

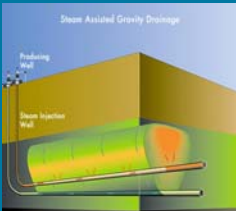

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Challenges in Water Treatment for Generation of 100% Steam Quality

Presentation in partnership between EnCana Oil & Gas Oil Recovery Business Unit and G.E. Infrastructure Water and Process Technologies.

Presented by:
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Oil Recovery Business Unit: SAGD Operations



Current Boilers being used range from 50,000 to 330,000 lbs/hr steam capacity

Average oil production is approximately 900 barrels per day per well pair

Background:

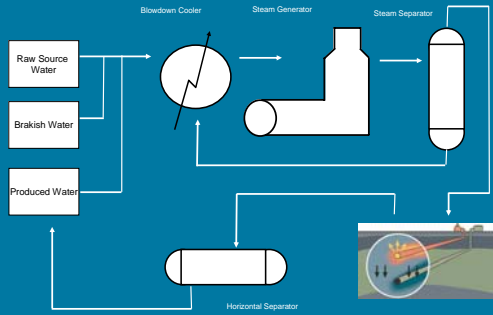
The Oil Recovery Business Unit (ORBU) consists of existing Senlac, Christina Lake, and Foster Creek Facilities with future development of the Borealis Project. Case studies in this presentation are based on combined history of service conditions at all three facilities. Christina Lake and Senlac Plants were previously Pilot Projects utilizing fresh source water to produce Boiler Feed water (BFW). The Foster Creek SAGD Commercial Plant has utilized water re-use technology to recycle Produced Water (PW) in conjunction with Brakish Water* (BW) for BFW make-up in steam production.

Process Objective:

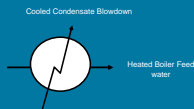
Cost effective production of heavy oil through steam assisted gravity drainage process (SAGD). One key element is process design to maximize heat recovery which directly reduces fuel gas expense during steam generation.

*Brakish Water – contains total dissolved solids greater than 4,000 ppm

Simplified Process Flow Diagram



Blowdown Cooler Exchange



Shellside – Boiler Condensate Blowdown	
Inlet temperature	320 C
Outlet temperature	130 C
Operating Pressure	11000 kpa
Tubeside – BFW	
Inlet temperature	135 C
Outlet temperature	180 C
Operating Pressure	13 – 15000 kpa
* average process conditions	

Steam Generators



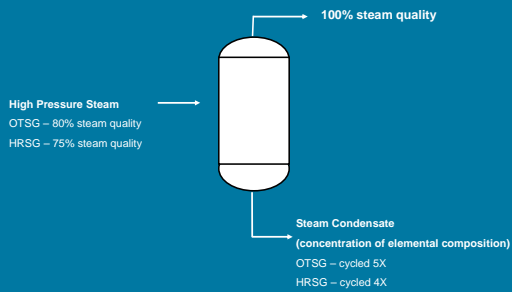
Once Through Steam Generators (OTSG)

- Designed to operate @ 80% steam quality

Heat Recovery Steam Generators (HRSG)

- Designed to operate @ 75% steam quality

Steam Separation



General Design

- Carbon steel materials
 - SA 106 B, SA 106C piping and boiler tubes
 - SA 179 exchanger tubes
 - SA 516 70N vessel shells
- Sulfite injection to control Dissolved Oxygen
- Chelant Chemistry to control scaling at the boilers

	BFW pH	Condensate pH		Iron	Chlorides
Average	8.5	12.0		.5 ppm	BFW 500 – 1000 ppm BD 2500 – 5000 ppm
	Sulfite (SO ₃) ppm	Dissolved Oxygen ppb	Alkalinity P – ppm	Alkalinity M – ppm	Hardness ppm
Targets	12 – 19	5	25 – 40	Average 350	< 0.1

History:

Foster Creek (FC) and Christina Lake were commissioned in the fall of 2001 and spring of 2002 respectively. Both the FC Pilot Plant and Senlac Facility were commissioned in 1996.

Integrity inspection at the Pilot Plant consisted of Ultrasonic Thickness (UT) measurements and external visual inspection. Quantitative UT measurements performed on the Blowdown (BD) service components (vessels, exchangers and piping) reflected no measurable corrosion loss. It is noted that the information was obtained after approximately six years of service with no previous baseline or related inspection history for comparison. Senlac records were incomplete for related equipment.

Prior to 2005:

Baseline UT surveys were conducted at Foster Creek and Christina Lake in 2002 *. Initial inspection confirmed nominal thickness with no indication of deviation from the original design. Qualitative similar service comparison was recorded from annular integrity assessment of the related upstream steam generators. Integrity inspection included UT measurements, radiographic profile images (shadow shots), internal mechanical cleaning (pigging) and visual assessment. No related visual corrosion mechanism was evident. Routine solids collected from cleaning process determined a nominal accumulation of scale product.

*As per API 510 section 7.1.2 – Corrosion Rate Determination

During 2005 Facility Shutdown:

In accordance with the EnCana corporate Integrity Management System (Owner User Program) and compliance with Alberta Boiler Safety Association (ABSA) inspection and service requirements*, internal thorough inspections were performed at all three facilities.

No measurable corrosion loss was determined by Remote Field Eddy Current (RF EC), I.R.I.S 9000®, UT and visual inspection methods.

However...

*From AB506 Inspection and Servicing Requirements for Pressure Equipment Rev. 3

During 2005 Facility Shutdown:



Foster Creek E201 A1



Senlac E101

During 2005 Facility Shutdown:

The exchanger was jack & rolled from position and removed from site for refurbish.

The E201 A1 Exchanger required two 50 ton rams hooked up to an electric power pack to spread the tubesheet from the shell flange.

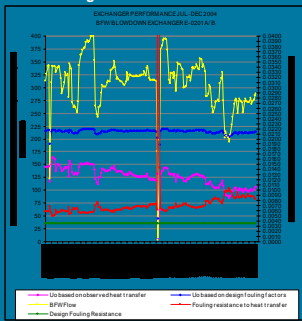
The same set-up was used to remove the studs.

The issue of fouling was forwarded to operations and process engineering for evaluation. After reviewing the heat efficiency historical trend, a very distinct pattern reflected continuous fouling.



Exchanger Performance JUL – DEC 2004 (6 months)

BFW / Blowdown Exchanger E-0201 A/B



Impact is determined by the following:

Equipment integrity:


- Bundle replacement between \$25 - \$45K (pending bundle size)

Process Expense:

- Thousands of dollars per day (pending variables include extent of fouling, flow volumes and fuel gas cost)

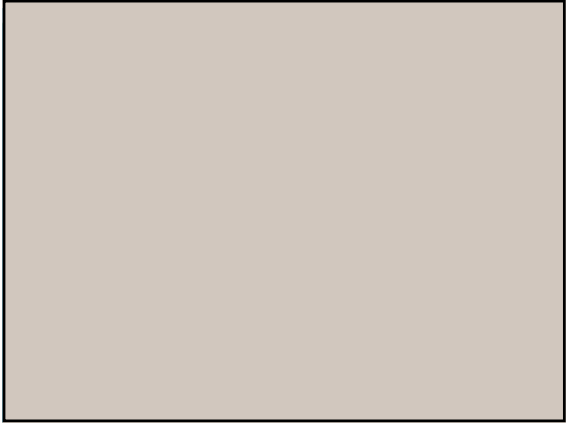
Lost production:

- Not applicable as the maintenance was in conjunction with planned outage



Responsive Actions:

- Review process treatment with chemical service provider.
- Analyze scale chemistry.
- Monitor process conditions and combine sample analysis to quantify current deposition rates.
- Review potential methods for mitigation.
- Assign process group to review finds and evaluate cost effective maintenance program.



- I. Water quality monitoring
- II. Chemical Treatment
 - Current chemical treatment goals
 - Fouling mechanism
 - Iron dispersing technology
- III. Process Modeling



I. Water Quality Monitoring

- Elaborate water quality testing is necessary for evaluating the problem and the planned solution.
- High purity analysis of iron will allow accurate evaluation of iron deposition across the heat exchangers.
- Testing through Ion Chromatography will be utilized.



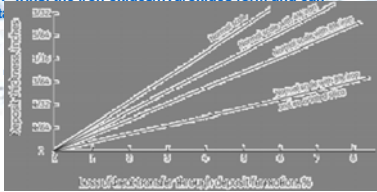
II. Chemical Treatment

Current Treatment Goals

- Combined chelant/polymers technology is best suited because of the extremely high skin temperature and pressure.
- Chelants work by inhibiting the cation part of any silica/carbonates based deposition; specifically: Iron, Calcium, and Magnesium.
 - $EDTA^{4-} + Ca^{2+} \rightarrow EDTA (Ca)^{2-}$
 - $EDTA^{4-} + Mg^{2+} \rightarrow EDTA (Mg)^{2-}$
 - $EDTA^{4-} + Fe^{2+} \rightarrow EDTA (Fe)^{2-}$
- Polymer controls deposition through mechanisms of complexation, crystal modification and dispersion.
- Dosage depends on Total hardness (TH) and iron concentrations in Boiler Feed Water (BFW).

Chemical Treatment
Fouling mechanism

- steam separation leads to increase in ion concentration, 5 folds in OTSG and 4 folds in HRSG.
- Increase in Hydroxide (OH) concentration and pH
- "Competition" between the remaining Anticoagulant (EDTA) and the OH ions for the hydrated iron ions.
- When the OH- wins, the iron oxides/hydroxides form and can precipitate



II. Chemical Treatment
Iron Dispersing Technology

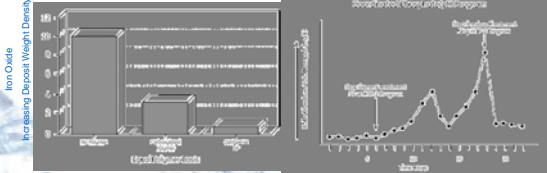
A low molecular weight Polymeric dispersant provides effective control of iron deposition in thermally stressed systems. It is designed to supplement the dispersant capability of Phosphate or Chelant-based treatment programs.

Multifunctional: contains HTP-2 polymers (Poly (isopropenyl phosphonic acid) ... PIPPA) which reduces iron deposition through reducing particle size and distorting crystal growth.

- by altering the surface charge of the suspended particle, the attraction between the heat transfer wall and the particle is significantly reduced.
- distort Crystal growth by promoting surface adsorption and distortion of the crystal lattice of deposit particles.

Standard Metal oxide dispersant (carboxylated polymer) vs. modified phosphate based polymer (HTP-2 technology)

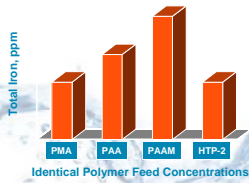
Deposit control comparison



QC Tip

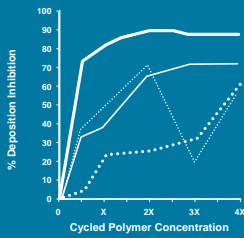
An iron sampling monitoring program should be implemented during the trial period to determine the effectiveness of the application as well as to help determine the best dosage.

**Research Economizer Data
Relative Iron Transport (160°C)**

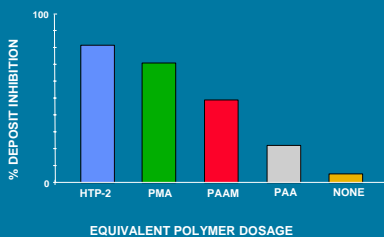


- PMA = polymethacrylate
- PAA = polyacrylate
- PAAM = polyacrylate/acrylamide copolymer
- HTP-2 = poly (isopropenyl phosphonic acid)

**Polymer Dose Response Curves
(1450 psig)**



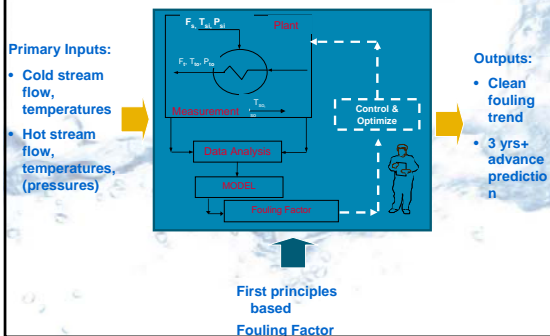
Research Boiler Deposit Inhibition Comparison (1450 psig)



III. Process Modeling

- The use of advanced Logic computer technology tools to monitor and predict the performance of Heat Exchangers
- Smart algorithms working with plant instruments to detect and predict exchanger performance
- GE CHEX advanced modeling software calculation engine is consisted of the following modules:
 - a) Data Quality Enhancement
 - b) Fouling Detection
 - c) Fouling Prediction.

The computed trouble shooting / prediction process



Predictive modelling

- Wiener Filter – Norbert Wiener - 1940
- Kalman Filter – Rudolf Kalman - 1960

Predictive model (Chex)®
Hybrid Kalman Filter

"It's used in just about every inertial navigation system" – James Burrows, Boeing
 "Anything that moves, if it's automated, is a candidate for a Kalman filter,"
 - Blaise Morton, Honeywell's Systems and Research.

Future:
 - Smart Highways
 - Active Noise Control

Predictive model (Chex)®

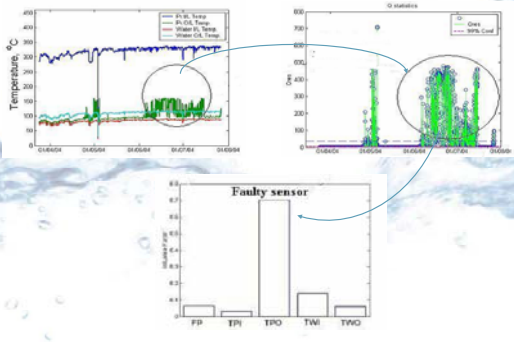
Detect and predict fouling
 Diagnose and prescribe corrective action

No indication of fouling
 No adjustment in treatment

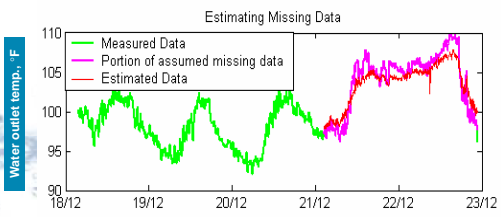
Shut down to clean

Clean at shut down

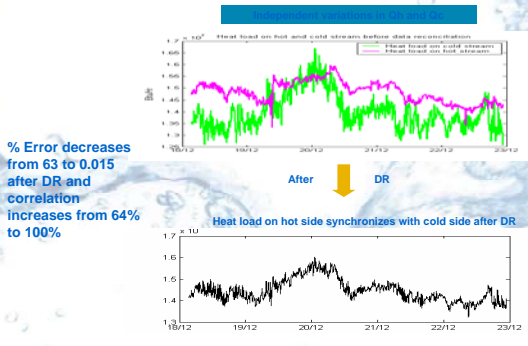
Example - Fault Detection

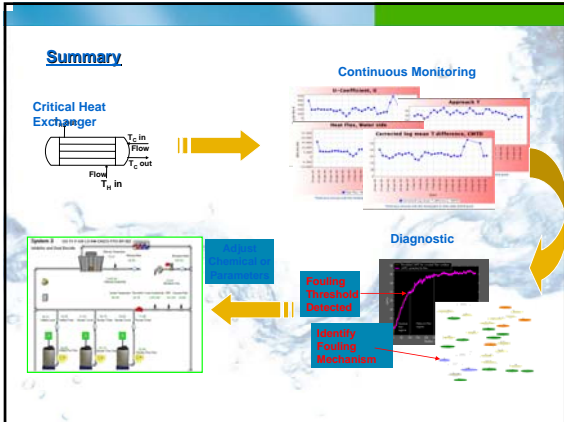


Example - Missing data estimation



Example - Data Reconciliation





Current Progress:

- Testing program established in conjunction with both EnCana & G.E.
- Sample coolers installed at Foster Creek for online analysis and accumulation of process data utilizing ion chromatography.
- Study to focus on deposit lay down across the blowdown cooler with attention to iron*, mineral, and dissolved solids count (high purity testing).
- New blowdown cooler being installed is to be monitored by advanced logic computer technology (Chex) from baseline clean conditions
- Heat efficiency is being monitoring at Christina Lake with Chemical Cleaning** trials.
- Dispersant chemical injections trials at Senlac.

*Reference NACE Standard RP0192-98 Monitoring Corrosions in Oil & Gas Production with Iron Counts
 **Reference Corrosion Paper No. 622, Corrosion Paper No. 03583, Corrosion Paper No. 03589 – cleaning related papers, Everyday Safe work Procedural Guideline CCF132.

Testing data and predictive modeling will allow planning time to mitigate expenses related lost heat recovery potential. Predetermined targets will initiate corrective action. Ongoing trials include the following:

- Chemical Cleaning – Flush with inhibited organic Hydrochloric Acid. This method requires process isolation. However, the cost to apply is minimal without having to remove the tube bundle.
- Mechanical Cleaning – Remove the bundle at designated interval and high pressure wash the tubes. This method has limited potential due to difficulty with flow access in fouled bundles. Optimization of process outage would likely include procuring a redundant bundle to swap with.
- Chemical Treatment – Dispersant chemical can suspend and carry limited solids (percent by volume) through exchanger and downstream. Further study required to ensure impact to downstream equipment.

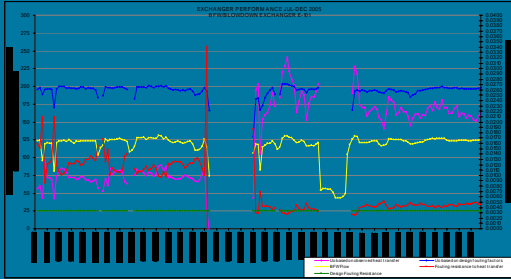
* Each method will have limited effectiveness based on the degree of scaling prior to corrective action.

In Summary:

Successful efficient operation depends on integrated strategy inclusive of design, monitoring and verification through inspection. In our example, in-sufficient monitoring over-looked accumulation of fouling mechanism with impact to mechanical integrity and process costs.

Ongoing programs to be implemented in efforts to mitigate fouling and manage maintenance and operational expense. Evaluation of process systems by computerized programs and sample analysis is anticipated to provide qualitative resource to effectively reach heat recovery and process cost goals.

Christina Lake E-101 Exchanger Performance After Chemical Cleaning:



*Total cost for acid cleaning was \$5449.97, completed September 12, 2005.

HRSG Process Condensate Scale Analysis:

Consistent results indicating high silicate constituent with lower Iron Oxide levels.

FC E-201C Scale Analysis March 2006

PRIMARY COMPOSITION (%)	
Silicon, SiO ₂	37
Magnesium, MgO	34
Loss on Ignition LOI	20
Iron, Fe ₂ O ₃	7
Sodium, Na ₂ O	1
Aluminum, Al ₂ O ₃	1

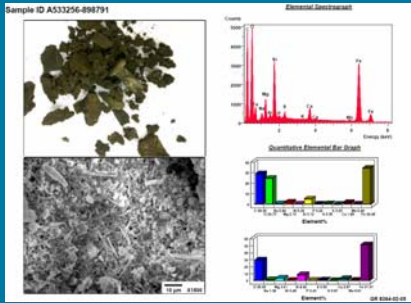
FC V-201B Scale Analysis April 2006

PRIMARY COMPOSITION (%)	
Silicon, SiO ₂	36
Magnesium, MgO	32
Loss on Ignition LOI	17
Iron, Fe ₂ O ₃	8
Sodium, Na ₂ O	2
Aluminum, Al ₂ O ₃	2
Calcium, CaO	2
Phosphate, P ₂ O ₅	1

X-ray fluorescence detects between fluorine and uranium in atomic number. Any of these elements not reported are below detection limits.

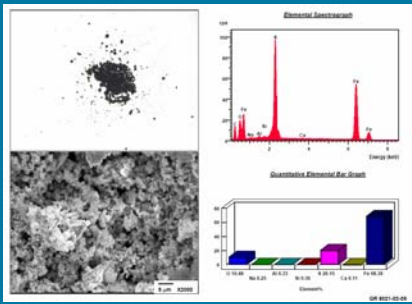
HRSG Process Condensate Scale Analysis – HR 1202:

Consistent results indicating high iron and silicone components.



OTSG Process Condensate Scale Analysis – E-201 A1:

Consistent results indicating high Iron Sulphide products.



OTSG Process Condensate Scale Analysis:

Consistent results indicating high Silicon component with higher Iron Oxide levels.

CL E-101 Scale Analysis

PRIMARY COMPOSITION (%)	
Iron, Fe ₂ O ₃ + Fe ₃ O ₄	41
Magnesium, MgO	25
Silicon, SiO ₂	24
Loss on Ignition LOI	6
Phosphate, P ₂ O ₅	1
Sodium, Na ₂ O	1
Calcium, CaO	1
Cobalt, Co ₂ O ₃	1

