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
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.

SPE 140654 9

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.

Dave Sherman, Apache Canada, 2010

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**		**Water Temp**
Water Vel	**3.6**	**m/s**		**Water 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**

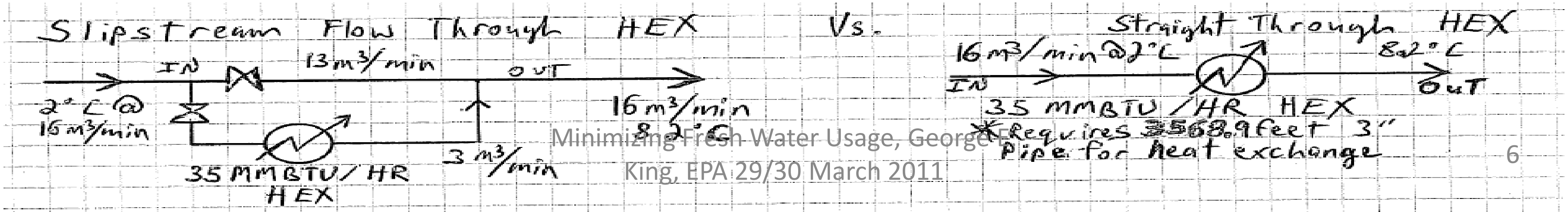
Size and type of heat exchanger required for water flows at 100 – 125 bbl

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

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

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



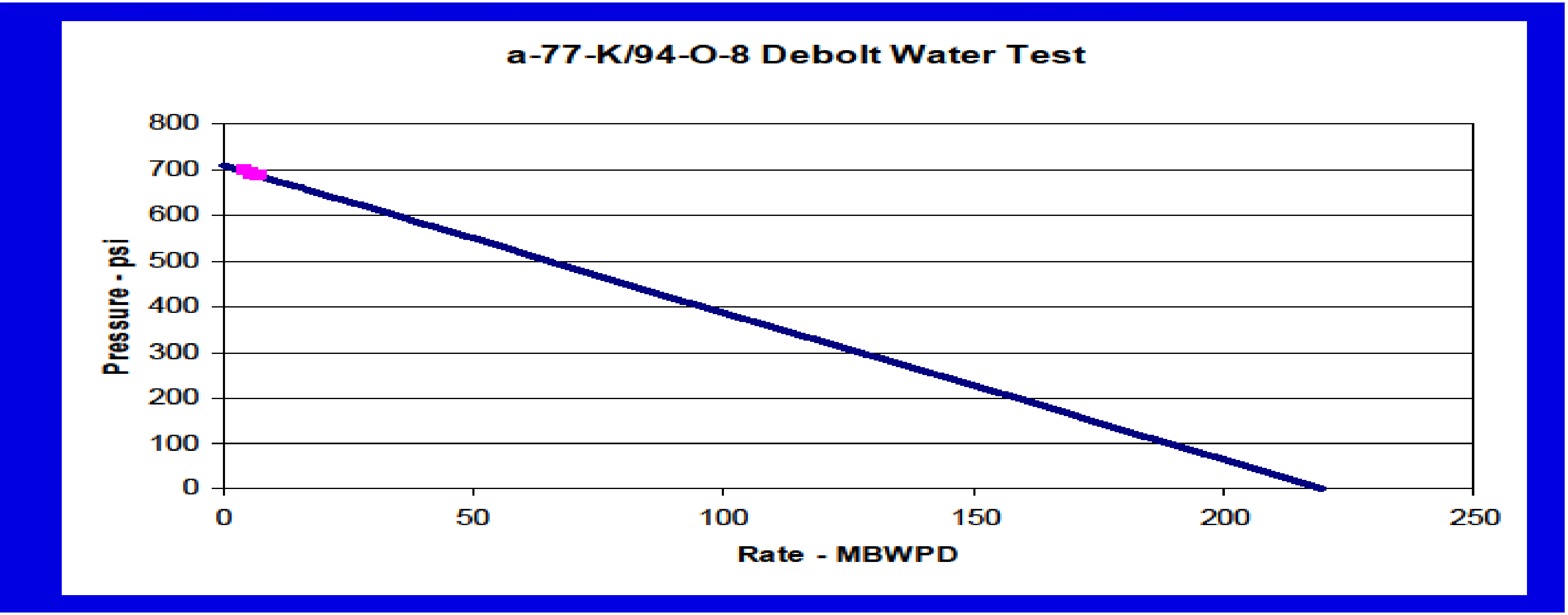
Water Management

- Large volumes of <u>fresh</u> 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

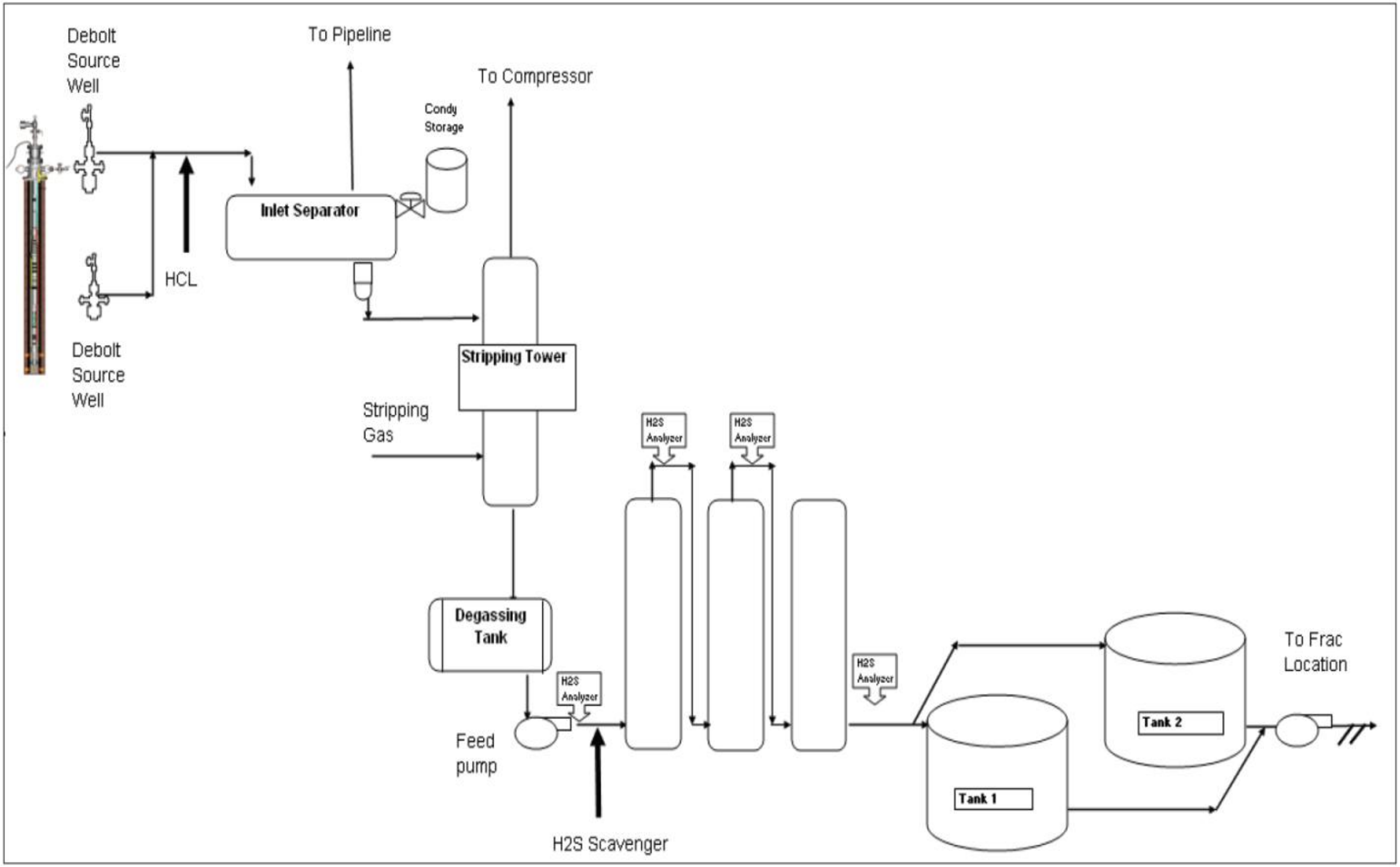
- High perm sand w/ 35,000 ppm, sour (H_2S) brine is present ~ 2,000’ above gas shale target zone.
- Brine can be supplied at high rate to the treating facility for sweetening and then to the frac spread for pumping.
- Flowback water is cleaned and re-injected.
- Advantages:
  - Fresh water use is cut 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

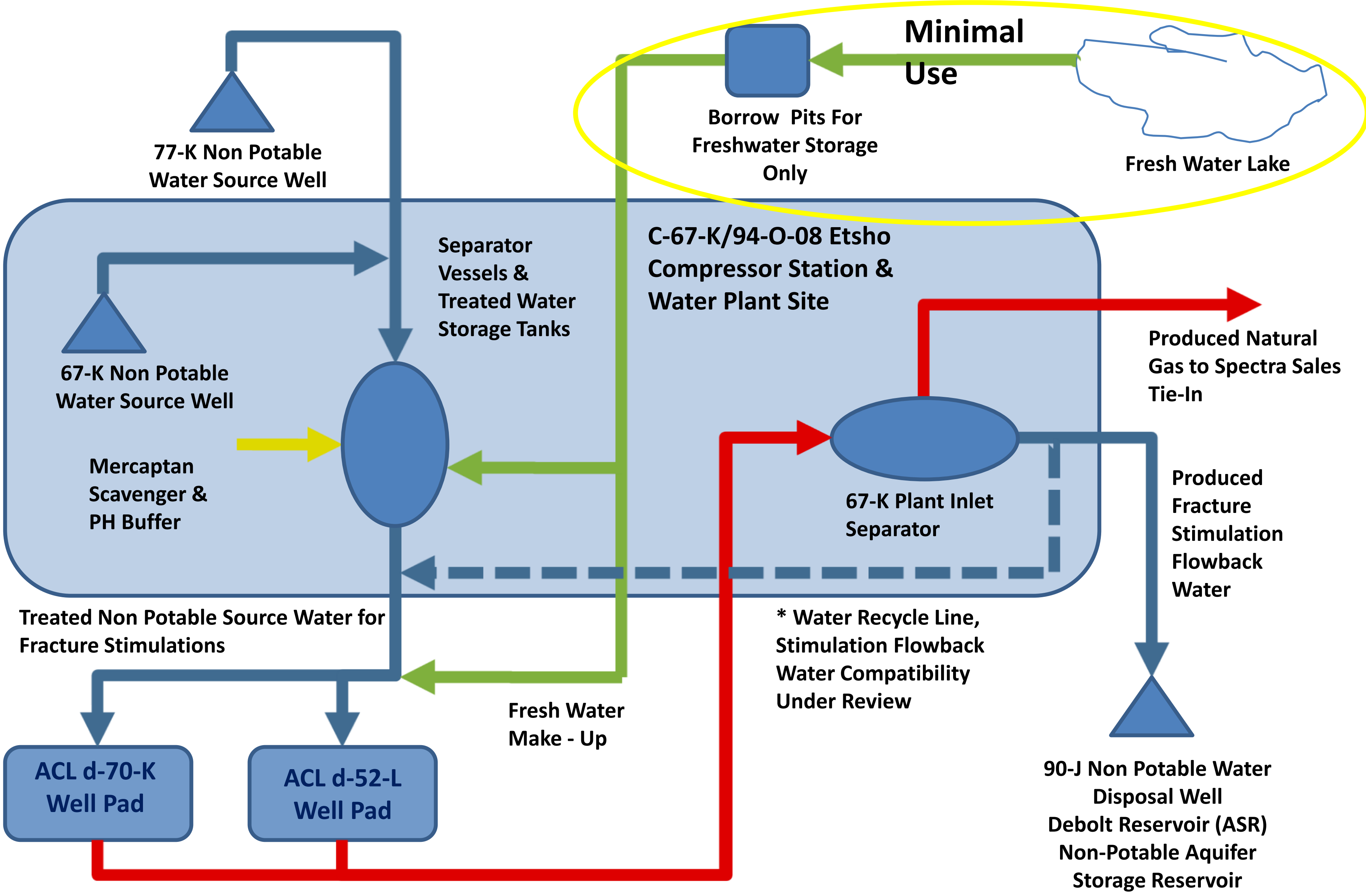


- 2009 Capital spending to be minimized where possible
- Apache completions to begin October 2009
- Design for average of 3 Fracs a day with enough water for goal of 4 ~ 4,000 m3 fracs per day
- Lowest environmental impact and smallest footprint possible
- Repairs to water system can be performed in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

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



Getting away from fresh water use – Saline Water Supply Schematic



Minimal Use

Borrow Pits For Freshwater Storage Only

Fresh Water Lake

77-K Non Potable Water Source Well

Separator Vessels & Treated Water Storage Tanks

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

67-K Non Potable Water Source Well

Produced Natural Gas to Spectra Sales Tie-In

Mercaptan Scavenger & PH Buffer

67-K Plant Inlet Separator

Produced Fracture Stimulation Flowback Water

Treated Non Potable Source Water for Fracture Stimulations

*** Water Recycle Line, Stimulation Flowback Water Compatibility Under Review**

Fresh Water Make - Up

ACL d-70-K Well Pad

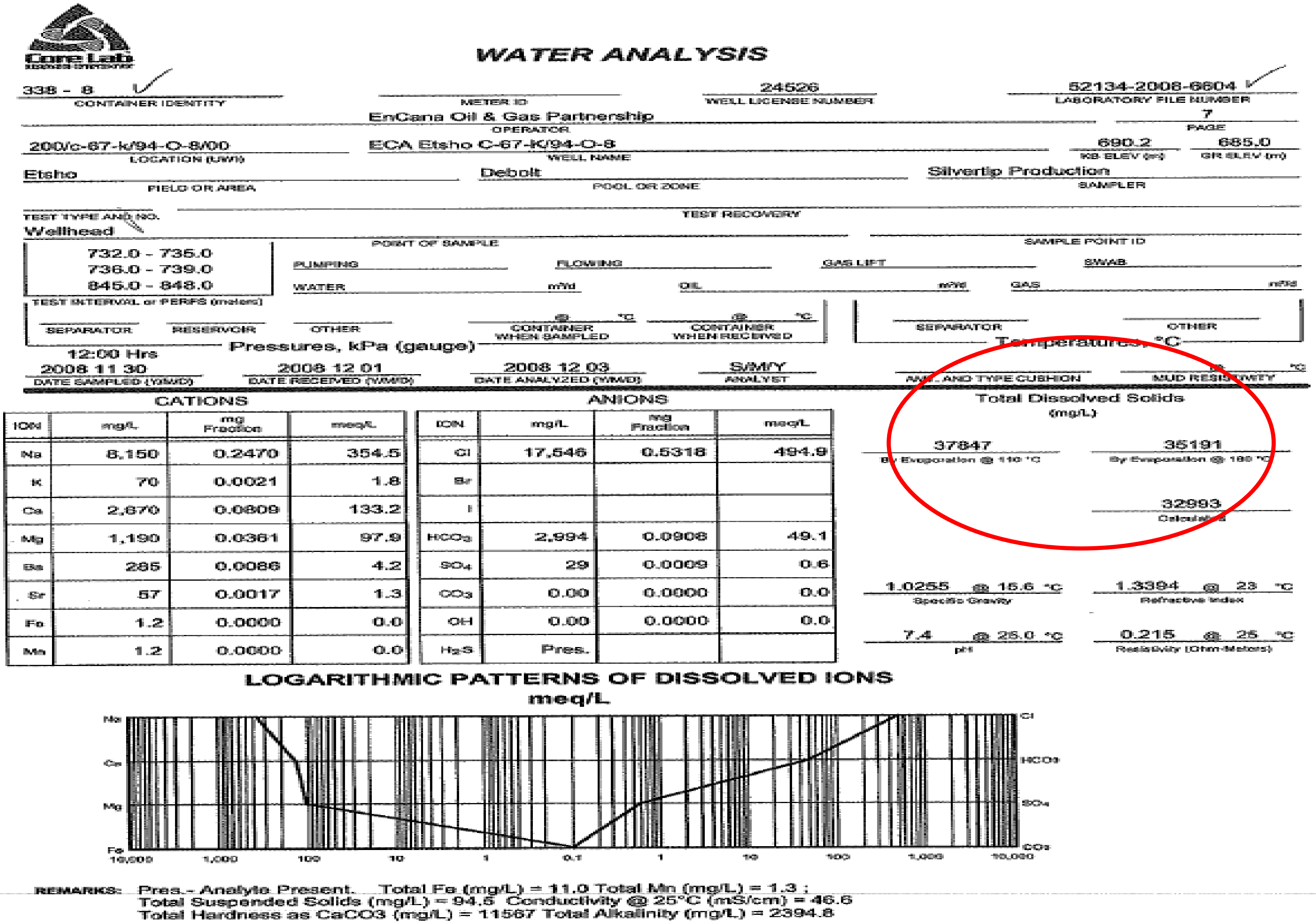
ACL d-52-L Well Pad

90-J Non Potable Water Disposal Well
Debolt Reservoir (ASR)
Non-Potable Aquifer Storage Reservoir

Produced Shale Gas & Fracture Stimulation Flowback Water

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

Debolt Water Analysis



Core Lab

WATER ANALYSIS

CONTAINER IDENTITY: 338 - 8

METER ID:

WELL LICENSE NUMBER: 24526

LABORATORY FILE NUMBER: 52134-2008-6604

OPERATOR: EnCana Oil & Gas Partnership

PAGE: 7

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

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

KB ELEV (m): 690.2

GR ELEV (m): 685.0

FIELD OR AREA: Etsho

POOL OR ZONE: Debolt

SAMPLER: Silvertip Production

TEST TYPE AND NO.:

TEST RECOVERY:

POINT OF SAMPLE: Wellhead

SAMPLE POINT ID:

TEST INTERVAL or PERFS (meters):
732.0 - 735.0
736.0 - 739.0
845.0 - 848.0

PUMPING:

FLOWING:

GAS LIFT:

SWAB:

WATER: m³/d

OIL: m³/d

GAS: m³/d

Pressures, kPa (gauge):

SEPARATOR:

RESERVOIR:

OTHER:

CONTAINER WHEN SAMPLED: @ °C

CONTAINER WHEN RECEIVED: @ °C

Temperatures, °C:

SEPARATOR:

OTHER:

DATE SAMPLED (Y/M/D): 2008 11 30, 12:00 Hrs

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

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

ANALYST: S/M/Y

AMT. AND TYPE CUSHION:

MUD RESISTIVITY: @ °C

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_3	2,994	0.0908	49.1
Ba	285	0.0086	4.2	SO_4	29	0.0009	0.6
Sr	57	0.0017	1.3	CO_3	0.00	0.0000	0.0
Fe	1.2	0.0000	0.0	OH	0.00	0.0000	0.0
Mn	1.2	0.0000	0.0	H_2S	Pres.		

Total Dissolved Solids (mg/L)

By Evaporation @ 110 °C: 37847

By Evaporation @ 180 °C: 35191

Calculated: 32993

Specific Gravity: 1.0255 @ 15.6 °C

Refractive Index: 1.3394 @ 23 °C

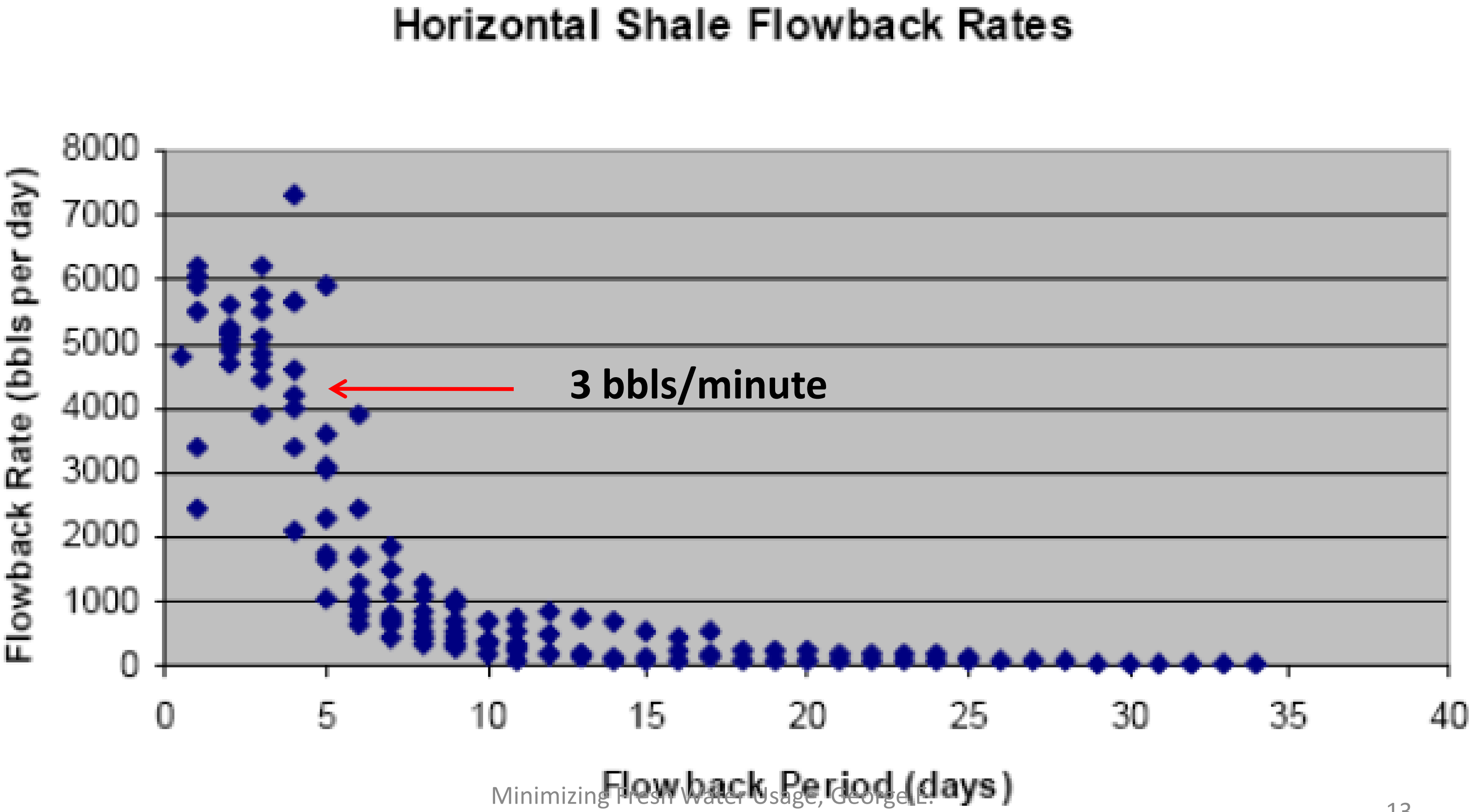
pH: 7.4 @ 25.0 °C

Resistivity (Ohm-Meters): 0.215 @ 25 °C

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 CaCO3 (mg/L) = 11567 Total Alkalinity (mg/L) = 2394.8

Flow Back vs. Time

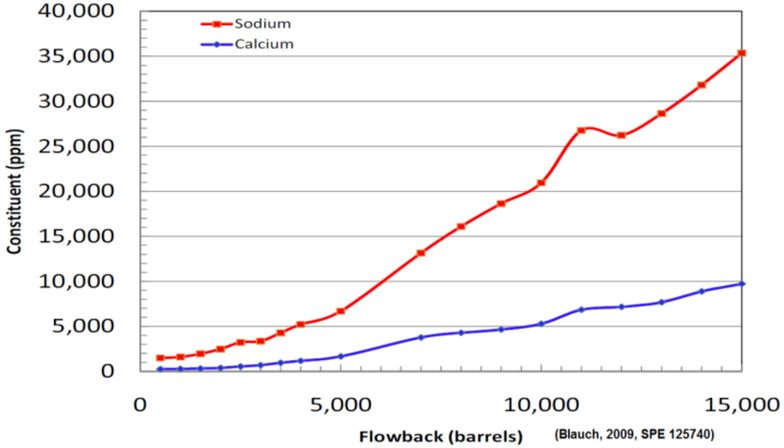


Flowback water from a shale frac. The yellow color is from iron in contact with oxygen from the air.

Slight adjustment to pH results in a clear solution.

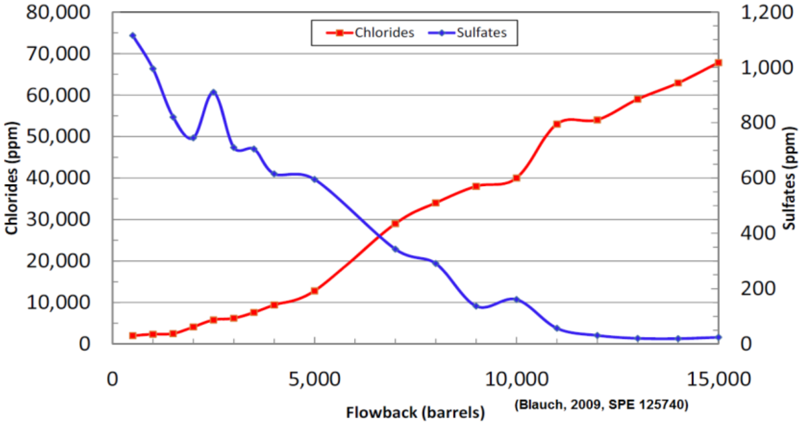
Background salinity varies with the shale.

Ion variation in the backflow



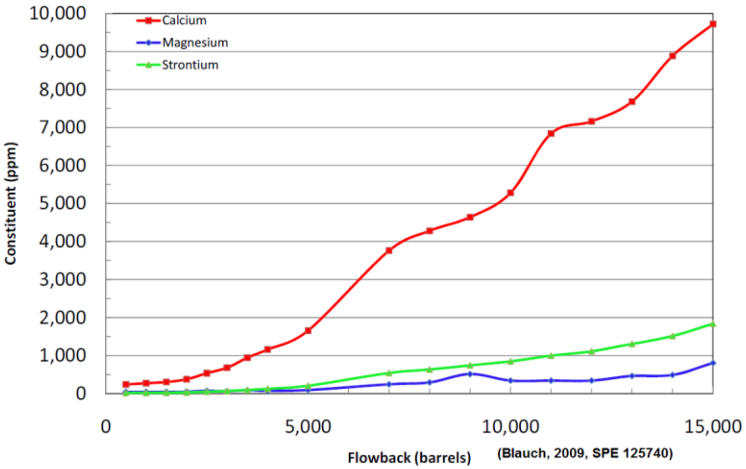
(Blauch, 2009, SPE 125740)

Marcellus Shale Well A flowback analysis–major cation trend.



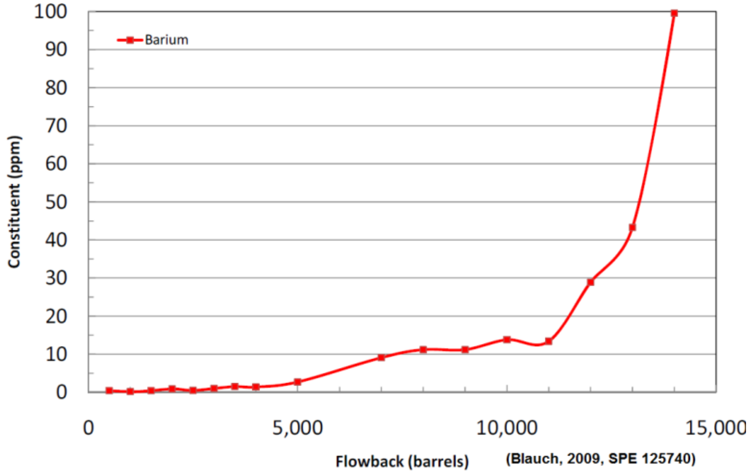
(Blauch, 2009, SPE 125740)

Marcellus Shale Well A flowback analysis–anion trend.



(Blauch, 2009, SPE 125740)

Marcellus Shale Well A flowback–divalent cation trend.



(Blauch, 2009, SPE 125740)

Marcellus Shale Well A flowback–barium trend.

Matt Blauch, SPE

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

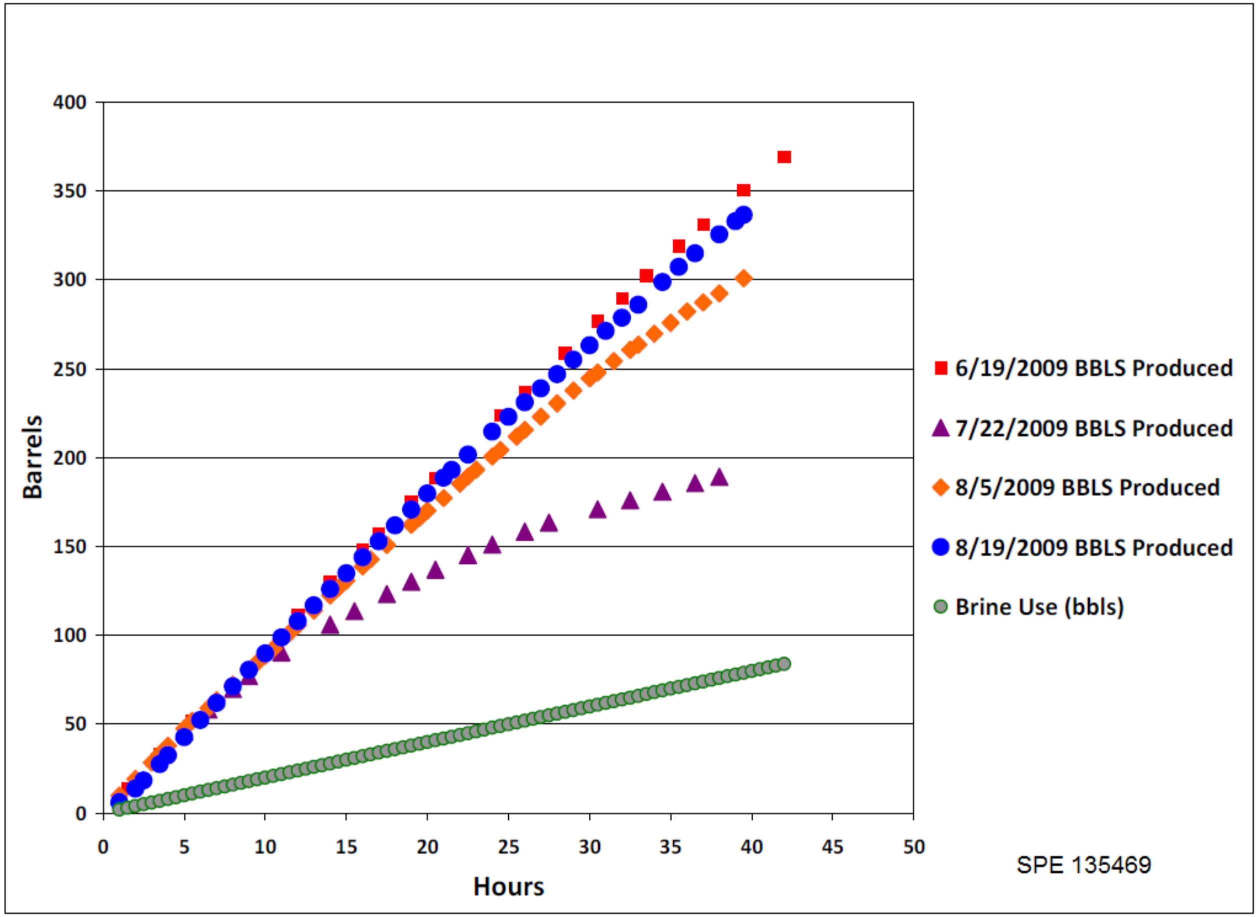
- Forward Osmosis Clean-Up
- Water Districts and Plastic Pipe Supply Lines
- Types of Treatment

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 4. Results of Pilot Tests

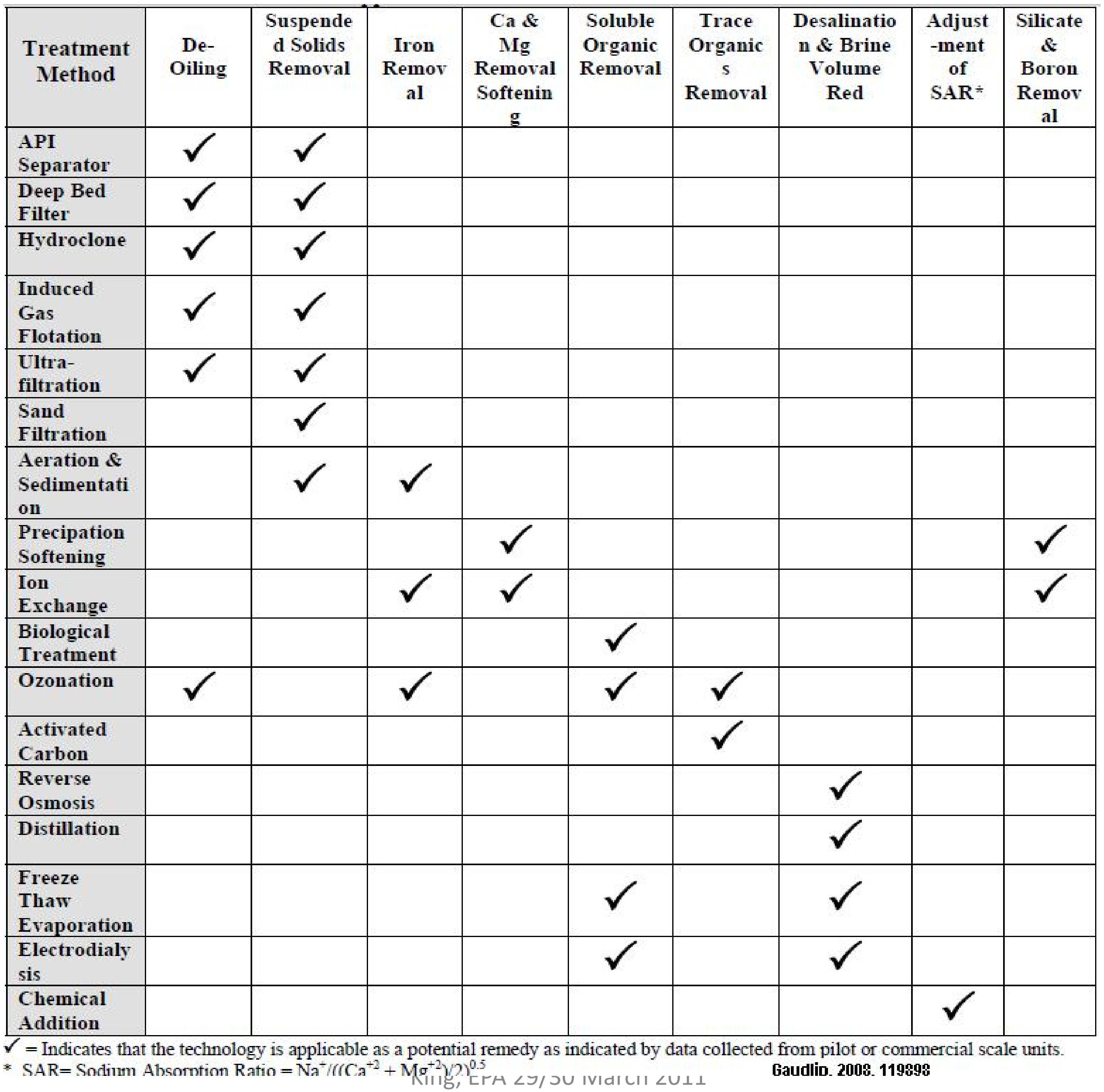


SPE 135469

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

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

Gaudlip, 2008, 119898

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 35,000 ppm Brine from a Dedicated Deep Reservoir as a Fracture Fluid for Shale

George E. King
Apache Corporation

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 Colombia, 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_2S), and equipment to recover the after-frac produced water from the wells and reinject the fluids into the Debolt formation.

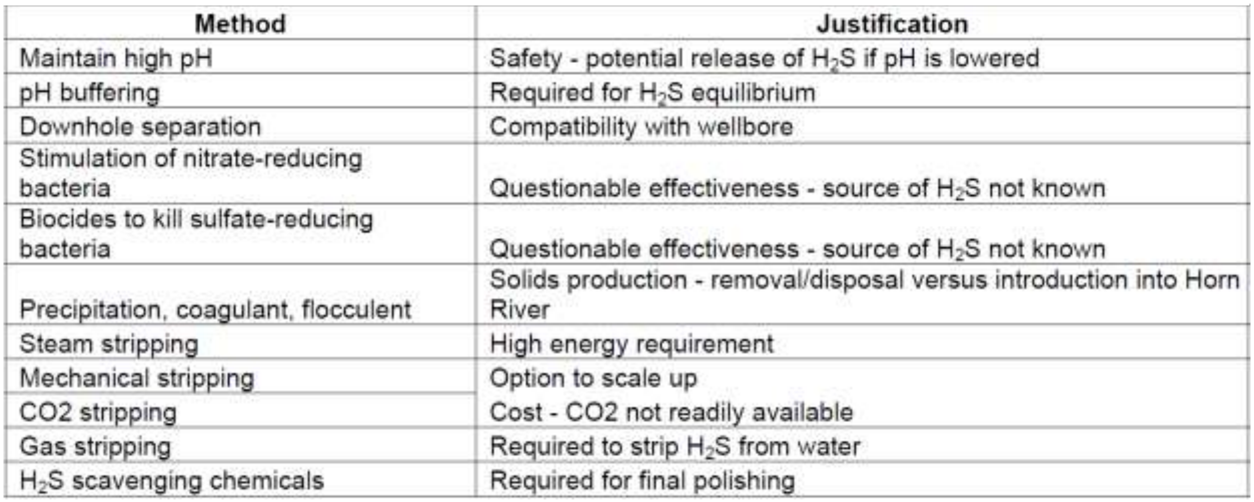
Shale gas developments in North America have centered on using fresh water as a fracturing base fluid since about year 2000, when the C.W. Slay well in the Barnett shale was refractured after foam fracture treatment and gelled fracture treatments were found to be expensive and created substandard well 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 10,000,0000+ 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_2S (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_2S if pH is lowered
pH buffering	Required for H_2S equilibrium
Downhole separation	Compatibility with wellbore
Stimulation of nitrate-reducing bacteria	Questionable effectiveness - source of H_2S not known
Biocides to kill sulfate-reducing bacteria	Questionable effectiveness - source of H_2S 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
CO2 stripping	Cost - CO2 not readily available
Gas stripping	Required to strip H_2S from water
H_2S scavenging chemicals	Required for final polishing

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

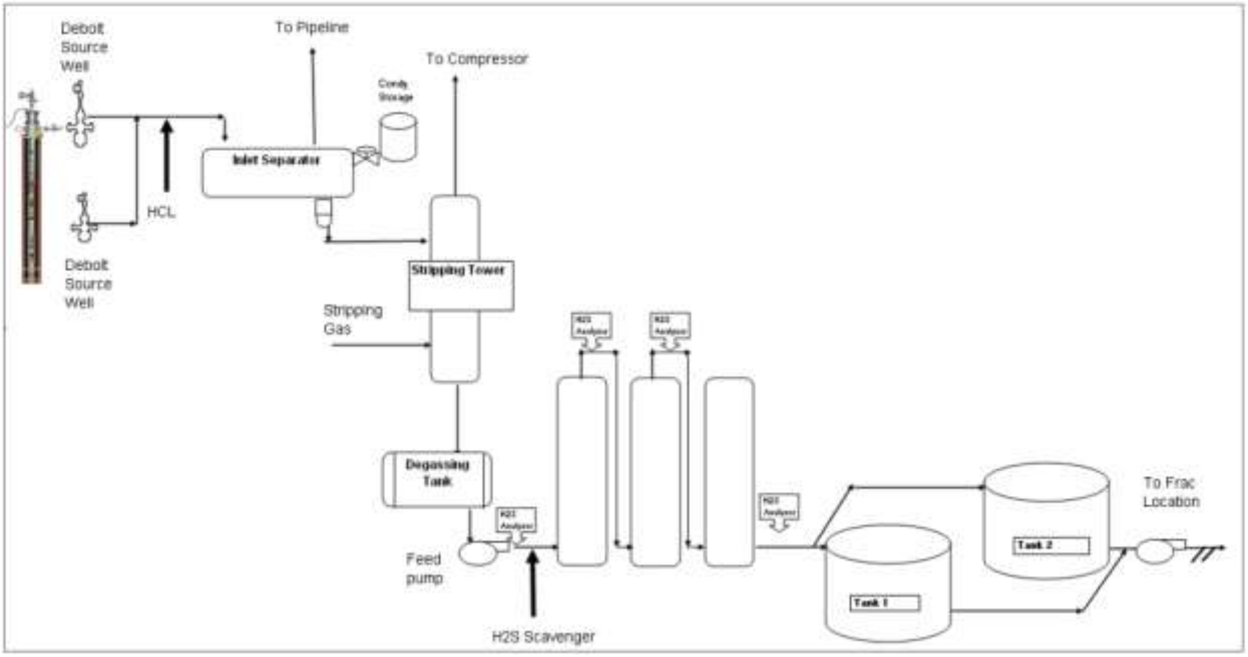
- Dilute HCl with corrosion inhibitor injected downstream of supply wellhead to lower pH and prevent scaling.
- Inject high pressure natural gas to strip H_2S and CO_2. Second step was low pressure gas stripping of water.

- 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_2S 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_2S 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

Arthur, J.D., Bohm, B., Coughlin, B.J., Layne, M.: "Evaluating Implications of Hydraulic Fracturing in Shale Gas Reservoirs," Paper SPE 121038, presented at the 2009 SPE Americas Environmental and Safety Conference, San Antonio, TX USA, 23-25 March.

Arthur, J.D., Bohm, B, Cornue, D.: "Environmental Considerations of Modern Shale Developments," Paper SPE 122931, presented at 2009 SPE Annual Technical Meeting, New Orleans, LA, USA, 4-7 October.

Blauch, M.E., Myers, R.R., Moore, T.R., Houston, N.A.: "Marcellus Shale Post-Frac Flowback Waters – Where is All the Salt Coming From and What are the Implications?," Paper SPE 125740, presented at the 2009 SPE Regional Meeting, Charleston, WVA, USA, 23-25 September.

Coulter, G.R., Benton, E.G., Thomson, C.L.: "Water Fracs and Sand Quality: A Barnett Shale Example," Paper SPE 90891, presented at the 2004 SPE Annual Technical Conference and Exhibition, Houston, Sept 26-29.

Coulter, G.R., Gross, B.C., Benton, E.G., Thomson, C.L.: "Barnett Shale Hybrid Fracs – One Operator's Design, Application and Results, "Paper SPE 102063, presented at 2006 SPE Annual Technical Conference and Exhibition, San Antonio, TX, USA, 24-27 September.

DeMong, K., Hands, R., Affleck, B.: "Advances in Efficiency in Horn River Shale Stimulation," SPE 140654, SPE Hydraulic Fracturing Technology Conference, 24-26 Jan 2011, The Woodlands, TX, USA.

Ferguson, M.L.: Comparing Friction Reducers' Performance in Produced Water From Tight Gas Shales," SPE Technology Update, J.P.T., November 2009, pp 24-27.

Gaudlip, A.W., Paugh, L.O., Hayes, T.D.: "Marcellus Water Management Challenges in Pennsylvania," Paper SPE 119898, presented at the 2008 SPE Shale Gas Production Conference, Ft. Worth, TX, USA, 16-18 November.

Grieser, B, Hobbs, J., Hunter, J., Ables, J.: "The Rocket Science Behind Water Frac Design," Paper SPE 80933, presented at 2003 SPE Production Operations Symposium, OK City, OK, USA, 22-25 March.

King, G. E.: "Thirty Years of Gas Shale Fracturing: What Have We Learned?", SPE 133456, SPE Annual Technical Meeting and Exhibition, Spet 20-22, 2010, Florence, Italy.

King, G.E., Lee, R.M.: "Adsorption and Chlorination of Mutual Solvents Used in Acidizing," SPE Production Engineering, Cvol.3, No. 2, May 1988, pp 205-209.

King, G.E., Warden, S.L.: "Introductory Work in Scale Inhibitor Squeeze Performance: Core Tests and Field Results,"Paper SPE 18485, presented at 1989 SPE International Symposium on Oilfield Chemistry, Houston, TX, USA, 8-10 February.

Palisch, T.T., Vincent, M.C., Handren, P.T.: " Slickwater Fracturing-Food For Thought," Paper SPE115766, presented at 2008 SPE Annual Technical Meeting, Denver, CO, USA, 21-24 September.

Pond, J., Zerbe, T., Odland, K.: "Horn River Frac: Past, Present, and Future," SPE 138222, 2010 Canadian Unconventional Resources & International Petroleum Conf., 19-21 October, Calgary, Alberta, Canada.

Schein, G.: "The Application and Technology of Slickwater Fracturing," Distinguished Lecturer Presentation, SPE 108807, presented 2004-2005.

Steinsberger, N.: "The Barnett Shale and the Evolution of North American Shale Plays," Presentation and Slides, presented at 2009 SPE GCS Westside Study Group.