

# 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

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EPA Workshop on Hydraulic Fracturing

March 29/30, 2011

# 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.

Figure 1 Aerial Photo of the Horn River 70-K pad, EPA 29/30 March 2011

# A Unique Frac Water Source

- Debolt formation, above the Horn River Play (British Colombia, Canada)
- Water
  - 35,000 ppm TDS
  - H<sub>2</sub>S (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	Water Volume
Tm	5	Deg C	Temp Water
Water Vel	3.6	m/s	Velocity
ID	25.4	m	Pipe ID
Tamb	-25	Deg C	Air Tamb
Air Vel	1.4	m/s	Wind Speed
Water Kin Vis	0.000001519	m^2/s	Kin Viscosity
k	0.609	W/(m Deg C)	Thermal Cond
Pr	11.57	Prandtl Number	Water near zero
Reynolds Number	UmD/v	601974.9835	
Inside Film Coefficient hi	=(Nu)*k/Di	4832.525724	W/(m^2*Deg C)
Outside Film Coefficient ho	=NU*k/Do	14.02886245	W/(m^2*Deg C)
Overall Heat Transfer Coefficient U	=1/(1/hi+1/ho)	13.98825443	W/(m^2*Deg C)
Intrinsic Heat load			
Heat Loss Per Meter Pipe Q	=A*U*Delta T	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
	1543666.667	=Joule/sec
Meters to Freezing	4609.83	m

## What happens when the water stops moving?

6" AL Pipe	10" AL Pipe	12" AL Pipe
Time to Freeze	Time to Freeze	Time to Freeze
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	kJ/kg*K
Delta T	8	Deg C
Mass Flow	16000	kg/min
Specific Heat	538880	=kJ/min
	30,645,580.01	=BTU/Hour

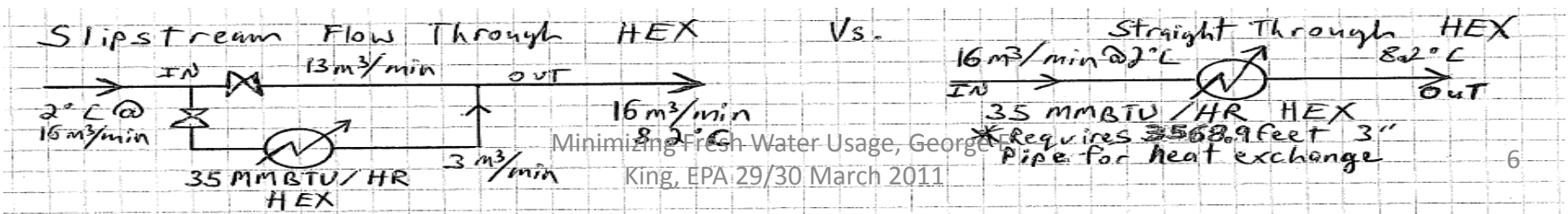
Size and type of heat exchanger required for water flows at 100 – 125 bbl

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

Q=mCp(DeltaT)	
Q=266.7 kg/sec X 4210 J/Kg*K X 8 Deg C	
=8981333.3 Watts	
Area = Q/(U X DeltaT <sub>LMTD</sub> )	
Hex Area =	260.4 m^2
Length 3 Inch	= 1087.8 m

Daily Water Volume Transferred	16000	m3	
ID	30.48	cm	
Tamb	-25	Deg C	
Overall Heat Transfer Coefficient U	=1/(1/hi+1/ho)	12.9539951	W/(m^2*Deg C)
Heat Loss Per Meter Pipe Q	=A*U*Delta T	372.1258318	W/m
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

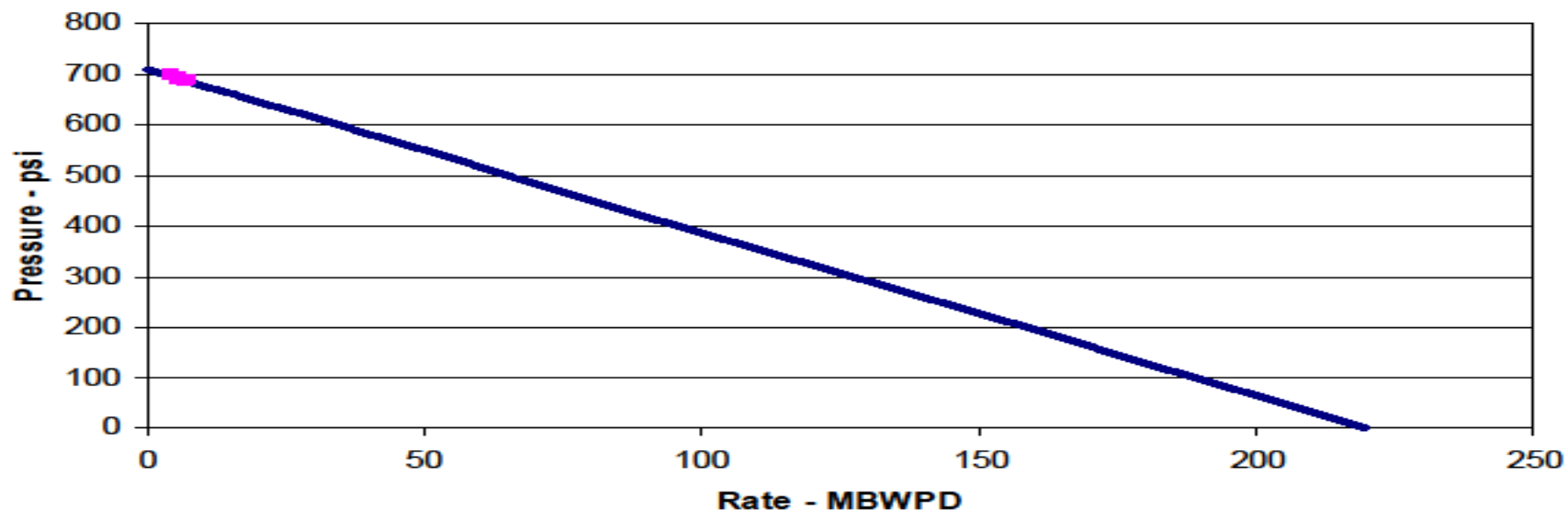
- High perm sand w/ 35,000 ppm, sour ( $\text{H}_2\text{S}$ ) brine is present  $\sim 2,000'$  above gas shale target zone.
- Brine can be supplied at high rate to the treating facility for sweetening and then to the frac spread for pumping.
- Flowback water is cleaned and re-injected.
- Advantages:
  - Fresh water use is cut to a minimum.
  - High  $\text{Cl}^-$  brine eliminates or reduces many chemicals
  - Surface storage of frac brine is  $\ll 5\%$  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





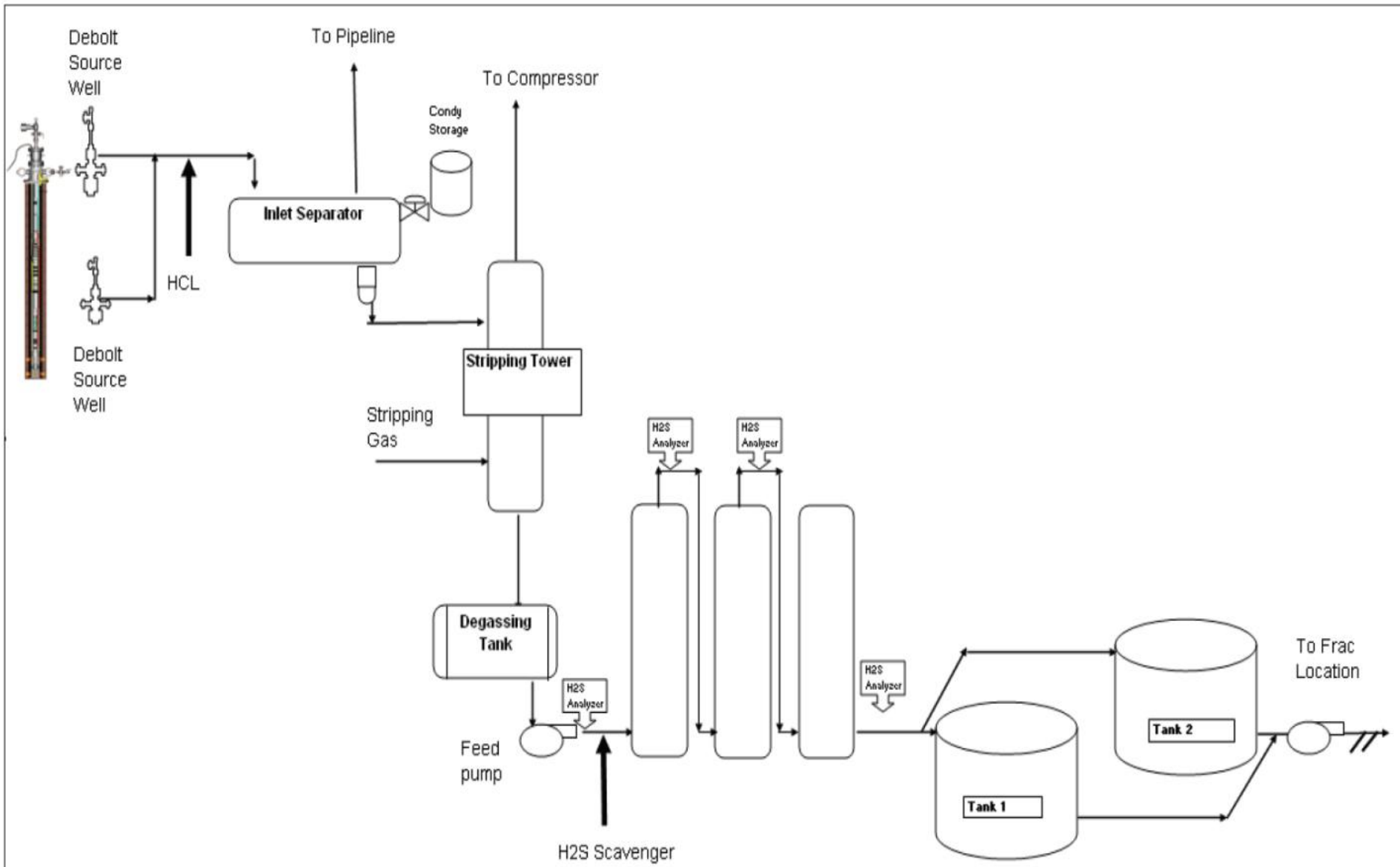
# Moderate Salinity Brine Supply for Frac Water

**a-77-K/94-O-8 Debolt Water Test**

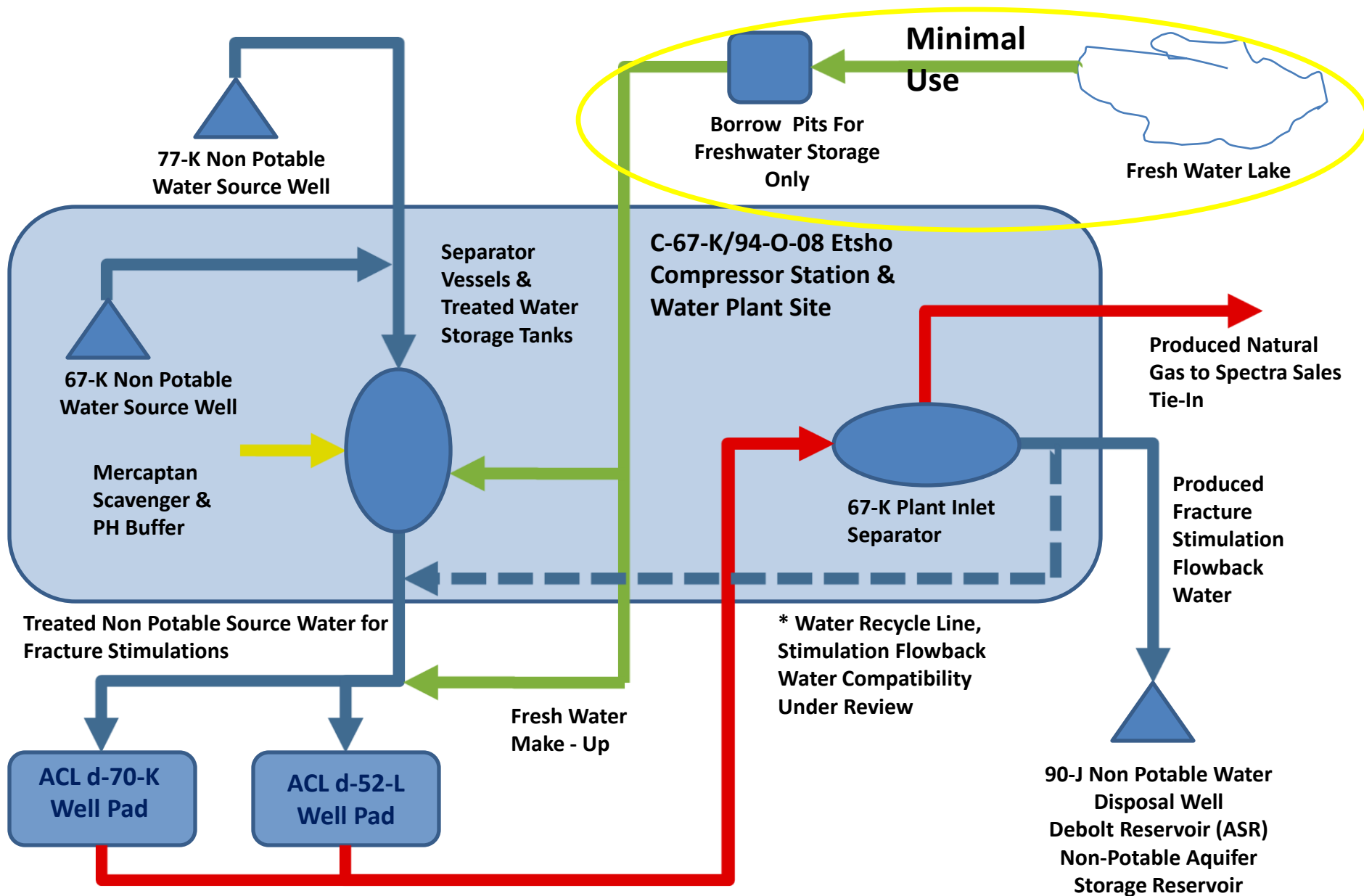


- 2009 Capital spending to be minimized where possible
- Apache completions to begin October 2009
- Design for average of 3 Fracs a day with enough water for goal of 4 ~ 4,000 m3 fracs per day
- Lowest environmental impact and smallest footprint possible
- Repairs to water system can be performed in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

# SPE 138222, Pond, et al., (EnCana)



# Getting away from fresh water use – Saline Water Supply Schematic



Produced Shale Gas & Fracture Stimulation Flowback Water Usage, George E.

King, EPA 29/30 March 2011

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

# Debolt Water Analysis



## WATER ANALYSIS

338 - 8 ✓ CONTAINER IDENTITY

METER ID: EnCana Oil & Gas Partnership OPERATOR

WELL LICENSE NUMBER: 24526

LABORATORY FILE NUMBER: 52134-2008-6604 ✓

200/c-67-k/94-O-8/00 LOCATION (UWI)

ECA Etsho C-67-K/94-O-8 WELL NAME

690.2 KB ELEV (m)

685.0 GR ELEV (m)

Etsho FIELD OR AREA

Debolt POOL OR ZONE

Silvertip Production SAMPLER

TEST TYPE AND NO. Wellhead

TEST RECOVERY

732.0 - 735.0  
736.0 - 739.0  
845.0 - 848.0

POINT OF SAMPLE

PUMPING FLOWING GAS LIFT SWAB

WATER m/d OIL m/y GAS m/d

TEST INTERVAL or PERFS (meters)

SEPARATOR RESERVOIR OTHER

CONTAINER WHEN SAMPLED CONTAINER WHEN RECEIVED

12:00 Hrs Pressures, kPa (gauge)

2008 11 30 DATE SAMPLED (Y/M/D)

2008 12 01 DATE RECEIVED (Y/M/D)

2008 12 03 DATE ANALYZED (Y/M/D)

S/M/Y ANALYST

SEPARATOR OTHER

Temperatures, °C

ANY AND TYPE CUSHION MUD RESISTIVITY

CATIONS				ANIONS			
ION	mg/L	mg Fraction	meq/L	ION	mg/L	mg Fraction	meq/L
Na	8,150	0.2470	354.5	Cl	17,546	0.5318	494.9
K	70	0.0021	1.8	Br			
Ca	2,670	0.0809	133.2	I			
Mg	1,190	0.0361	97.9	HCO <sub>3</sub>	2,994	0.0908	49.1
Ba	285	0.0086	4.2	SO <sub>4</sub>	29	0.0009	0.6
Sr	57	0.0017	1.3	CO <sub>3</sub>	0.00	0.0000	0.0
Pb	1.2	0.0000	0.0	OH	0.00	0.0000	0.0
Mn	1.2	0.0000	0.0	H <sub>2</sub> S	Pres.		

### Total Dissolved Solids (mg/L)

37847

By Evaporation @ 110 °C

35191

By Evaporation @ 185 °C

32993

Calculated

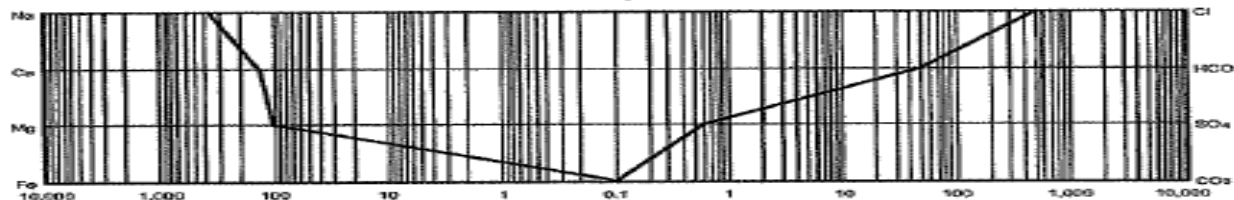
1.0255 @ 15.6 °C  
Specific Gravity

1.3394 @ 23 °C  
Refractive Index

7.4 @ 25.0 °C  
pH

0.215 @ 25 °C  
Resistivity (Ohm-Meters)

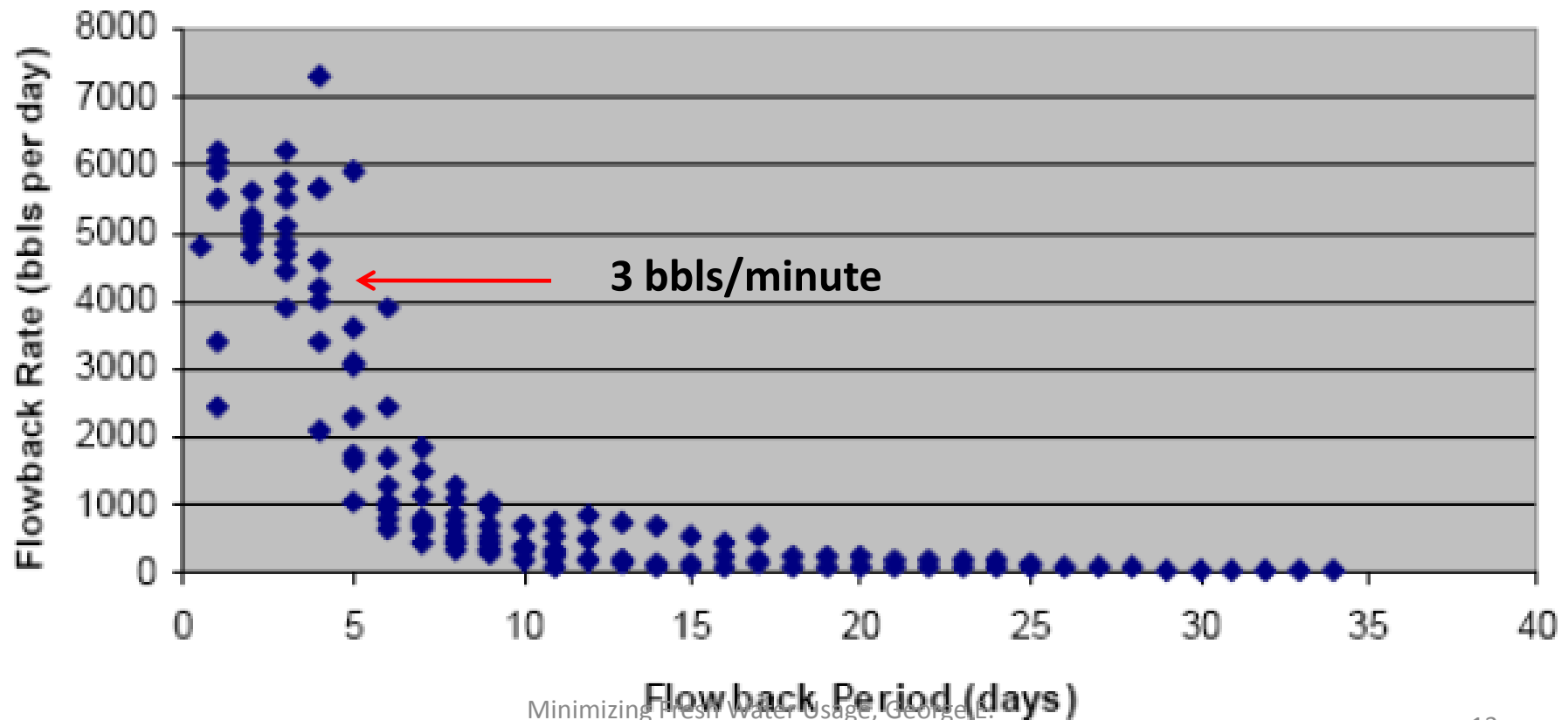
### LOGARITHMIC PATTERNS OF DISSOLVED IONS meq/L



REMARKS: Pres. - 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 CaCO<sub>3</sub> (mg/L) = 11567 Total Alkalinity (mg/L) = 2394.8

# Flow Back vs. Time

## Horizontal Shale Flowback Rates



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

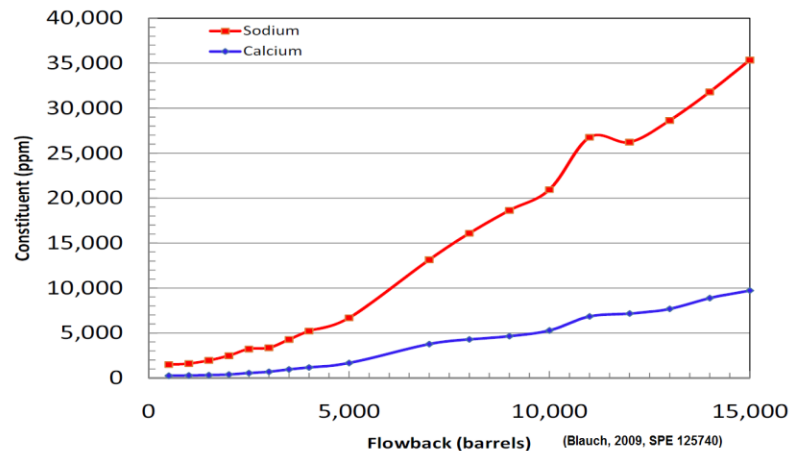
Slight adjustment to pH results in a  
clear solution.

Background salinity varies with the  
shale.

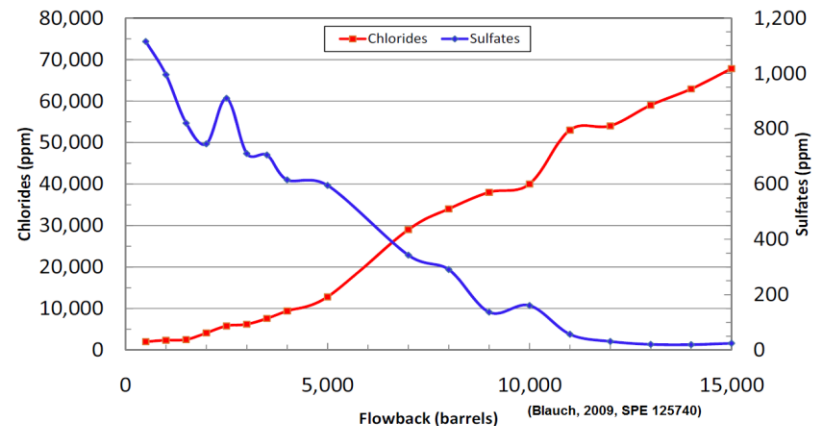




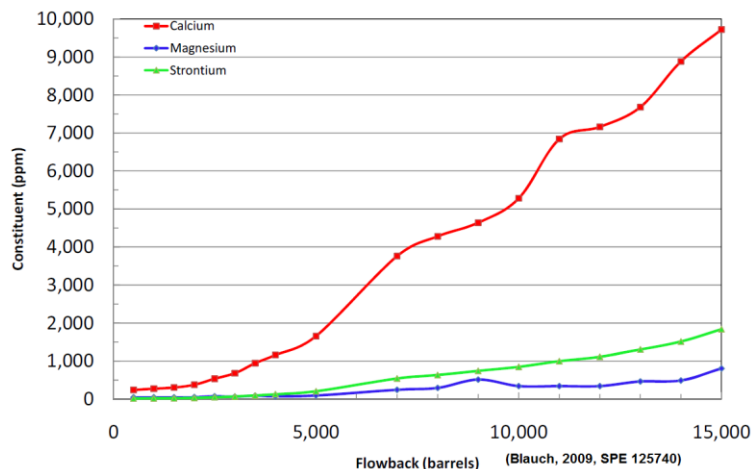
# Ion variation in the backflow



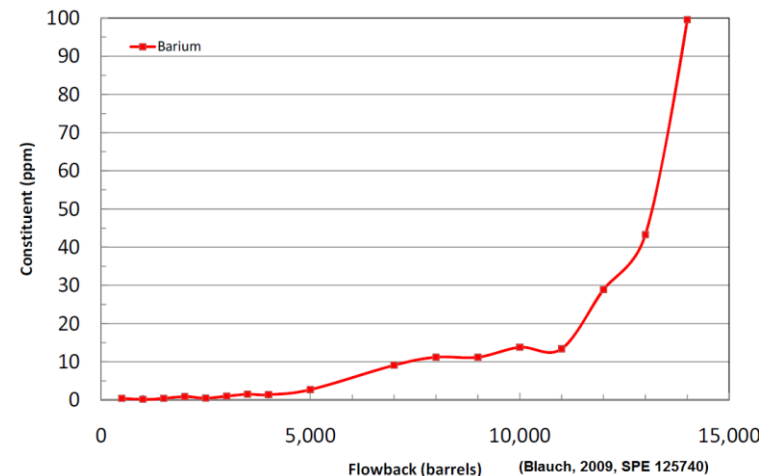
Marcellus Shale Well A flowback analysis—major cation trend.



Marcellus Shale Well A flowback analysis—anion trend.



Marcellus Shale Well A flowback—divalent cation trend.



Marcellus Shale Well A flowback—barium trend.

# 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

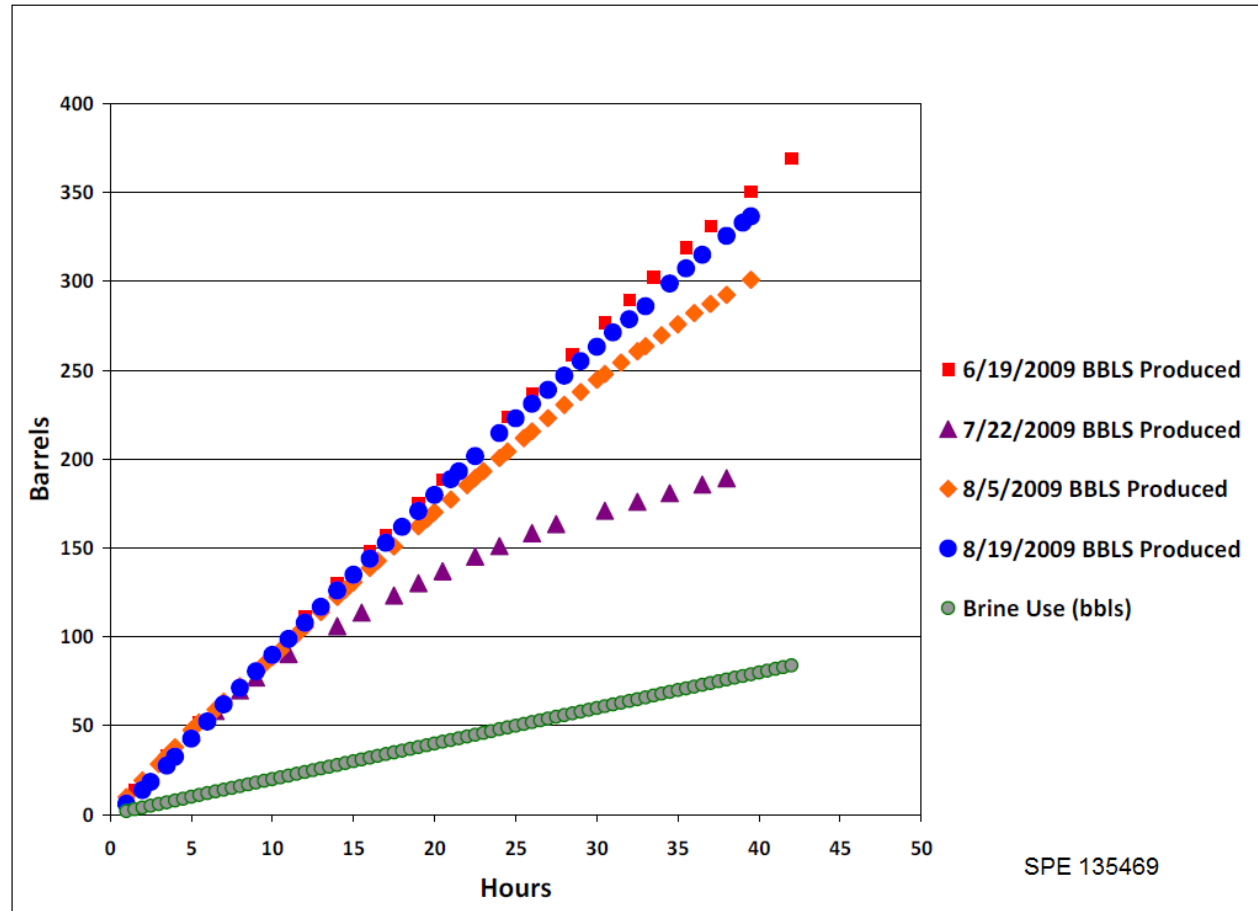
Water treated by forward osmosis is not fresh water – it is a clean saline base fluid that can be used for fracturing.

Salinity of the water delivered by FO can be programmed.

Figure 5. Before (Reserve Pit) and After (FO-Reclaimed) Water Samples

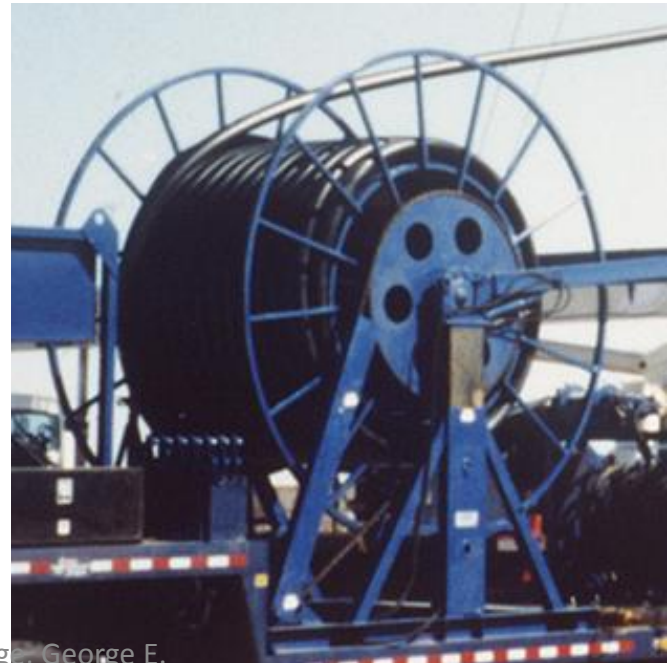


Figure 4. Results of Pilot Tests



# Water Districts

- Flexible (e.g., HDPE) pipes – surface or subsurface to transfer water to and from wells without truck traffic.



Treatment Method	De-Oiling	Suspended Solids Removal	Iron Removal	Ca & Mg Removal Softening	Soluble Organic Removal	Trace Organics Removal	Desalination & Brine Volume Red	Adjustment of SAR*	Silicate & Boron Removal
API Separator	✓	✓							
Deep Bed Filter	✓	✓							
Hydroclone	✓	✓							
Induced Gas Flotation	✓	✓							
Ultra-filtration	✓	✓							
Sand Filtration		✓							
Aeration & Sedimentation		✓	✓						
Precipitation Softening				✓					✓
Ion Exchange			✓	✓					✓
Biological Treatment					✓				
Ozonation	✓		✓		✓	✓			
Activated Carbon						✓			
Reverse Osmosis							✓		
Distillation							✓		
Freeze Thaw Evaporation					✓		✓		
Electrodialysis					✓		✓		
Chemical Addition								✓	

✓ = 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 =  $\text{Na}^+ / ((\text{Ca}^{+2} + \text{Mg}^{+2}) / 2)^{0.5}$

KLING, EPA 23/50 MARCH 2011

Gaudin, 2003, 119898



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*Minimization of Fresh Water Use: The Use and Reuse of 35,000 ppm Brine from a Dedicated Deep Reservoir as a Fracture Fluid for Shale*

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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 (H<sub>2</sub>S), 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 (Arthur, 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<sub>2</sub>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*

Method	Justification
Maintain high pH	Safety - potential release of H <sub>2</sub> S if pH is lowered
pH buffering	Required for H <sub>2</sub> S equilibrium
Downhole separation	Compatibility with wellbore
Stimulation of nitrate-reducing bacteria	Questionable effectiveness - source of H <sub>2</sub> S not known
Biocides to kill sulfate-reducing bacteria	Questionable effectiveness - source of H <sub>2</sub> S not known
Precipitation, coagulant, flocculent	Solids production - removal/disposal versus introduction into Horn River
Steam stripping	High energy requirement
Mechanical stripping	Option to scale up
CO <sub>2</sub> stripping	Cost - CO <sub>2</sub> not readily available
Gas stripping	Required to strip H <sub>2</sub> S from water
H <sub>2</sub> S scavenging chemicals	Required for final polishing

General water treating steps and rationale behind the operation was as follows:

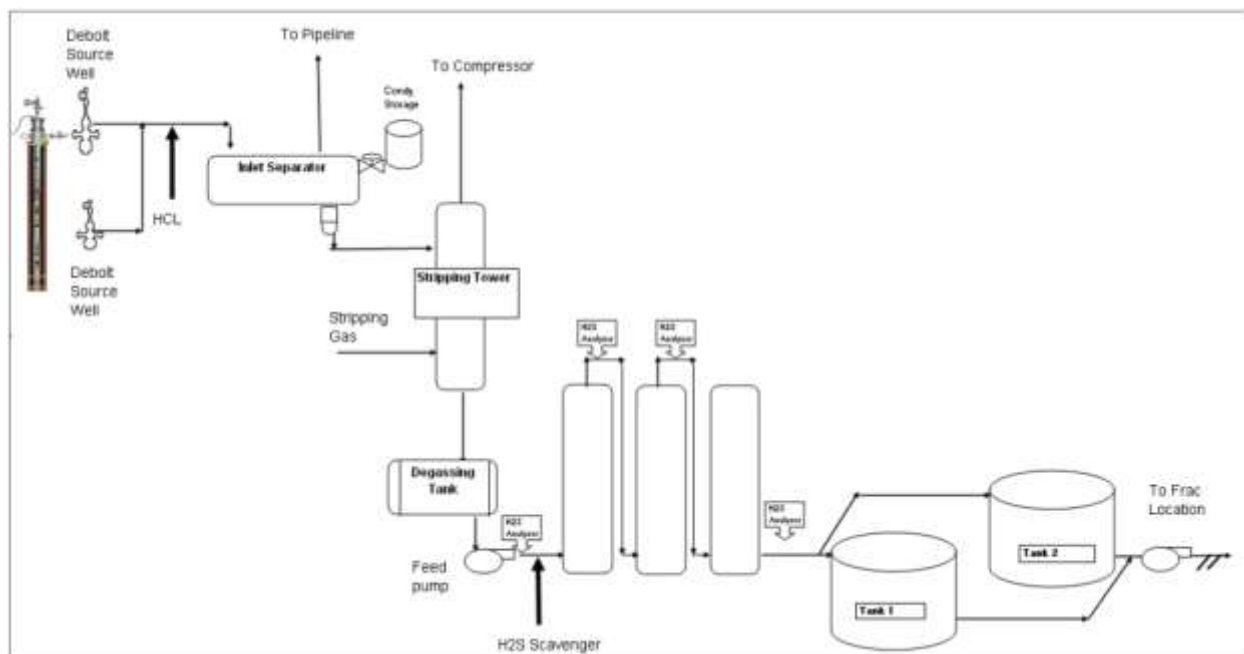
- Dilute HCl with corrosion inhibitor injected downstream of supply wellhead to lower pH and prevent scaling.
- Inject high pressure natural gas to strip H<sub>2</sub>S and CO<sub>2</sub>. Second step was low pressure gas stripping of water.

- 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<sub>2</sub>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<sub>2</sub>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<sup>3</sup>/d). The water treatment plant is designed for 100,000 barrels per day (16,000 m<sup>3</sup>/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<sup>3</sup>) 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.

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