slides

- Forward Osmosis Clean-Up
- Water Districts and Plastic Pipe Supply Lines
- Types of Treatment
Cleaning Up Drilling Fluids

Water treated by forward osmosis is not fresh water – it is a clean saline base fluid that can be used for fracturing.

Salinity of the water delivered by FO can be programmed.
Water Districts

• Flexible (e.g., HDPE) pipes – surface or subsurface to transfer water to and from wells without truck traffic.
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✓ — Indicates that the technology is applicable as a potential remedy as indicated by data collected from pilot or commercial scale units.

* SAR = Sodium Absorption Ratio = Na⁺/(Ca²⁺ + Mg²⁺)₀.₅

Gaudin et al. 2008: 119898
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The statements made during the workshop do not represent the views or opinions of EPA. The claims made by participants have not been verified or endorsed by EPA.

A non-fresh water source has been proposed and tested in the laboratory and field for application as a fracturing fluid in shale gas formations, with potential to replace a very high percentage of the fresh water used in the Encana and Apache area of the Horn River Basin in British Columbia, Canada (Pond, 2010; DeMong, 2011). The water source is the Debolt formation, which overlies the Horn River Play gas zones by several thousand feet. The Debolt formation in the EnCana/Apache area of the Horn River Basin contains a moderately saline water (35,000 ppm TDS), in a high strength, high permeability rock matrix capable of supplying thousands of barrels of water per hour. The intent of the project is to sharply reduce the amount of fresh water used in fracturing and to form a closed loop system that will reduce storage of water at the surface. Additional benefits include reduction of air emissions (pumps and heaters), reduction in chemicals (oxygen scavengers and biocides) and overall reduction in surface pipe lines and truck traffic. The project equipment involves dedicated water supply wells, large electric submersible pumps (ESP), a stand-alone water treating plant (to remove hydrogen sulfide gas (H₂S), and equipment to recover the after-frac produced water from the wells and reinject the fluids into the Debolt formation.

Shale gas developments in North America have centered on using fresh water as a fracturing base fluid since about year 2000, when the C.W. Slay well in the Barnett shale was refractured after foam fracture treatment and gelled fracture treatments were found to be expensive and created substandard well performance (Steinsberger, 2009; Grieser, 2003; Palisch, 2008; Schein, 2004; Arthur, 2009). The slick water re-fracture on this well (slick water contains 0.25 gallons of polyacrylamide polymer friction reducer per 1000 gallons of water, plus smaller amounts of scale inhibitor, biocide and oxygen scavenger (Authur, 2009)) provided gas rates above even the initial rates from the well when it was first stimulated in 1983. The ability of slick water fracturing to enhance the productivity of shale well from the unfractured initial flows of 0 to less than 100 scf/d, to fracture stimulated average initial flows of 1,000,000 to 10,000,000+ scf/d, has been shown to be controlled by penetration of the low viscosity water (water at 0.6 to 1.0 centipoises) into the natural fractures of the shales, providing ability for the increasing pressure to widen the natural fractures, opening up flow paths to the natural gas trapped within the shale. Previous fracture fluids were less effective in the shales due to higher viscosity preventing fluids from invading and opening the natural fracture systems and the high
cost of gelled and foam fracturing fluids with accompanying large amounts of expensive additives. Well performance has been directly linked to larger amounts of water, larger amounts of proppant and higher injection rates (Coulter, 2004; 2006, King 2008, 2010).

Objections to fresh water use for hydraulic fracturing have risen in several places and, while the quantity of fresh water is lower in these shale developments than many local industries, agriculture and municipal uses, the returning water is often highly saline, making water recovery to the fresh water supply more technologically difficult (Gaudlip, 2008; Blauch, 2009).

This presentation focuses on a joint project by EnCana and Apache to use the moderately saline water from the Debolt formation as a primary source for fracturing fluid for the Horn River Basin (HRB) Shales in the northern British Columbia (BC) Province of Canada. The pilot projects and initial fracturing operations from multi-well pads in the HRB area was accomplished with fresh water from municipal water sources and finally from the local lakes within the guidelines set up by the BC Oil and Gas Commission (OGC). For larger scale operations, the companies sought a source of water that was more stable and less environmentally intrusive, settling on the Debolt formation brine.

Laboratory testing (Pond, 2010) identified the water treatment necessary to address H$_2$S (60 to 80 ppm in water phase and up to a few thousand in the water vapor phase) and several other considerations. The following chart from SPE 138222 summarizes the EnCana work.

**Table 5. Source: SPE 138222**

<table>
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<th>Method</th>
<th>Justification</th>
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<tr>
<td>Maintain high pH</td>
<td>Safety - potential release of H$_2$S if pH is lowered</td>
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<td>pH buffering</td>
<td>Required for H$_2$S equilibrium</td>
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<tr>
<td>Downhole separation</td>
<td>Compatibility with wellbore</td>
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<td>Stimulation of nitrate-reducing bacteria</td>
<td>Questionable effectiveness - source of H$_2$S not known</td>
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<td>Biocides to kill sulfate-reducing bacteria</td>
<td>Questionable effectiveness - source of H$_2$S not known</td>
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<td>Precipitation, coagulant, flocculent</td>
<td>Solids production - removal/disposal versus introduction into Horn River</td>
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<td>Steam stripping</td>
<td>High energy requirement</td>
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<td>Mechanical stripping</td>
<td>Option to scale up</td>
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<td>CO$_2$ stripping</td>
<td>Cost - CO$_2$ not readily available</td>
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<tr>
<td>Gas stripping</td>
<td>Required to strip H$_2$S from water</td>
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<tr>
<td>H$_2$S scavenging chemicals</td>
<td>Required for final polishing</td>
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General water treating steps and rational behind the operation was as follows:
- Dilute HCl with corrosion inhibitor injected downstream of supply wellhead to lower pH and prevent scaling.
- Inject high pressure natural gas to strip H$_2$S and CO$_2$. Second step was low pressure gas stripping of water.
- Collect water in a tank and flash off gas and vapor for treatment and recovery or incineration.
- Monitoring water flow rate accomplished by inline measurement.
- Small storage of water was accomplished in positive pressure tanks with a propane atmosphere.
- Final “polishing” step with a chemical scavenger reduced H$_2$S in the frac water to zero.

The process was brought to a commercial, high rate level with twenty-one total potential steps and optional steps (Table 6). The testing met objectives of 0 ppm H$_2$S with no unfavorable by-products. Detailed water monitoring checked on bicarbonate concentrations, scale potential, barium concentration and iron sulfide content. Other testing on biocides, scale inhibitors and general shale impact of the Debolt water showed minimum impact. The salinity of the water did require re-engineering of some additives.

The Debolt water source is provided by two ESP pumped wells. Each ESP has an operating envelope in the range of 31,250 to 50,000 barrels per day (5000 to 8000 m$^3$/d). The water treatment plant is designed for 100,000 barrels per day (16,000 m$^3$/d), which is sufficient for 3 to 4 fracs per day.

Table 6. The Debolt Process Flow Diagram (SPE 138222)

There are two tanks, each with a volume of 9375 bbls (1500 m$^3$) for storage of processed water (sweet). A frac spread may only draw from a full tank, eliminating the possibility of an upset in the treating system supplying out-of-spec water to the pumping equipment.
Post-frac produced water flow from the wells will be processed with a minimum of treatment except to remove solids and gas, and then re-injected into the Debolt formation. On-going studies will monitor both the supply and the disposal.

Conclusions

- The Debolt water source is a regional sour aquifer with a TDS level unsuitable for either agriculture or drinking water.
- Use of the Debolt water required a series of tests focused on water treatment, formation interaction and disposal potential.
- Environmental impact improvements are seen in a number of areas:
  - Minimization of water heater emissions by using the hot water from the Debolt (approximately 140 °F/60 °C) instead of heating lake water to prevent freezing in the -20C operations.
  - Minimization of fresh water usage. Fresh water still used for surface drilling and cementing.
  - Possible reduction of biocides and elimination of several other chemicals by keeping oxygen out of the water.
  - Reduction of surface frac water storage to less than 5% of total needed
  - Reduction of surface pipe from lakes.
  - Reduction of truck traffic and roads by using the closed-loop system.

References


