Advanced Stripper Gas Produced Water Remediation

Final Project Report

Western SynCoal, LLC

Harry Bonner
Roger Malmquist

NOVEMBER 2003

Grant DE-FG26-00NT40965

Western SynCoal, LLC
120 North Parkmont
Butte, MT 59701

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Abstract

Natural gas and oil production from stripper wells also produces water contaminated with hydrocarbons, and in most locations, salts and trace elements. The hydrocarbons are not generally present in concentrations that allow the operator to economically recover these liquids. Produced liquids, (Stripper Gas Water) which are predominately water, present the operator with two options; purify the water to acceptable levels of contaminates, or pay for the disposal of the water.

The project scope involves testing SynCoal as a sorbent to reduce the levels of contamination in stripper gas well produced water to a level that the water can be put to a productive use. Produced water is to be filtered with SynCoal, a processed sub-bituminous coal. It is expected that the surface area of and in the SynCoal would sorb the hydrocarbons and other contaminates and the effluent would be usable for agricultural purposes.

Test plan anticipates using two well locations described as being disparate in the level and type of contaminates present. The loading capacity and the rate of loading for the sorbent should be quantified in field testing situations which include unregulated and widely varying liquid flow rates. This will require significant flexibility in the initial stages of the investigation.

The scope of work outlined below serves as the guidelines for the testing of SynCoal carbon product as a sorbent to remove hydrocarbons and other contaminants from the produced waters of natural gas wells. A maximum ratio of 1 lb carbon to 100 lbs water treated is the initial basis for economic design. While the levels of contaminants directly impact this ratio, the ultimate economics will be dictated by the filter servicing requirements. This experimental program was intended to identify those treatment parameters that yield the best technological practice for a given set of operating conditions. The goal of this research was to determine appropriate guidelines for field trials by accurately characterizing the performance of SynCoal over a full range of operating conditions.

Executive Summary

April through June 2003. Work during this period consisted of pilot plant operations to produce SynCoal for additional testing. The SynCoal available was tested and determined to be unreactive for oil removal purposes. As a condition of the transfer of Western SynCoal, LLC from Westmoreland Coal Sales to EnPro, LLC on January 3, 2003, Westmoreland had agreed to assist in the production of SynCoal.

The pilot plant equipment, currently located at Westmoreland's Rosebud Mine, was used to produce the SynCoal required for project testing. The produced SynCoal was screened and cleaned to provide the project with a usable material for further testing. Subsequent testing indicated the SynCoal was suitable for oil removal purposes.

January through March 2003. Work during this time period consisted of coordinating efforts to restart the former Western SynCoal facility in order to make additional SynCoal for use in processing the produced water.

Through December 2002 - Due to a number of factors including the sale of Western SynCoal's parent company and continued transition efforts at NARCo related to its sale to Pan Canadian, no additional experimentation was completed during this period. The project team did meet, reviewed the data collected to date and developed a plan for the next phase of testing.

Work on the project has been hampered by the transition of both NARCo and Western SynCoal into their new organizations after their respective divestiture from Montana Power's group of companies. The overall program is achieving the desired removal of oils and greases from the produced waters but is suffering from inconsistent results leaving questions about the sampling and/or analyses.

Work completed during the first quarter of 2001 included a second series of filtration tests and air sparging of the filtered produced water to test the ability to further reduce lighter weight hydrocarbon contents. The actual filtration tests were run on twelve (12) selected days between February 1 and 20. The filtering process was typically operated for 6-8 hour period during each day with samples taken near the end of the processing period. These tests used the same SynCoal that was originally employed in the November testing. The column pressure remained constant throughout the test and the flowrate was held steady at a little over two gallons per minute. Analyses indicated that the hydrocarbon retention was reduced substantially from the initial test although the water clarity continued to appear greatly improved at the column discharge. Major ions and trace metals were largely unaffected during the testing. Air sparging of the filtered water showed remarkable removal of BTEX constituents and appears to be promising.

Work completed from August 31, 2000 through December 31, 2000 included construction of test columns and support facilities to conduct the preliminary scoping trials to process produced water with SynCoal. The construction,

installation, column packing and acquisition of water to be treated required three weeks of effort. The actual test runs ran two consecutive days of constant flow at a rate of approximately three gallons per minute. Three gallons per minute is similar to the rate of water production from the majority of wells in the Denver-Julesberg (D-J) basin. A single SynCoal column with 104 lbs of media was employed for this preliminary test. The column pressure remained constant throughout the test period. Analysis indicated good hydrocarbon retention on the SynCoal averaging 90% or better removal from the produced water. Water clarity was observed to be greatly improved at the column discharge. Major ions and trace metals were largely unaffected by exposure to SynCoal.

Experimental

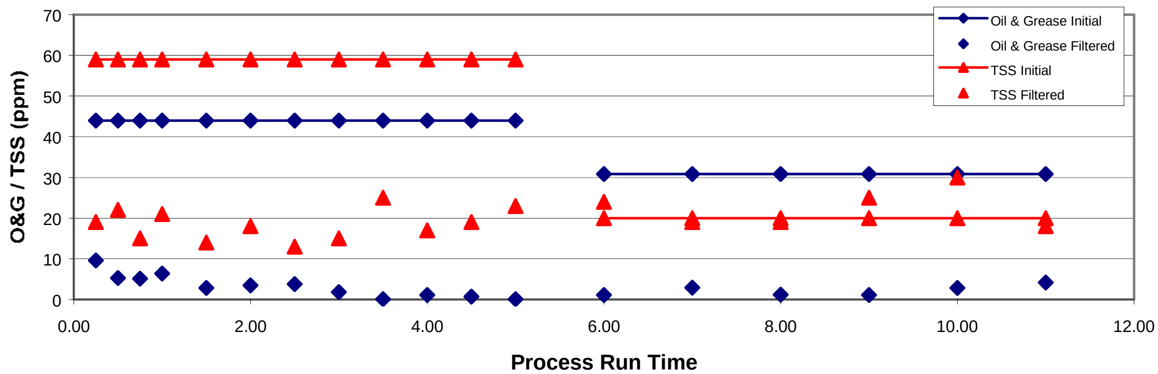
08/31/2000 through 12/31/2000

After a prototype "filter canister" was designed and fabricated from steel pipe, the project team decided to construct the test units from six inch PVC pipe and fittings and mount them on portable angle iron skid mounted stands to simplify construction, modification and installation. NARCo's Wattenberg shop and lab buildings were cleaned out to provide work space near the production field. In October 2000, fabrication of a two stage filter unit constructed of schedule 40 PVC pipe and related fittings was completed. Initially, some difficulty was encountered in preventing the migration of coal particles from the canister but after trying several screen / packing materials the filter retained the coal without losing particles with the water flow. The filter unit is mounted in an angle iron frame which can be easily be modified to provide an insulated shed around the filter unit with an access door in front. With the filter unit housed in an insulated structure coupled with a small catalytic heater, this unit should prove to be functional in winter as well as summer.

The filter unit was installed into a single stage separator at the Ione #11 production battery in an effort to evaluate the functionality of the unit under field conditions. While the unit was determined to be of the correct design for generic connection to a separator unit, the surge discharge pressure of the single stage unit at the Ione battery was greater than anticipated (+ 200 psig). In order to use the PVC filter unit on locations with pressures in excess of 50 psig, a surge tank is needed to control the impact force of the water discharged to the filter unit.

The filter unit was moved back to the Wattenberg location where it was installed with a surge feed tank, a pump to supply a steady flow to the filter and a "clean" water tank to characterize the filter. The initial testing was conducted on November 1 and 2, 2000 with water flowing through the filter for approximately 12 hours at a 3.0 to 3.5 gpm rate. Pre-treatment and post-treatment water samples were collected and analyzed. It appeared from visual observation of the pre-treatment and post-treatment water samples that the filter unit is removing insoluble and colloidal particulates in the produced water being treated. The analyses indicated that the oil and grease content was reduced from an average of over 36.8 mg/l to under 2.4 mg/l, approximately 93 percent reduction. Total suspended solids were reduced from 59 mg/l in the initial sample to under 20 mg/l on average. Copper and silver concentrations appeared to be reduced as well. Unfortunately, the sodium, calcium, magnesium and potassium concentrations did not appear to be affected.

Preliminary Column Test



01/01/2001 through 03/31/2001

In reviewing the data, it was postulated that the remaining oil and grease concentration was primarily light hydrocarbons that could be removed by simple air sparging. Additionally, concepts of using SynCoal with a high limestone content as the filter media may enhance the removal of the dissolved salt mineral content. Further testing to determine the filter material's saturation point, if the high limestone content SynCoal would remove more of the dissolved solids and if the remaining oil and grease levels could be removed by air sparging was determined to be an appropriate next step.

In late January, work was completed to winterize the test filter unit and a 110 volt ¾ h.p. electric centrifugal pump with a by-pass system and a 1 inch brass Neptune water meter with totalization capabilities were installed.

A second series of flow tests were conducted on the 1st stage of the prototype canister filter unit. The primary objective of this test series was to determine the point of climax or saturation of the filter media.

From February 2 to February 20, the unit was tested in 6-8 hour sequences on 12 individual days. During that test period, 3 different batches of untreated water were received at the test facility and processed through the filter unit. A total of 10,520 gallons of produced water was processed through the stage one filter at an average inlet pressure of 10 psig and an average flow rate of 133.5 gallons per hour or 2.23 gpm. A sample of the treated and untreated water was collected initially and at the end of the first days' run; and at the end of each days run thereafter. The samples were placed in glass jars and labeled. As the attached data indicates, each new batch of untreated water presented a different set of organic concentrations. In an attempt to minimize the impact of this fluctuation in the chemical makeup of the water, the sample protocol for this phase of testing provided for the collection of an *"in or untreated"* sample at the beginning of the daily flow test and an *"out or treated"* sample at the ending of the daily flow test. The water quality changed with each new batch of untreated water. The following is a brief summary of the organic concentration.

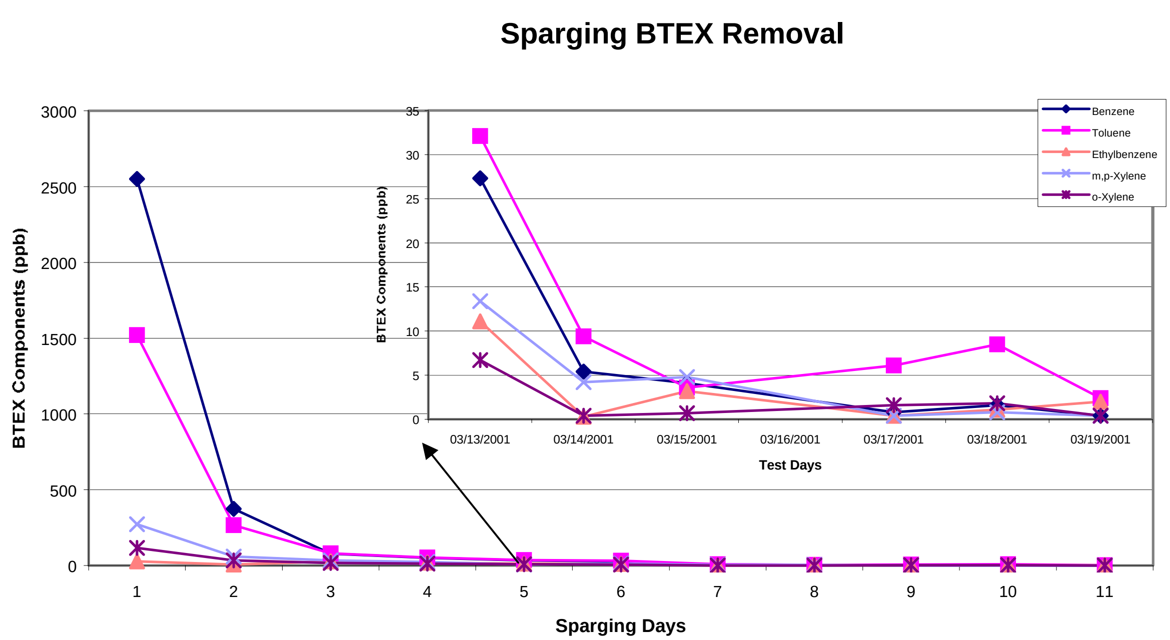
As part of the second stage testing protocol, the treated water from the filter unit was placed in a 100 barrel steel water tank recently removed from an operating production facility. The tank was not cleaned prior to use in this test in an effort to maintain realistic field conditions. An air sparging unit was fabricated and air at 20 psig continuous flow was sparged through approximately 80 barrels of treated water.

Second Test Series Summary Results

Sample ID	Untreated Oil & Grease ppm	Treated Oil & Grease ppm	Removal Efficiency	Untreated BTEX ppm	Treated BTEX ppm	Removal Efficiency
Batch 1 Ave	126.5	63.5	50%	1055	908	14%
Batch 2 Ave	228.6	234.8	-3%	2071	1685	19%
Batch 3 Ave	5.6	7.9	-41%	4462	4820	-8%

Sparging Test Results

Sample ID	Benzene (ppb)	Toluene (ppb)	Ethylbenzene (ppb)	m.p Xylene (ppb)	o-xylene (ppb)
Initial Sample	2550	1520	28.5	272	117
5th Day Sample	33.2	35.5	12.8	6.0	8
11th Day Sample	<0.4	2.4	2.0	0.4	<0.4

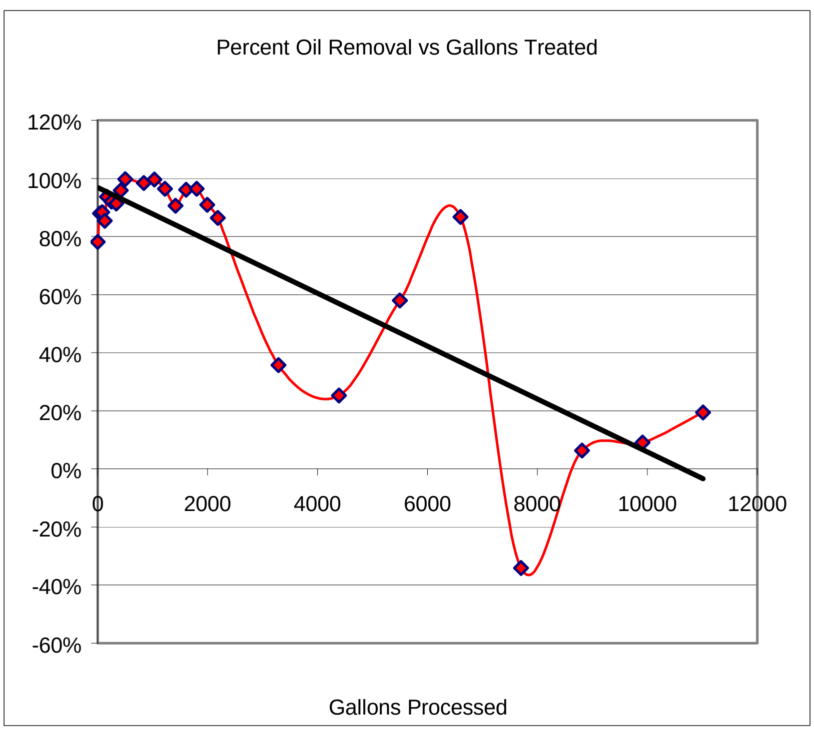


This data indicates a dramatic decrease in the BTEX concentration of the treated water in a very short period of time and under less than ideal conditions (cold temperatures and limited venting of the tank). Air sparging was conducted from the morning of February 27 through the evening of March 3 when the air sparging operation was suspended after the 5th day pending test results. After receiving the data, the air sparging tests were continued beginning March 13, 2001 and concluding March 19, 2001.

The second series of BTEX analysis on the 80 barrel batch of filtered and sparged produced water was completed and the results indicate that air sparging of the water filtered by a single stage of the test filter unit has removed all of the benzene and o-xylene with only a trace of the toluene, ethylbenzene, and m,p,-xylene all concentrations of which are well below any action levels.

The inorganic test data is confusing with regard to the effects the filtering process has on the inorganics in the water sampled. Of the salts, the sodium and potassium numbers are significant and appear to increase. Heavier metal seems to be decreased. The remaining inorganic numbers are insignificant. This raises the possibility that the treated water, once subject to air sparging to remove the VOC's could be recycled as makeup water for frac jobs or drilling fluids.

Lifetime Efficiency of the Initial Test Column



4/1/2001 through 6/30/2001

Due to a number of factors including the sale of Western SynCoal's parent company and continued transition efforts at NARCo related to its sale to Pan Canadian, no additional experimentation was completed during this period. The project team did meet and evaluate results to date. These efforts resulted in a plan for the next phase of testing which involved the following tasks:

1) Reloading the twin filter canisters with SynCoal in the first stage canister and dolomitic SynCoal in the second stage canister.

2) The air sparge tank would be steam cleaned to remove any historical oil/grease residues.

3) The produced water from a single well unit would be used in this test protocol.

4) An initial water sample of the untreated produced water would be collected and analyzed for inorganics, organics, TRPH, and BTEX concentrations.

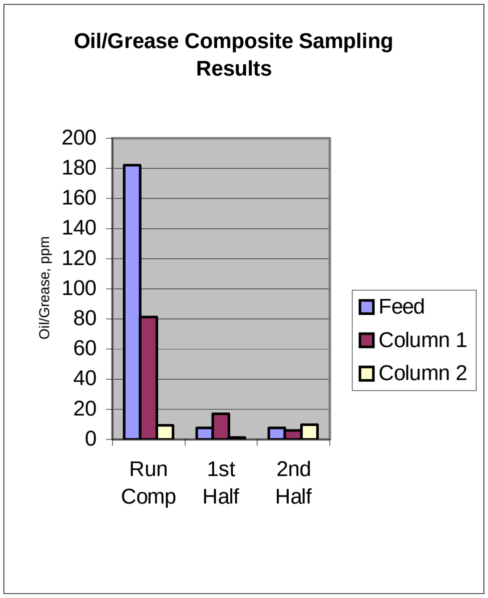
5) The filter/sparge system would be set up on a timer to operate 4 hours per 24 hour period. The flow rate would be established at 2 gallons/minute or 120 gallons/hr, or 480 gallons/day. Assuming an initial untreated volume of 80 bbls, the test was run for approximately 7 days.

6) At the end of the batch testing period, the same analysis profile as was listed in "4" above will be run to provide the treated numbers for each batch.

7) The test protocol would be repeated with each 80 bbl. Batch of water taken from the designated well unit in an effort to determine the saturation point of the filter units. The marker to be used to determine the saturation point would be the TRPH analysis.

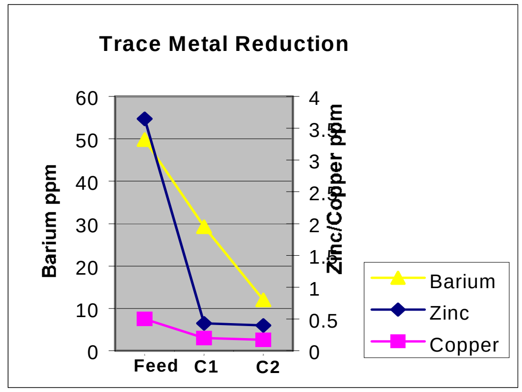
7/01/2001 to 9/31/2001

Test work this quarter focused on both sampling technique and preliminary evaluation of SynCoal tailings material to address inorganic contaminant reduction. A two column test apparatus was configured with 110 lbs of SynCoal Product in the first column and 120 lbs of SynCoal tails in the second column. SynCoal tailings contain partially calcined dolomites and stable massive pyrite, previously tested in weathering tests to exhibit a buffering capacity towards both pH and trace metals. Composite sampling was attempted to reduce the risk of previously encountered inconsistent results. The duration of the test was 6 hours at a feed rate of 3 gpm. The following graph shows the results from this sampling.



The first series of columns (Run Comp) is the analysis of composite sample increments taken hourly over the duration of the entire six hours. The second series of bars is a composite of hourly increments taken during the first half of the test run and the third data set shows a composite of hourly increments from the second half of the test run. Consistency of sampling and analysis remain problematic.

Major cation/anion reduction was not achieved by using the SynCoal tails in column 2, as the analyses indicates a slight increase in sodium and calcium. Trace metal analysis indicates a significant reduction in zinc, copper, barium, aluminium, cadmium, and chromium. Dissolved chloride appears unchanged.



Analytical results are shown in the appendix.

Review of the data sets to date still indicate a problem remains in sampling and/or analysis. The next investigation will configure four columns of SynCoal in series, the discharge of each to be sampled hourly with the goal of defining the hydrocarbon loading capacity of SynCoal tracing the "breakthrough" of hydrocarbons through a four column series.

Other activities during this quarter include the preparation of this projects presentation for a meeting of the Petroleum Technology Transfer Institute on November 27, 2001 in Denver, Colorado. Interest in the project has also been noted by several other groups in the industry requesting further information.

4/01/2003 to 6/30/2003

The validity of the tests performed in February of 2001 were questioned due to possible degradation of the SynCoal used for these tests. It is generally accepted that SynCoal will oxidize and the reactivity will be lessened if SynCoal is not stored properly. In an effort to minimize the possible impacts of

SynCoal deterioration, a fresh batch of SynCoal was produced, processed and stored in sealed containers to ensure the viability of the material

Westmoreland's Rosebud Mine personnel performed a maintenance and operations check of the pilot plant equipment prior to April 14, 2003. Pre-operations inspections and testing was conducted on April 14 under the supervision of Western SynCoal, LLC. Commencing April 15, Rosebud coal was processed at a rate of 100 lbs/hr by Rosebud Mine personnel, supervised by Western SynCoal, LLC. Approximately 1600 lbs of Rosebud coal was processed with processing completed April 17.

The produced SynCoal, approximately 1100 lbs, was screened at ¼ inch and 6 mesh. The sized material, ¼ inch x 6 mesh, was processed by gravity separation to remove pyrite and rocks. A sample of the sized and cleaned SynCoal was tested to determine the suitability of the material to meet the needs of the project. The balance of the material was packaged and taken to Butte, Montana pending preparation of test protocols for the additional oil stripping testing.

Results and Discussion

Further testing was necessary to verify the results obtained so far and to improve the experimental techniques. The anticipated testing for the next phase was intended to accomplish these goals. The disruption in the activities caused by the changes in corporate ownership were overcome (or significantly reduced) during the next quarter allowing the project work to get back on track.

The testing during the first quarter of 2001 used the same filter and media as used in the initial testing. This filter media has been sitting unused for approximately 90 days since the last testing was concluded. The produced water treated came in three batches each with different organic concentrations. The first batch had substantially higher organic concentrations than the initial work in November and filters efficiency was much lower than the initial work indicated which could have been a result of the filter having a loading which started to affect its efficiency. Although looking at the data, it appears the final portion of this batch was more efficient than the initial portion.

The second batch was even higher in organic concentration and it appeared that the filter had reached its saturation point as the untreated and treated water samples were effectively the same in oil and grease concentration for both the second and third batch of produced water.

The BTEX appeared to be generally unchanged throughout the range of samples from untreated to treated and generally increased in concentration with each batch processed. The inorganic analyses from samples taken on February 7 indicate that the sodium, potassium, calcium, magnesium, zinc, and manganese concentrations were increased probably due to leaching of the inorganic material within the filter media. The concentrations of iron, copper, cadmium, and lead were decreased at least theoretically due to the reaction with the filter material. The theory that the organic material that was not being captured was lighter hydrocarbons, seems to be well worn out by the air sparging test work and the reduction in BTEX material concentration over very short periods of time as a result of air sparging.

Conclusions

The SynCoal® filter media can be effective in removing oil and grease until it becomes saturated at which point its effectiveness is reduced. It is possible that the filters effectiveness was impacted by the long layoff and some subsequent reaction of the previously loaded oil and grease on the carbon material or further oxidation of the carbon as it sat for the prolonged period of time in the filter.

The organic material that escapes the filter media appears to be lighter weight hydrocarbons that can be effectively removed by air sparging to achieve acceptable levels of hydrocarbon concentration.

Further, the effective on dissolved inorganic concentrations is inconclusive although there is apparently leaching of sodium, potassium, calcium and magnesium materials from the filter media.

Further work is necessary to repeat these tests to eliminate the impact of the extended inactive period with the filter and to further define the capacity and limitations of the filter media.

The results to date are encouraging in that the SynCoal® filter media removes substantial quantities of hydrocarbons. If it is merged with a air sparging system the levels of total hydrocarbons can be reduced to very low levels. The inorganic concentrations are not effected significantly, although some results indicate that they are altered in some manner that is not yet understood. Future testing should attempt to repeat these observations and identify the mechanisms impacting these concentrations. If they can be identified perhaps they can be controlled.

The inconsistent results between repetitive samples has been plaguing the test program causing the need to repeat test sequences and limiting the confidence in the conclusion.

Test work 2003

The intent of the original test protocol was to demonstrate the effectiveness of using SynCoal® to remove oils and grease (O&G) from well water produced in conjunction with crude oil and natural gas. Water is typically recovered as a by-product with crude oil and/or natural gas. Oil and water separation techniques are not completely effective and result in small concentrations of oil in the water. Removal of the entrained oil could result in processed water suitable for industrial purposes. If the O&G concentrations are sufficiently low, subsequent water treatment schemes may become viable that could allow this water to be used for agricultural purposes. For example, reverse osmosis equipment will not tolerate O&G in the feed water as the organics destroy the membrane.

Initial testing in the laboratory appeared to be promising and subsequent testing was performed in the field. Produced water was provided from stripper gas wells in the DJ Basin of Colorado. Analytical results were confusing due to the extreme variation of the O&G in the feed water. The test water provided had O&G suspended in the water. This variability exacerbated by the lack of adequate mixing prior to delivery of the test water to the filtration columns. This condition resulted in erratic feed compositions with O&G values that varied widely. Further complications resulted from extreme temperature variations encountered during testing.

Due to the difficulties encountered with using test water with highly variable concentrations of O&G levels and the unpredictable temperatures of testing conditions, the final testing was performed under more controlled conditions. The test water was prepared using Westin County, Wy crude and city water to produce a test feed water with more consistent O&G in the suspended phase. Previous testing indicated that SynCoal was removing a portion of the O&G, the process did not appear to be capable of reducing O&G concentrations to levels that would be acceptable for final water processing equipment. Although disappointing, SynCoal® did indicate removal capacity sufficient to act as a pre-treatment for more aggressive O&G removal using an activated charcoal. This was considered positive as SynCoal, with a significantly lower cost, could be used as a partial replacement for activated carbon

The final test protocol was prepared with the concept that a more consistent feed be used while testing the hypothesis that SynCoal® would remove the bulk of the O&G. The intent was to determine the final concentration of the O&G. Two sets of columns using SynCoal® would be tested in parallel to mitigate the impacts of suspended O&G on sampling variability. These results were compared with a set of columns filled with a limestone, used to assess the impacts of O&G adhering to the components of the system.

The test feed water was prepared by mixing crude oil from Newcastle, Wyoming with tap water from the City of Butte, MT. 34.12 grams of oil was added to 45 gallons of tap water and mixed vigorously. This was intended to produce a test feed material that contained 200 ppm O&G in the water. Two drums were prepared to accommodate the testing requirements. Samples collected during testing indicated the average O&G for the test water was 171 ppm. It is assumed the preparation and storage components sorbed the balance of the oil.

Each test set consisted of four columns packed with either 6.63 pounds of SynCoal® or 14.73 pounds of limestone. Each individual three inch diameter column was packed to provide 36 inches of material. The four columns of each test set were arranged to receive test water in series. The fluid velocity through the columns was estimated to be 0.10 inches per second (0.5 feet per minute) using a feed rate of 3.30 gallons per hour. The materials used were determined to have a void volume of about 30%.

The flow to each column and the final effluent were to be sampled at one hour intervals over test duration of eight hours. A total of 135 samples were collected and analyzed for total O&G.

An initial period of 30 minutes was used to establish and verify flow rates.
The pump used to provide flow to the columns was considerably oversized for the flow rates required. This allowed a large recycle stream to be returned to the storage containers in an effort to enhance mixing and reduce variation in the O&G concentrations. The test water was vigorously mixed from the time of sample preparation through testing to enhance consistency of feed throughout the testing.

The data representing samples collected during the test are provided in Attachment 1 of this report. O&G concentrations varied from 68 ppm to 257 ppm, averaging 171 ppm. The standard deviation of the 27 samples of feed collected was 55.7. Individually, the two column sets compared quite well, with one set having an average inlet concentration of 171 ppm and the other averaging 166 ppm. The feed to the limestone column set averaged 176 ppm.

The two column sets loaded with SynCoal® reduced the O&G to an average of 7 ppm after 8 hours of testing. The limestone column set reduced the O&G to 140 ppm. The average reductions for the test in two hour intervals are presented below.

Average Reduction in O&G
Values in ppm O&G

Column Description	SynCoal 1	SynCoal 2	Limestone
2 Hour Test; Average Values; First 2 Hours of Testing			
Feed	142	221	176
Column 1 Exit	50	57	175
Column 2 Exit	18	14	122
Column 3 Exit	7	7	119
Column 4 Exit	3	4	112
4 Hour Test; Average Values; First 4 Hours of Testing			
Feed	176	181	191
Column 1 Exit	60	65	144
Column 2 Exit	21	17	132
Column 3 Exit	11	10	120
Column 4 Exit	4	4	116
6 Hour Test; Average Values; First 6 Hours of Testing			
Feed	174	167	185
Column 1 Exit	64	71	153
Column 2 Exit	28	23	146
Column 3 Exit	14	17	131
Column 4 Exit	5	5	125
8 Hour Test; Average Values for Complete Test			
Feed	171	166	176
Column 1 Exit	73	76	163
Column 2 Exit	32	30	152
Column 3 Exit	18	20	147
Column 4 Exit	6	8	140

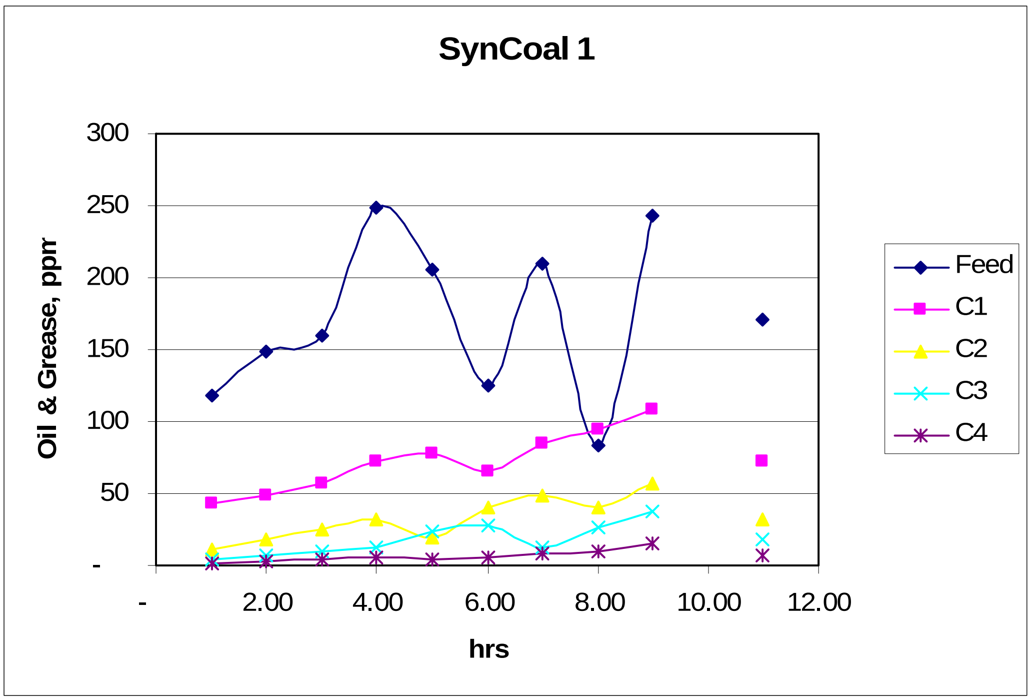
The data suggests that O&G levels can be reduced to very low concentrations, provided sufficient filtration media is provided. SynCoal removed approximately 97% of the Oil & Grease from the water and the limestone achieved about 52% removal. While each column exhibited a loading maximum, the successive column was able to reduce the O&G further. Upon review of the Column 1 Exit concentrations at 2 through 8 hours, the column appeared to be approaching saturation as the values increased from 50 to 73. This same relationship is exhibited for all of the SynCoal columns. The limestone columns reacted in a similar manner, but did not approach the filtration efficiency of SynCoal.

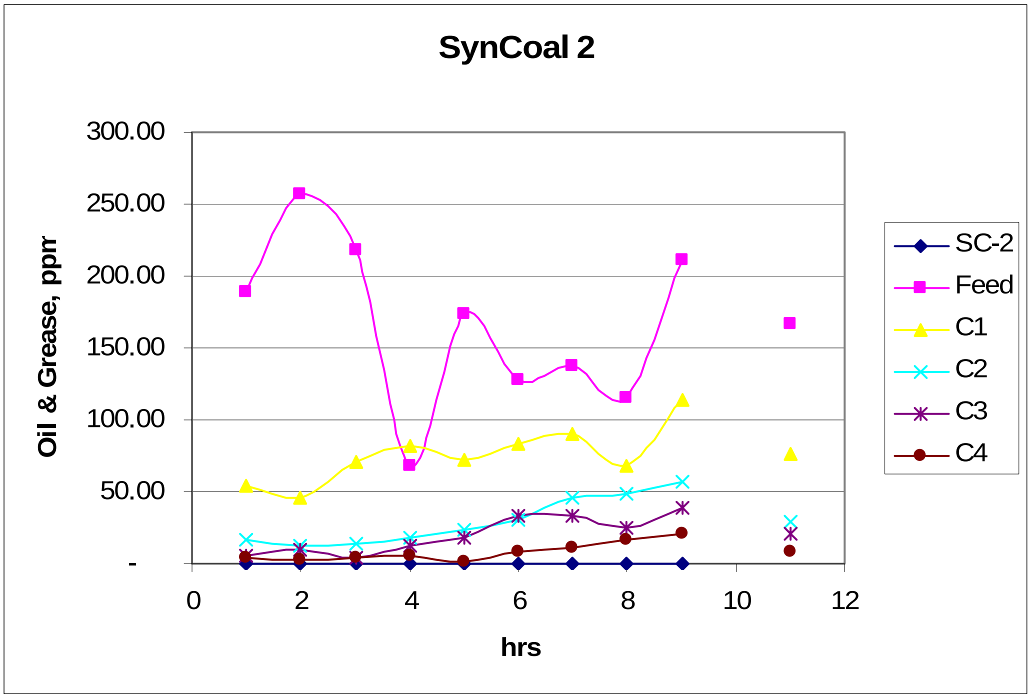
The ability of SynCoal to remove suspended O&G was demonstrated and removal efficiency was adequate to approach low levels of dissolved (or colloidal) O&G. It is unclear why each successive column was increasingly less efficient with time. The SynCoal loading was decreased with each column. Flow, O&G delivered and loading for each column is provided below for comparative purposes.

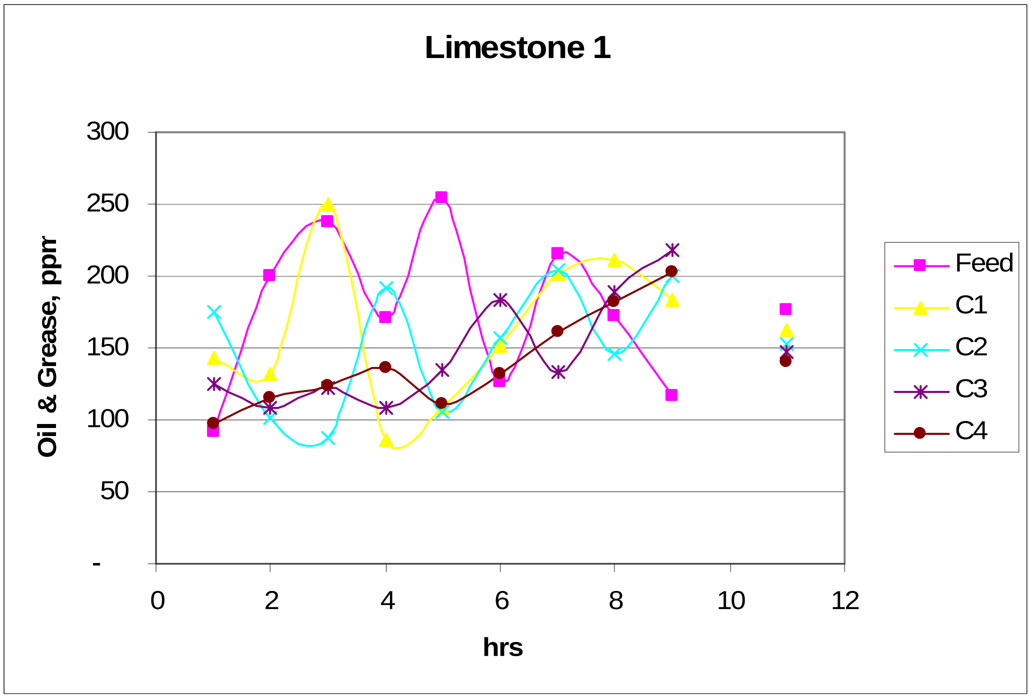
O&G Loading and Flow by Column

	Total Flow To Column Liters	Total O&G in Feed grams	O&G Removed grams	O&G Loading grams of O&G per lb of SynCoal
SynCoal Column Set 1				
C1	91.06	15.60	8.98	1.36
C2	82.06	5.96	3.30	0.50
C3	73.06	2.37	1.07	0.16
C4	64.06	1.14	0.73	0.11
SynCoal Column Set 2				
C1	91.06	15.15	8.26	1.25
C2	82.06	6.21	3.78	0.57
C3	73.06	2.16	0.68	0.10
C4	64.06	1.30	0.78	0.12

The flow to each column decreases due to sample extraction. 2.71 grams of O&G were contained in the samples from Set 1 and 2.70 grams from Set 2. There were 0.35 grams of O&G in the effluent of C4 of Set 1 and 0.5 grams from C4 of Set 2.




SynCoal 2
Oil & Grease, ppm
300.00
250.00
200.00
150.00
100.00
50.00
-
0
2
4
6
8
10
12
hrs
SC-2
Feed
C1
C2
C3
C4


Limestone 1
Oil & Grease, ppm
300
250
200
150
100
50
-
0
2
4
6
8
10
12
hrs
Feed
C1
C2
C3
C4

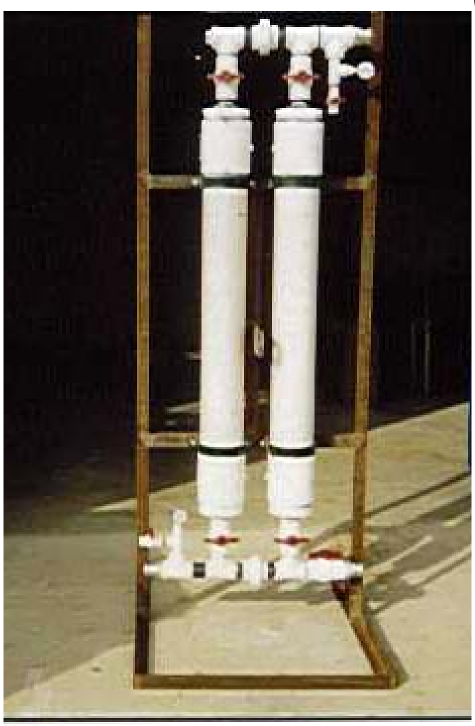
Although SynCoal did not completely remove all of the O&G from the test water, the levels were reduced sufficiently to allow the effluent to be discharged to more aggressive forms of purification. It appears that final polishing with activated carbon would be appropriate before attempting further processing with reverse osmosis.

The filtration process used may be less economically favorable than stirred tank absorption. Using a technique widely accepted by the gold industry, referred to as carbon in pulp, or carbon in leach, SynCoal would be mixed with the well water in stirred tanks. Typically, several tanks are used in series. The well water would be introduced into the first tank and cascade to subsequent tanks. The SynCoal is "advanced" from the last tank to the first tank. Simple screens and pumps are used to recover the solids from each tank for delivery to the appropriate vessel. This places the freshest and most active SynCoal in the tank with the lowest O&G concentration and the least reactive material can be used to sorb O&G from the inlet feed water. This mechanism may be the most compatible method of taking advantage of the sorption characteristics of the SynCoal.

Comparing SynCoal to activated carbon does not seem appropriate, as SynCoal will not adsorb nearly the amount of O&G. However, using SynCoal as a pre-treatment seems to merit further discussion. Activated carbon costs average \$0.85 per pound (\$1700 per ton) as opposed to the cost of SynCoal at \$0.025 per pound (\$50 per ton). The spent SynCoal should have a value of \$0.021 per pound, as the moisture would be increased from 2% to 15%, reducing the calorific value from 11,000 to 9400 Btu/lb. The ability to use the spent SynCoal as a boiler fuel is a powerful argument for using SynCoal as a pre-treatment for subsequent processing with activated carbon. The net effective cost of SynCoal would be \$0.0037 per pound. Activated carbon would cost about 230 times as much as SynCoal.

Prototype “Filter Canister”
From Steel Pipe

Filter Unit Installed at
Field Site



Portable Skid
Mounted PVC Filters

Initial Column Test Notes & Results

Wattenburg Location SynCoal Water Treatment Test Series 1 Nov. 1, 00

Sample Log R Malmquist

ID	Interval	Time	pH	Cond, ms/cm	Notes	
NA-001A	0.00	11:30	6.5	2.84	Flow adjusted to 3.3gpm, inlet = 11psi	
NA-001B	0.00		6.5		Outlet = <3psi	
NA-001C	0.00		6.5			
NA-002A	0.25	11:45	6.5	2.08		
NA-002B	0.25		6.5			
NA-002C	0.25		6.5			
NA-003A	0.50	12:00	6.5	2.30	Flow 3.3gpm	
NA-003B	0.50		6.5			
NA-003C	0.50		6.5			
NA-004A	0.75	12:18	6.5	2.27		
NA-004B	0.75		6.5			
NA-004C	0.75		6.5			
NA-005A	1.00	12:32	6.5	2.26	Inlet = 12.5psi	Flow = 3.5gpm
NA-005B	1.00		6.5		Outlet = <3psi	
NA-005C	1.00		6.5			
NA-006A	1.50	13:00	6.5	2.27		
NA-006B	1.50		6.5			
NA-006C	1.50		6.5			
NA-007A	2.00	13:35	6.5	2.25		
NA-007B	2.00		6.5			
NA-007C	2.00		6.5			
NA-008A	2.50	14:00	6.5	2.30	Inlet = 15 psi	
NA-008B	2.50		6.5		Outlet = <3psi	
NA-008C	2.50		6.5			
NA-009A	3.00	14:30	6.5	2.30		
NA-009B	3.00		6.5		inlet = 16psi	
NA-009C	3.00		6.5		Flow = 2.1gpm	
NA-010A	3.50	15:00	6.5	2.39	SAMPLES:	
NA-010B	3.50		6.5			
NA-010C	3.50		6.5		A: Preserved w/5ml HCl for Oil & Grease,	
NA-011A	4.00	15:30	6.5	2.32	1 liter sample	
NA-011B	4.00		6.5		B: Preserved w/1ml HNO3, filtered through	
NA-011C	4.00		6.5		0.45 micron filter for trace metal	
NA-012A	4.50	16:00	6.5	2.39	analysis. 250ml sample	
NA-012B	4.50		6.5		C: Unpreserved sample for TSS, cation	
NA-012C	4.50		6.5		anion balance, pH, Cond. 500ml	
NA-013A	5.00	16:30	6.5	2.39		
NA-013B	5.00		6.5		Estimated gallons treated =	925
NA-013C	5.00		6.5			
Wattenburg Location			SynCoal Water Treatment Test Series 1			Nov. 2, 00
NA-014A	0.00	10:00	6.5	2.42	NA-014A,B,C IS INFEED SAMPLE	
NA-014B	0.00					
NA-014C	0.00				flow 3.0gpm	

NA-015A	1.00	11:00	6.5	2.35	inlet 17psi		
NA-015B	1.00						
NA-015C	1.00						
NA-016A	2.00	12:00	6.5	2.30	flow 3.3gpm		
NA-016B	2.00						
NA-016C	2.00						
NA-017A	3.00	13:02	6.5	2.33	inlet 17psi		
NA-017B	3.00						
NA-017C	3.00						
NA-018A	4.00	14:00	6.5	2.34			
NA-018B	4.00						
NA-018C	4.00				inlet 17psi		
NA-019A	5.00	15:00	6.5	2.36	flow 3.3gpm		
NA-019B	5.00						
NA-019C	5.00						
NA-020A	6.00	16:00			Gallons Treated	=	1152
NA-020B	6.00				Previous day		925
NA-020C	6.00				Total for single column to date =		2077

Preliminary Laboratory Results

Lab Results
Weld Laboratories, Inc.
Lab No: 4287

	Oil/Grease	Ca	Na	Mg	K	SO4	Cl
NA-001 FEED	**44.0**	**231**	**5480**	**38.6**	**38.0**	**<1.0**	**4550**
NA-002	9.6	241	5380	30.0	36.0	<1.0	4550
NA-003	5.3	239	5460	28.8	42.0	<1.0	4640
NA-004	5.1	242	5610	112.6	40.8	<1.0	4290
NA-005	6.4	223	5360	38.6	41.8	<1.0	4730
NA-006	2.8	239	5570	29.0	47.8	<1.0	4640
NA-007	3.5	238	5540	43.7	49.3	<1.0	4550
NA-008	3.8	241	5330	31.1	45.3	<1.0	4550
NA-009	1.8	246	5570	41.0	47.3	<1.0	4460
NA-010	<0.1	238	5310	32.3	51.3	<1.0	4640
NA-011	1.1	243	5230	35.1	48.5	<1.0	4640
NA-012	0.7	250	5230	27.7	48.3	<1.0	4550
NA-013	<0.1	245	5000	27.9	46.0	<1.0	4550
NA-014 FEED	**30.8**	**245**	**5040**	**25.8**	**48.5**	**<1.0**	**4460**
NA-015	1.1	245	5040	47.3	44.8	<1.0	4640
NA-016	2.9	246	5120	89.3	51.0	<1.0	4460
NA-017	1.2	242	5100	49.6	46.3	<1.0	4550
NA-018	1.1	240	5020	36.5	48.5	<1.0	4550
NA-019	2.8	245	5100	48.7	51.0	<1.0	4640
NA-020	4.2	237	5120	59.2	48.0	<1.0	4550

	Cr	Mo	Ni	Pb	Ag	Hg	Ba	Cd
NA-001 FEED	**<0.01**	**<0.05**	**<0.01**	**<0.01**	**0.183**	**<0.0002**	**<1.0**	**0.080**
NA-002	<0.01	<0.05	<0.01	<0.01	0.000	<0.0002	<1.0	0.065
NA-003	<0.01	<0.05	<0.01	<0.01	0.013	<0.0002	<1.0	0.065
NA-004	<0.01	<0.05	<0.01	<0.01	0.034	<0.0002	<1.0	0.063
NA-005	<0.01	<0.05	<0.01	<0.01	0.020	<0.0002	<1.0	0.065
NA-006	<0.01	<0.05	<0.01	<0.01	0.028	<0.0002	<1.0	0.065
NA-007	<0.01	<0.05	<0.01	<0.01	0.030	<0.0002	<1.0	0.065
NA-008	<0.01	<0.05	<0.01	<0.01	0.033	<0.0002	<1.0	0.070
NA-009	<0.01	<0.05	<0.01	<0.01	0.035	<0.0002	<1.0	0.065
NA-010	<0.01	<0.05	<0.01	<0.01	0.043	<0.0002	<1.0	0.068
NA-011	<0.01	<0.05	<0.01	<0.01	0.045	<0.0002	<1.0	0.068
NA-012	<0.01	<0.05	<0.01	<0.01	0.050	<0.0002	<1.0	0.068
NA-013	<0.01	<0.05	<0.01	<0.01	0.050	<0.0002	<1.0	0.068
NA-014 FEED	**<0.01**	**<0.05**	**<0.01**	**<0.01**	**0.053**	**<0.0002**	**<1.0**	**0.068**
NA-015	<0.01	<0.05	<0.01	<0.01	0.058	<0.0002	<1.0	0.075
NA-016	<0.01	<0.05	<0.01	<0.01	0.058	<0.0002	<1.0	0.068
NA-017	<0.01	<0.05	<0.01	<0.01	0.050	<0.0002	<1.0	0.070
NA-018	<0.01	<0.05	<0.01	<0.01	0.060	<0.0002	<1.0	0.068
NA-019	<0.01	<0.05	<0.01	<0.01	0.065	<0.0002	<1.0	0.068
NA-020	<0.01	<0.05	<0.01	<0.01	0.065	<0.0002	<1.0	0.068

	CO3	TSS	Zn	Fe	Mn	Cu	Al
NA-001 FEED	**119**	**59**	**0.40**	**69.1**	**0.92**	**0.265**	**<0.1**
NA-002	108	19	0.55	77.9	0.93	0.050	<0.1
NA-003	118	22	0.55	76.4	0.89	0.028	<0.1
NA-004	119	15	0.44	75.3	0.88	0.033	<0.1
NA-005	114	21	0.93	72.6	0.87	0.030	<0.1
NA-006	114	14	0.94	73.9	0.87	0.035	<0.1
NA-007	114	18	1.28	73.9	1.00	0.033	<0.1
NA-008	119	13	1.10	72.5	0.96	0.043	<0.1
NA-009	108	15	1.07	72.5	0.97	0.033	<0.1
NA-010	114	25	0.90	71.4	1.00	0.033	<0.1
NA-011	102	17	0.63	68.8	0.96	0.028	<0.1
NA-012	102	19	0.90	71.0	0.90	0.023	<0.1
NA-013	102	23	1.00	69.9	0.90	0.023	<0.1
NA-014 FEED	**108**	**20**	**1.16**	**69.9**	**0.95**	**0.043**	**<0.1**
NA-015	119	24	1.11	69.4	0.88	0.045	<0.1
NA-016	114	19	1.28	69.8	0.89	0.035	<0.1
NA-017	102	17	1.28	72.6	0.91	0.038	<0.1
NA-018	91	25	1.10	72.6	0.89	0.043	<0.1
NA-019	97	30	1.18	72.8	0.89	0.033	<0.1
NA-020	97	18	1.19	72.6	0.90	0.035	<0.1

Second Test Series Results Using Initial Column Filters

Laboratory No. 4372 First Batch Of Produced Water
Date Sampled: 2/1-7/2001
Date Received: 2/13/01

Sample ID	ppb Benzene	Toluene	Ethylbenzene	M,p-Xylene	o-Xylene	ppm Oil & Grease
01-Feb I	100	121	4.5	23.4	12.3	182
01-Feb O	35.5	46.2	6.5	8	2.4	117
02-Feb I	404	583	8.7	118	50.9	106
02-Feb O	603	707	7.6	109	48.9	79.2
05-Feb I	499	602	7.4	101	45.4	100
05-Feb O	517	501	55.2	69	35.1	42
06-Feb I	651	723	8.5	107	49.8	118
06-Feb O	357	414	4.5	70.8	34.2	15.7

Laboratory No. 4372 Second Batch Of Produced Water
Date Sampled: 2/7-12/2001
Date Received: 2/13/01

Sample ID	ppb Benzene	Toluene	Ethylbenzene	M,p-Xylene	o-Xylene	ppm Oil & Grease
07-Feb I	448	368	24.1	174	81.8	258
07-Feb O	362	225	6.6	51.6	25.4	403
07-Feb I	493	429	26.2	186	79.6	179
07-Feb O	466	296	10.6	73.6	37.2	140
08-Feb I	1530	1140	63.4	302	126	255
08-Feb O	916	670	32.7	201	87.6	239
09-Feb I	624	360	14	87.8	42.8	276
09-Feb O	1350	865	30.2	189	87.9	251
12-Feb I	2010	1260	47.2	306	134	175
12-Feb O	1300	847	28.4	182	83.4	141

Laboratory No. 4383 Third Batch Of Produced Water
Date Sampled: 2/13-20/2001
Date Received: 2/22/01

Sample ID	ppb Benzene	Toluene	Ethylbenzene	M,p-Xylene	o-Xylene	ppm Oil & Grease
13-Feb I	1260	424	9.9	66.8	35.6	12.6
13-Feb O	1330	538	8.9	66.6	32.8	17.1
13-Feb I	1950	832	13.6	111	51.9	4.1
13-Feb O	1890	745	10.9	85.2	41.7	8.3
14-Feb I	1470	617	10.5	81.4	39.1	4.2
14-Feb O	2740	1280	22.2	172	78.6	3.8
19-Feb I	4150	2720	55.7	471	190	4.3
19-Feb O	4560	2640	50.1	422	181	8.2
20-Feb I	4240	2770	57.9	484	197	2.8
20-Feb O	4010	2540	50.5	424	178	2

Second Test Series Results Comparison

Sample ID	Untreated Oil & Grease ppm	Treated Oil & Grease ppm	Untreated BTEX ppb	Treated BTEX ppb
01-Feb	182	117	261	99
02-Feb	106	79.2	1165	1476
05-Feb	100	42	1255	1177
06-Feb	118	15.7	1539	881
07-Feb	258	403	1096	671
07-Feb	179	140	1214	883
08-Feb	255	239	3161	1907
09-Feb	276	251	1129	2522
12-Feb	175	141	3757	2441
13-Feb	12.6	17.1	1796	1976
13-Feb	4.1	8.3	2959	2773
14-Feb	4.2	3.8	2218	4293
19-Feb	4.3	8.2	7587	7853
20-Feb	2.8	2	7749	7203

Second Test Series Summary Results

Sample ID	Untreated Oil & Grease ppm	Treated Oil & Grease ppm	Removal Efficiency	Untreated BTEX ppm	Treated BTEX ppm	Removal Efficiency
Batch 1 Ave	126.5	63.5	50%	1055	908	14%
Batch 2 Ave	228.6	234.8	-3%	2071	1685	19%
Batch 3 Ave	5.6	7.9	-41%	4462	4820	-8%

Analyses for Samples Gathered July 18, 2001

Laboratory No. 4622
30-Aug-01

Sample ID	Feed Comp	1st Half Feed	2nd Half Feed	C1 Comp	C1 H 0/2	C1 H 4/6	C2 Comp	C2 H 0/2	C2 H 4/6
Oil & Grease	182	7.83	7.8	81.1	17.2	5.91	9.2	1.28	9.66
Calcium	1610	1690	1650	1830	1750	1790	1820	1840	1660
Magnesium	298	310	285	315	293	308	300	320	280
Sodium	13200	16400	16200	18300	17900	18800	19200	19700	18500
Potassium	5525	6050	5620	5870	5670	5770	5800	5900	5250
Zinc	3.65	4.08	0.38	0.43	0.53	0.68	0.4	0.33	2.18
Iron	400	528	383	385	373	368	358	398	340
Manganese	6	7.13	5.9	6.78	6	6.23	6.23	6.53	5.25
Copper	0.5	0.25	0.2	0.2	0.19	0.35	0.17	0.15	0.13
Aluminum	53.5	31.5	48.5	18.3	53.8	22.8	<1	7	41
Barium	49.8	21.8	14.8	29.3	23	9.8	12	19	8.8
Cadmium	0.15	0.1	0.07	0.08	0.09	0.07	0.11	0.04	0.09
Chromium	0.65	0.28	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Molybdenum	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

Nickel	1.38	1.43	1.25	1.3	1.23	1.1	1.08	1.13	1.13
Lead	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Silver	0.063	0.065	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Mercury	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Chloride	13500	13200	12300	13200	12900	13800	12900	13200	14700

Test Data 2003: Attachment 1

200.00	PPM O&G; Target Feed Water Concentration
45.00	gallon Lots of Feed Water
375.75	pound Lots of Feed Water
170,591	gram Lots of Feed Water
34.12	grams of O&G per Lot of Feed Water

Column Data

3.00	inch ID of Column
36.00	inch; Packed Column Height
254.47	cubic inches of Packing Material
7.07	square inches of Open Column Flow Area

2	Column Sets with SynCoal
1	Column Set with Limestone
3	Column Sets
4	Columns per Set
8.00	hour Test duration

		SynCoal	Limestone
Density	pounds per cubic foot	45.00	100.00
Loading	pounds of material per column	6.63	14.73
	Total Material Required; pounds	53.01	58.90

Residence	6.00	minutes per column
Feed Required	10%	Waste
	1.94	Lots of Feed

Voids Volume	30%	
Flow Area; Effective	2.12	square inches
Fluid Velocity	0.10	inches per second
	0.50	feet per minute
Flow Rate	0.21	cubic inches per second
	0.46	pounds per minute
	3.30	gallons per hour per Column Set
	12.51	liters per hour per Column Set

SC-1	T=0	T=1	T=2	T=3	T=4	T=5	T=6	T=7	T=8	Average
Feed	119	149	159	249	205	125	210	84	243	171
C1	43	49	57	73	78	65	85	95	109	73
C2	11	18	25	31	19	41	49	41	57	32
C3	4	7	9	12	23	27	13	26	38	18
C4	2	3	5	5	4	5	8	10	15	6

SC-2	T=0	T=1	T=2	T=3	T=4	T=5	T=6	T=7	T=8	
Feed	189	257	218	68	174	128	138	115	211	166
C1	55	45	71	82	73	83	90	68	114	76
C2	17	13	14	19	23	30	46	49	57	30
C3	6	10	5	13	19	33	34	25	39	20
C4	4	3	5	5	1	8	11	16	21	8

LS	T=0	T=1	T=2	T=3	T=4	T=5	T=6	T=7	T=8	
Feed	92	199	238	171	255	126	215	172	117	176
C1	143	132	251	86	108	151	201	211	183	163
C2	175	101	88	191	106	157	205	146	199	152
C3	125	109	123	109	135	183	133	189	218	147
C4	97	115	123	137	111	132	161	182	203	140

SC-1	2 Hour Average	4 Hour Average	6 Hour Average	8 Hour Average
Feed	142	176	174	171
C1	50	60	64	73
C2	18	21	28	32
C3	7	11	14	18
C4	3	4	5	6

	T=2 Hours	T=4 Hours	T=6 Hours	T=8 Hours
All Feed Samples	180	183	175	171
SC-1 & SC-2 Samples	53	63	68	74
SC-1 & SC-2 Samples	16	19	25	31
SC-1 & SC-2 Samples	7	11	15	19
SC-1 & SC-2 Samples	4	4	5	7

SC-2				
Feed	221	181	167	166
C1	57	65	71	76
C2	14	17	23	30
C3	7	10	17	20
C4	4	4	5	8

LS				
Feed	176	191	185	176
C1	175	144	153	163
C2	122	132	146	152
C3	119	120	131	147
C4	112	116	125	140

1,000	gram Samples
9,000	grams of Samples per Column
45,000	grams of Samples; Total

Flow Rate		Total Flow	Total O&G	O&G Removed	O&G in Samples	Average
liters/ hour		liters	grams	grams	grams	grams O&G / pound
12.51	Feed	100.6	17.14			
11.51	C1 Inlet	91.06	15.60		1.54	
10.51	C2 Inlet	82.06	5.96	8.98	0.65	1.36
9.51	C3 Inlet	73.06	2.37	3.30	0.29	0.50
8.51	C4 Inlet	64.06	1.14	1.07	0.16	0.16
7.51	C4 Outlet	55.06	0.35	0.73	0.06	0.11
					2.71	
12.51	Feed	100.6	16.65			
11.51	C1 Inlet	91.06	15.15		1.50	
10.51	C2 Inlet	82.06	6.21	8.26	0.68	1.25
9.51	C3 Inlet	73.06	2.16	3.78	0.27	0.57
8.51	C4 Inlet	64.06	1.30	0.68	0.18	0.10
7.51	C4 Outlet	55.06	0.45	0.78	0.07	0.12
					2.70	
12.51	Feed	100.6	17.63			
11.51	C1 Inlet	91.06	16.04		1.59	
10.51	C2 Inlet	82.06	13.37	1.20	1.47	
9.51	C3 Inlet	73.06	11.12	0.89	1.37	
8.51	C4 Inlet	64.06	9.41	0.38	1.32	
7.51	C4 Outlet	55.06	7.70	0.45	1.26	