FOSSIL ENERGY

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# OPTIMIZING THE AIR FLOTATION WATER TREATMENT PROCESS

Final Report
May 1997

By
Bob Barnett

September 1998

Performed Under Subcontract No. G4S50904 and Contract No. DE-AC22-94PC91008

James E. Russell Petroleum, Inc.
Chanute, Kansas

**National Petroleum Technology Office**
**U. S. DEPARTMENT OF ENERGY**
**Tulsa, Oklahoma**

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**SUB-CONTRACT #G4S50904**
**"Optimizing The Air Flotation Water Treatment Process"**
**Final Report**


## ABSTRACT

The injection water for the Nelson Project is a combination of produced and make-up water, typical of many Eastern Kansas operations. The make-up water is a low-salinity salt water from the Arbuckle Formation and contains dissolved minerals and sulfides. The produced water contains suspended oil, suspended clay and silt particles, along with a combination of other dissolved minerals. The combination of the two waters causes several undesirable reactions. The suspended solids load contained in the combined waters would plug a 75-micron plant bag filter within one day. Wellhead filters of 75-micron size were also being used on the injection wells. The poor water quality resulted in severe loss of injectivity and frequent wellbore cleaning of the injection wells.

Various mechanical and graded-bed filtration methods were considered for cleaning the water. These methods were rejected due to the lack of field equipment and service availability. A number of vendors did not even respond to our request. The air flotation process was selected as offering the best hope for a long-term solution.

The objective of this work is to: increase the cost effectiveness of the process through optimizing process design factors and operational parameters. A vastly modified air flotation system is the principal tool for accomplishing the project objective. The air flotation unit, as received from manufacturer Separation Specialist, was primarily designed to remove oil from produced water. The additional requirement for solids removal necessitated major physical changes in the unit. Problems encountered with the air flotation unit and specific modifications are detailed in the body of the report.

An order of magnitude improvement in water quality has been achieved. Wellhead filters of ten-micron size are now routinely utilized as compared to the previous 75-micron filters. Filter changing frequency is no different. The overall water treating chemical costs have been reduced. The frequency and severity of injection well cleaning jobs has been greatly minimized. Additional detail is being provided regarding the nature of the well cleaning jobs and the frequency with which they occurred during a two-year period. Although all problems are not solved, injectivity has been much easier to maintain as a result of the cleaner water. This is vividly demonstrated by the reduced frequency of injection well cleaning.

**SUB-CONTRACT #G4S50904**
**Final Report**

## INTRODUCTION

Satisfactory use and proper or legal disposal of produced water are common problems for the stripper waterfloods of Eastern Kansas. Legal disposal zones are diminishing and restrictions are increasing. Likewise, the sources of an adequate volume and quality of flood water for the projects are also diminishing. If the produced water can be economically treated for re-injection, then this step solves two problems.

Past attempts to solve water problems have ranged from simply disposing of the produced water, sometimes illegally, to various schemes of filtering and treating the water for re-injection. Most attempts to filter the water have used either cartridge or bag-type filters. In rare cases, graded bed filtration systems have been used. The result has generally been rapid loss of injectivity and plugging of injection wells with either suspended solids, entrained oil, or bacterial debris from the water.

Specific objectives of the project have been previously detailed in the contract, quarterly reports, and various progress reports. In summary, the objective is to apply the air flotation process to provide an adequate quality of injection water within economic guidelines.

## WATER QUALITY MEASUREMENT

One of the difficulties of evaluating the flotation process has been the lack of a suitable field test for water quality. The project was started using a 5-micron filter test procedure. This is an effective laboratory test but not well adapted for field use.

The original method of filtering a liter of water followed by drying and weighing the filter is too time consuming to be of practical value for routine field testing of injection water. A HACH DR/700 colorimeter was purchased for $495.00. The instrument is battery powered, portable, and found to be a useful tool for field personnel to measure water quality. The instrument can be turned on, zeroed, and a water sample measured in 30 seconds. Figure 1 illustrates the relationship between DR/700 reading for suspended solids and the milligrams of a quartz powder used to test the instrument. A similar correlation was found for water samples obtained from the flotation unit at various times, dates, and degree of success in the removal of solids. Effectiveness of the analytical procedure is depicted in Figure 2.

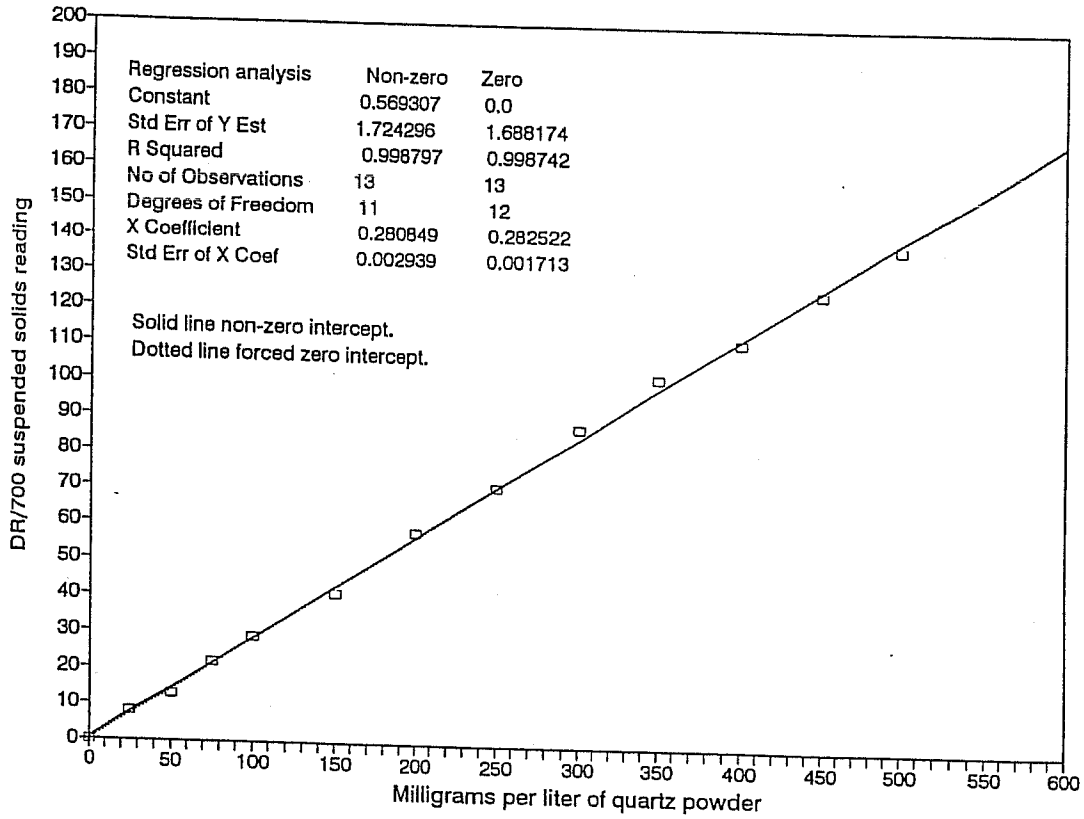



Figure 1

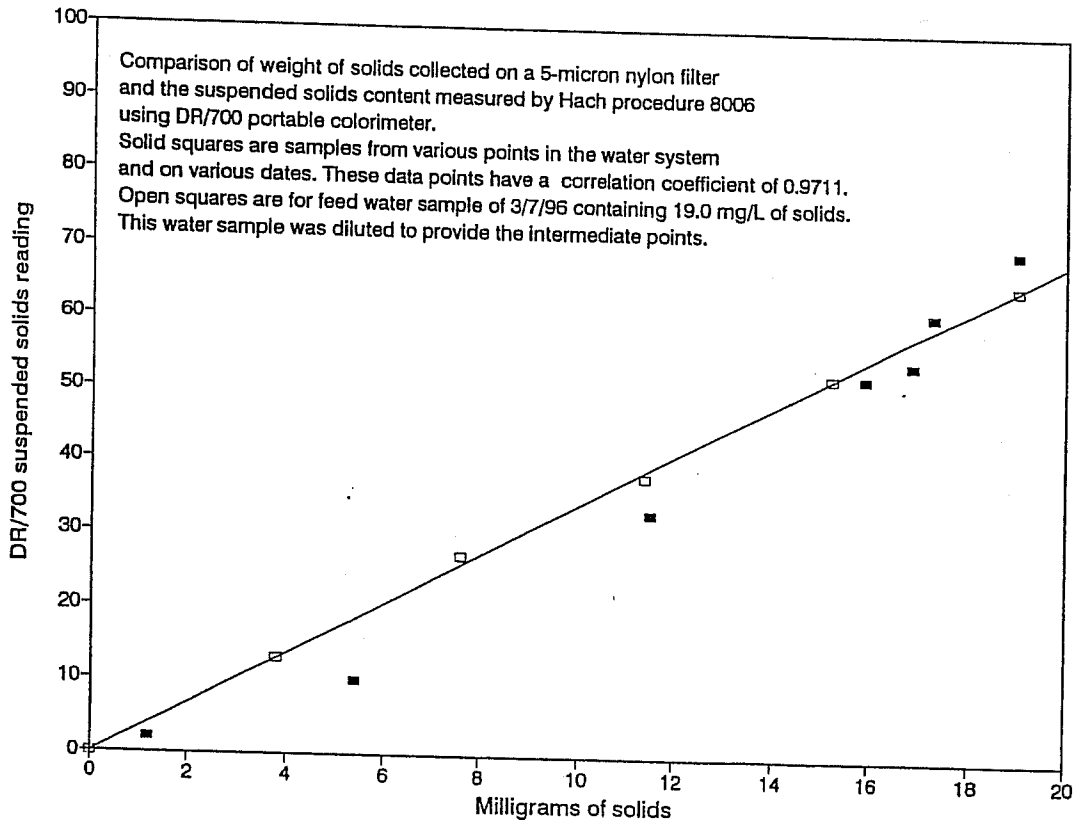



Figure 2

## ALTERATION OF FACILITIES AND OPERATIONS

Many alterations were made to plant facilities in order to accommodate the air flotation unit. Two additional clear water storage tanks were added. An additional tank was added as a mixing tank so the two waters could be blended and pretreated.

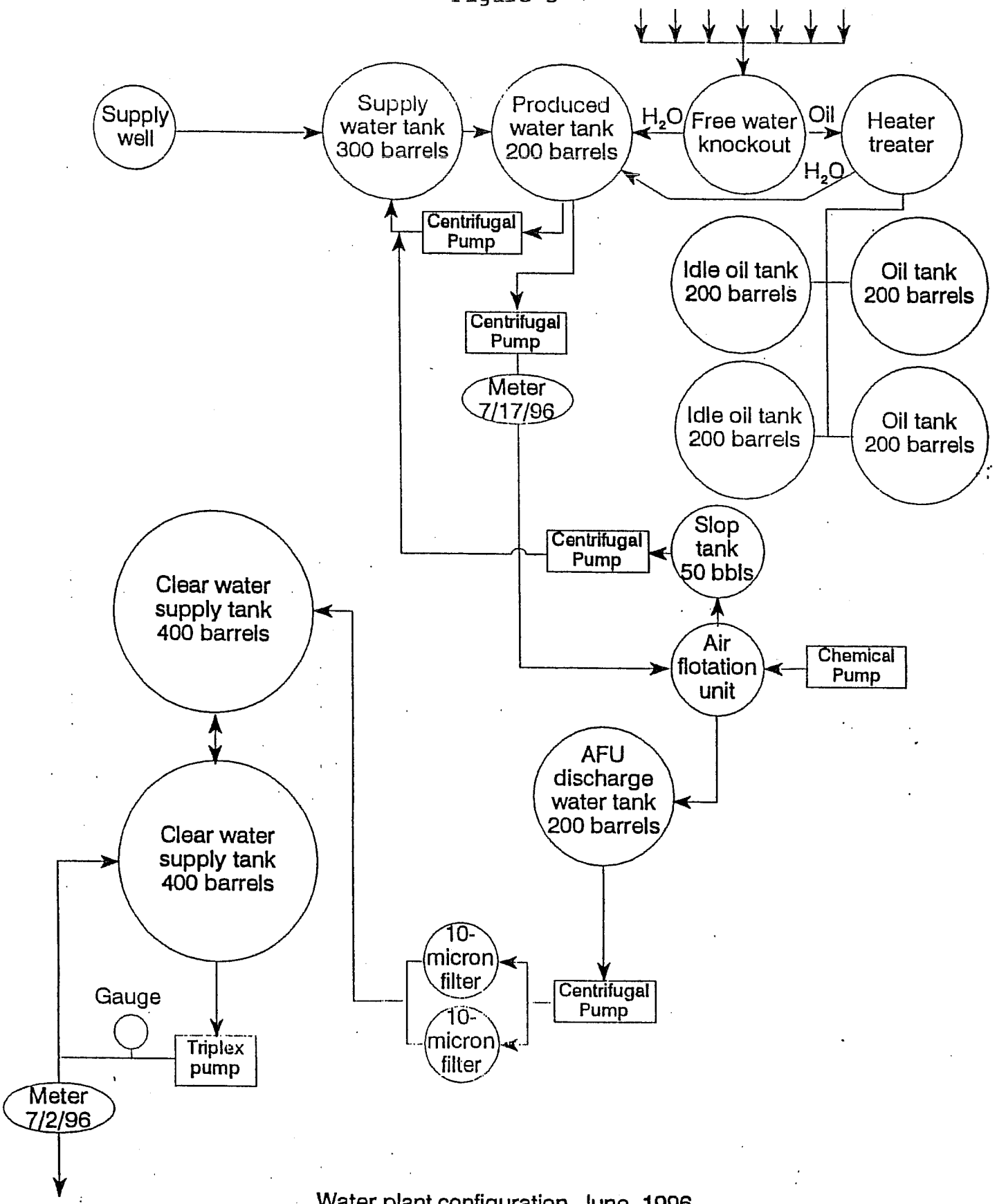
The 300-bbl. clear water supply tank was moved to become the supply circulating tank. A centrifugal pump was added so that the produced water and make-up water could be pre-mixed and circulated. Chemical pumps were added to provide for treatment with bleach, wetting agent, and floculating agent. An additional centrifugal pump was added at the slop tank to pick up and re-process the clear liquid. The 75-micron bag filter used for the produced water was discontinued. A centrifugal filter pump was set inside the plant building. This pump services the two bag filter assemblies set in parallel to polish the clean water.

Many of the changes involved the installation of new metering and control equipment. A Halliburton turbine-type flow meter with totalizer was installed downstream of the injection pump and another unit in the flow line from the water supply well. The cost of these units is $940 each. The installed cost is $1250 each. An Ecosol digital flow meter was installed in the transfer line measuring water feed to the AFU. This is a simpler paddle-wheel device that has an installed cost of $350. A problem with this meter is that the raw water scales and fowls the paddle wheel, requiring frequent cleaning. This meter design is being tested for a possible use in measuring the produced water rate. Strip chart devices were added for monitoring and recording the various functions.

The tank battery and oil handling vessels are standard with no unique features. All water tanks in the system are of fiberglass construction except for the slop tank, which is standard steel. Produced water from the tank battery flows into the 200-bbl. produced water tank. From here it is picked up by a centrifugal pump and circulated to the 300-bbl. supply tank where it is mixed with make-up water and then siphoned back to the produced water tank. Mixed water from the produced water tank is then pumped by another centrifugal pump through the Ecosol digital meter to the air flotation unit. Chemicals are added before and at the air flotation unit to augment the process. Clear liquid from the bottom of the air flotation unit flows into the 200-bbl. AFU discharge tank. Dirty water and froth from the top of the AFU is discharged into the slop tank. After allowing time for settling, the water is picked up from the top of the slop tank and re-processed through the system. The centrifugal filter pump acts on level control command from the clear water supply tanks. This pump pulls water from the AFU discharge tank, filters it through the bag filters, thus filling the clear water supply tanks. The injection pump, a standard Wheatley P-323 triplex pump, pulls water from the clear water supply tanks and discharges it through the Halliburton turbine meter for distribution to the field injection system.

A diagram of the final water plant configuration follows as Figure 3.

Figure 3




Water plant configuration, June, 1996
Nelson Lease, Savonburg Field NE
Allen County, Kansas



MJM 07-18-96

Modifications to the air flotation unit have been made throughout the reporting period. The domed top was cut from the unit to allow easier access for measurement, control, and the installation of auxiliary equipment. When the top was removed, the problem of froth removal became evident by the numerous eddy areas where solids would accumulate and then sink back into the tank. Many different designs of the waste removal weir have been tested. An effective design for the froth weir and removal system has finally been achieved. The weir is a plastic "U" channel set at the surface and extending the full width of the air flotation unit. Modifications have been made which allow the unit to operate more continuously and this has resulted in improved operations. This modification was achieved by down-sizing the filter pump so that its rate is more compatible with the throughput rate of the system. The filter pump, pumping against the 20' head of the new water supply tanks, fills the tanks more slowly thus providing a more continuous operation. The net effect of these changes is represented in Figure 4.

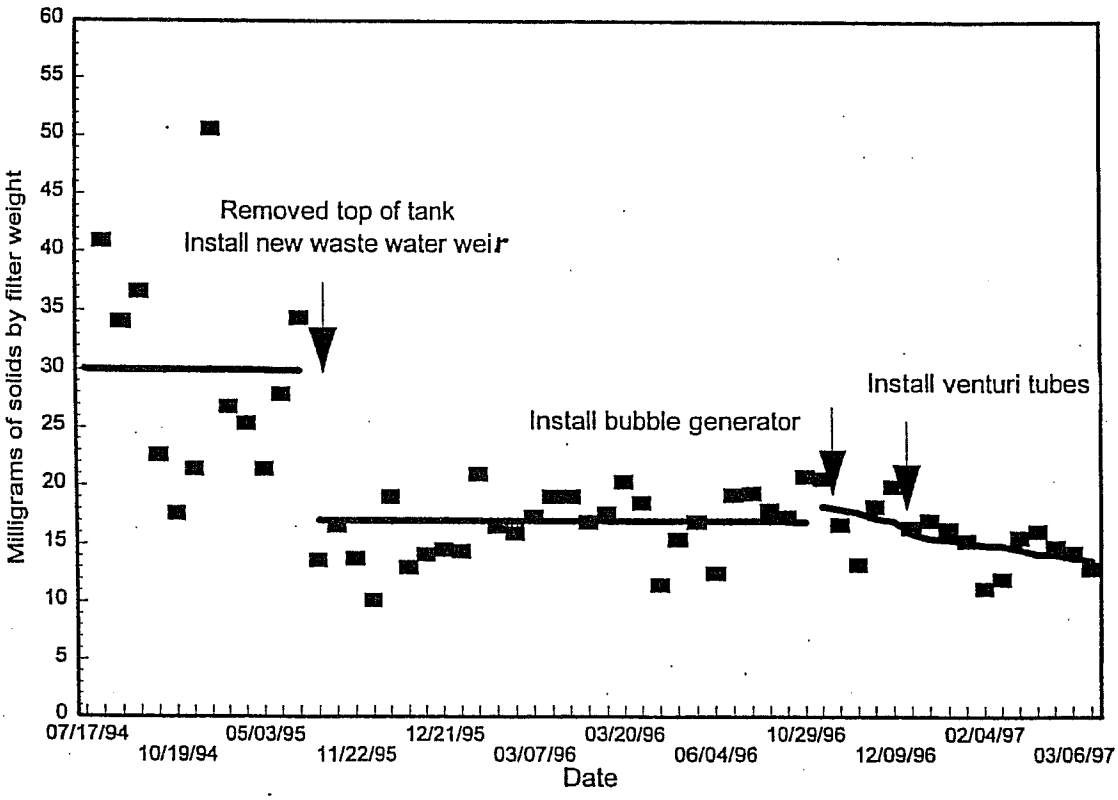



Figure 4

A rotating mechanical bubble wiper was installed on top of the unit. The purpose of this rotating brush was to sweep froth from the water's surface into the froth weir. This device has been found to be unnecessary, and has been removed. Improved circulating patterns allows the froth to adequately enter the froth weir. A strip chart has been utilized to measure the operating and shut-down time of the unit.

## PROBLEMS WITH THE AIR FLOTATION UNIT

The use of air flotation to clean produced water for injection has not worked as well as expected. The air flotation process was envisioned as a demonstration of known, off-the-shelf technology. Oil removal from the produced water has been lower than the maximum specified by the manufacturer of the unit. Solids removal has been more difficult. A major design error was found in the air turbine-agitator assembly in the air flotation unit as received from the vendor. A water-tight seal could not be maintained between the plastic bearing block and the inlet of the air turbine. The air turbine is a stamped, spot welded centrifugal pump impeller. The tolerance of the inlet to the air turbine is greater than the 0.003" required for most seals spinning at 3400 rpm. The plastic bearing block, the seal, and the turbine all become coated and filled with a barium sulfate scale and solids due to water evaporation. This indicates a leakage of water into the air side of the turbine. Repair costs was $350 for parts to repair the three air turbine-agitator assemblies. Initially custom rebuilding and alignment of the bearing block assemblies cost $1,000 per turbine unit. Each repair required two man-days of labor. The manufacturer is aware of this problem.

We designed and tested an air bubble generator. The bubble generator uses an inexpensive porous plastic muffler. Air is pumped through the muffler and very small air bubbles are generated as water is pumped past the muffler. The air bubble generator can be assembled from readily-available parts for less than $100. However, there was some additional cost of operating the air compressor.

A high air volume venturi tube was found to replace the air bubble generator. A 1" venturi tube costs $60. Two venturi tubes were found to function as well as the three air turbine generators. At the present time, the venturi tubes have operated 120 days with no problems. Replacement costs would be $120 and less than two man hours would be needed if the tubes need replacement. Operation of the venturi tubes requires only a simple centrifugal pump.

## SOLUTIONS

After two and one-half years of intensive experience in operating and modifying the unit, it is believed that a viable air flotation unit of similar size can be built for about one-half the cost of the present unit. The new unit would consist of a cylindrical fiberglass tank with all other piping and components being standard. The tank would be 4' in diameter and 8' in height, with a dish bottom. The vessel would be mounted on a stand for leveling purposes. It would contain two Venturi tubes positioned 2' from the vessel bottom and angled at 45 degrees from the tank center line. The tubes would be mounted at 180 degrees, or opposite sides. This will provide a sweep of air from bottom to the surface and impart rotation of water in the vessel. The raw water inlet will be 1' below the water surface and angled at 45 degrees from center line. The froth weir will be mounted at the water's surface to collect and drain solids as they accumulate. Cost estimates from vendors indicate a savings of approximately fifty percent as compared to the original unit.

## CHEMICAL TREATMENT FOR FLOTATION AID

Two flotation chemicals have been tested as wetting agents in conjunction with the current anionic polymer used as a flocculating agent. D-Sperse-C, a wetting agent for cement, was tried and found to be acceptable as a flotation agent. N-223, a biocide, which is a quaternary ammonium organic compound, is currently under investigation. This chemical is being utilized at a concentration of 12 ppm based on 100% active ingredients. This wetting agent also imparts a positive charge to the solid particles. The charged particles are attracted to the anionic polymer used as a flocculating agent. This combination of chemicals has produced the best water quality to-date. Suspended solids of the feed water is generally in the 80-150 mg/l range. The water sent to the field has contained less than 20 mg/l of suspended solids. Figure 5 depicts a typical test series.

A bench model air flotation unit has been constructed. Preliminary tests show the same degree of suspended solids as the 1000 barrel-per-day air flotation unit. This unit shows great promise in testing of produced waters.

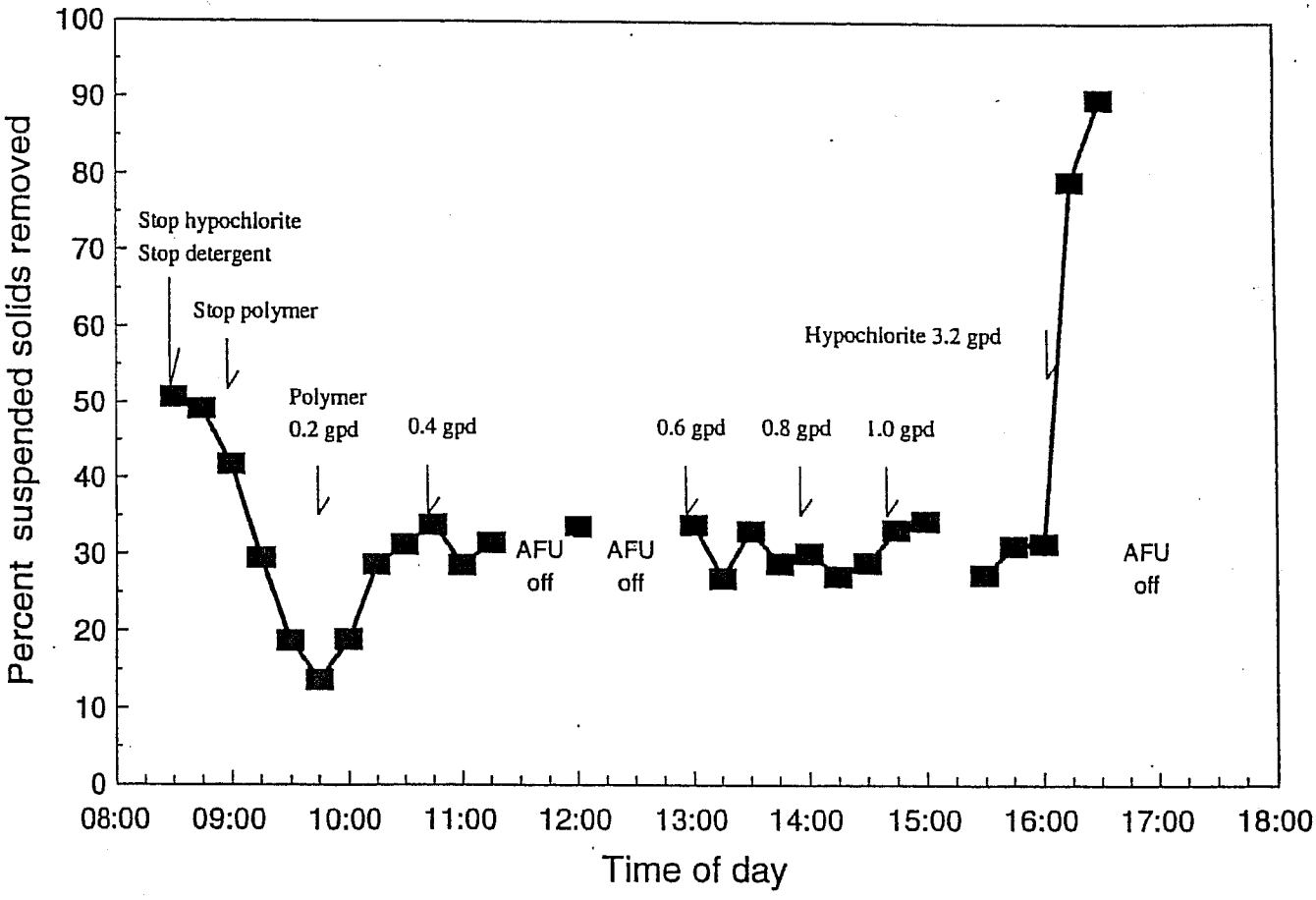



Figure 5

## PROJECT ACCOMPLISHMENTS

Injection Well Cleanouts:

Prior to installation of the air flotation unit and the resulting water quality improvement, a major cleaning/stimulation job was required for each injection well at least once per year. The procedure was to run a jet bit on tubing and wash/ream through the injection interval. After returns were clean, a ball was dropped to activate the jet tool and the formation face was jetted to remove additional solids. The near wellbore area was then stimulated with a treatment of acid plus additives. On most of these jobs it was found that the lower injection interval, B-3 Zone, would be totally covered with solids deposited from the injection water. Often the bridged solids were hard to drill, indicating that no injection water was reaching the critical B-3 Zone. In addition to these major yearly workover jobs, the wells often required interim stimulation to maintain injection rates. These treatments consisted of small batches of acid plus additives, either placed with a coil tubing unit or lubricated into the well.

Since improving the water quality, the frequency and severity of the cleaning jobs has diminished. Significant solids build-up in a well is now the exception rather than the rule. Solid, hard bridges are never found, making the cleanout jobs easier and faster to perform. Figures 6 and 7 present the comparative injection wellbore cleanout experience for two years. The number of cleaning jobs was reduced from 47 in 1995 to 21 in 1996.

**Figure 6**

**NELSON LEASE WELLBORE CLEANOUTS**
**1995**

| WELL NO. | WASH & ACIDIZED | COIL TUBING | LUBRICATED |
|---|---|---|---|
| RW-6 | 4/26 | 9/6 | |
| RW-8 | 4/13 | | |
| RW-13 | | 4/19, 9/7, 11/16 | |
| KW-7 | 4/19 | 9/5, 10/3, 11/20 | |
| KW-9 | | 4/27, 11/9, 12/2 | |
| KW-11 | | 4/20, 11/6 | 4/13 |
| RW-3 | 4/20 | 11/14 | |
| RW-9 | | 5/11, 7/12, 12/14 | |
| K-50 | 6/19 | | 7/24 |
| H-14 | 6/16 | | |
| RW-12 | | 7/12, 9/7 | |
| H-12 | | 7/10 | |
| RW-1 | 7/5 | 11/14 | |
| KCW-1 | | 9/7, 11/21 | |
| KW-6 | | 9/5, 11/21 | |
| KW-8 | | 9/7, 11/20 | |
| KW-10 | | 9/5, 12/13 | |
| RW-2 | | 10/5, 11/15 | |
| RW-14 | | 10/5 | |
| HW-1 | | 11/9 | |
| HW-18 | | 11/9 | |
| HW-23 | | 11/9 | |
| H-29 | | 11/10 | |
| HW-31 | | 11/9, 11/14 | |
| RW-7 | | 11/17 | |
| **TOTALS:** | 7 | 38 | 2 |

**TOTAL ALL TREATMENTS: 47**

**Figure 7**

**NELSON LEASE WELLBORE CLEANOUTS**
**1996**

| WELL NO. | WASH & ACIDIZED | COIL TUBING | LUBRICATED |
|---|---|---|---|
| K-42 | | | 2/20 |
| HW-23 | 3/5 | | |
| HW-18 | | 4/17 | |
| KW-7 | | 4/12 | |
| KW-8 | | 4/12 | |
| KW-11 | | 4/10 | |
| RW-1 | | 4/10 | |
| RW-2 | | 4/15 | |
| RW-6 | | 4/10, 9/23, 9/24 | |
| RW-8 | 9/24 & 9/25 | 4/17 | |
| RW-9 | | 4/17 | |
| RW-12 | | 4/17 | |
| HW-1 | | 5/15 | |
| H-12 | 5/3 | | |
| H-29 | 5/15 | | |
| HW-31 | 5/8 | | |
| KW-9 | | 5/21 | |
| RW-13 | | 5/15 | |
| KW-6 | 10/3 & 10/4 | | |
| **TOTALS:** | 6 | 14 | 1 |

**TOTAL ALL TREATMENTS: 21**

Reduced Chemical Cost:

Prior to installing the present program, the average water treating cost for chemical was $38 per day. This cost has been reduced by 34%, to $25 per day. We are confident that this cost can be reduced further by the planned improvements in mechanical operation of the unit. However, additional chemical costs may be necessary to solve the barium sulfate problem previously evidenced by scaled seals and meters.

Improved Water Filterability:

Injection water quality has improved since the start of the air flotation unit project. Injection wellhead filters have been changed from 75 to 10 micron size. A test well has been using a 5-micron filter, whereas the new injection well is utilizing a 2-micron filter. Filter change frequency for the 10 and 5-micron filters are similar to those experienced with the 75-micron filters before the air flotation unit was installed.

Water Quality Measurement:

One of the difficulties of evaluating the flotation process has been the lack of a suitable field test for water quality. The project was started by using a 5-micron filter test procedure. This is an effective laboratory test but not well adapted for field use. A colorimetric device has been established as the standard test aparatus and has yielded excellent results in the field. This unit is a HACH DR/700 Colorimeter. The device is easy for field personnel to use and has yielded excellent results and repeatability as compared to other devices.

Technology Transfer:

Technology Transfer is considered an important part of this project. The independent industry has shown great interest in this process through field tours and participation in workshops, seminars, and technical paper presentations. Examples of the workshops are:

-Exploitation of Mature Reservoirs - Results On Savonburg Project
August 8, 1995, Allen County Community College, Iola, KS;

-DOE Class I Traveling Workshop
Conducted at Bartlesville, Wichita, Denver, Billings, Oklahoma City, and Grayville, Illinois, during January & February, 1996.

Approximately 25 field tours have been conducted for various industry representatives. A list of tour participants is attached to the report as Appendix I and II. Additionally, lessors, landowners and neighbors have visited the installation.

Sample publications resulting from the project are:

"Savonburg Project"; published in the PTTC-North MidContinent News, 1st Quarter, 1996;

"Purifying System Works To Keep State's Oil Industry Alive", Chanute Tribune, May 4, 1996;

"Innovation Saves Money For Russell Petroleum", by Merle Grabhorn of The University of Tulsa, from the The Class Act, DOE's Reservoir Class Program Newsletter, Spring, 1996;

"Air Bubbles Clean Produced Water For Reinjection", Michnick, M.J.

"Development Of An Improved Waterflood Optimization Program In The Northeast Savonburg Waterflood", Barnett, G.B.; Schoeling, L.G.; Michnick, M.J.; Walton, A.W.; Green, D.W.; and Willhite, G.P.

"Engineering Aspects Of The Savonburg Class I Project", Barnett, G.B.;

"Problems In The Use Of Air Flotation For Cleaning Produced Water", Michnick, M.J.;

"Savonburg Project Progress Report", Barnett, G.B.

The last two publications were presented at the Twelfth Annual Oil Recovery Conference in Wichita, Kansas on March 20, 1997. These reports were well received by the 120 conference attendees.

## CONCLUSIONS

The air flotation unit has been successfully integrated into the water plant system. Alterations to the unit have dramatically cut downtime, maintenance costs and personnel time required to sustain operations.

Water treating costs have been reduced. An order-of-magnitude improvement in water quality has been achieved as demonstrated by filtration testing and actual field injection experience. The most dramatic reflection of improved water quality is the 55 percent reduction in the total number of wellbore cleanouts from 1995 to 1996.

A reliable field instrument for water quality measurement has been acquired and tested. A bench model testing device of one gallon capacity has been developed. It appears to closely approximate functionality of the air flotation unit. The device will be useful in projecting results from this work to other operators.

Much has been accomplished and much work remains. Most work to-date relates to the objective of increasing cost effectiveness of the process. A chemical vendor has shown interest in tailoring or blending products for this application. We plan to continue field work to optimize the air flotation process and are confident of further improvement.

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2. Schoeling, L.G.; Barnett, G.B.; Michnick, M.J.; Walton, A.W.; Green, D.W.; and Willhite, G.P., "Development Of An Improved Waterflood Optimization Program In The Northeast Savonburg Waterflood", presented at the 1996 SPE/DOE Tenth Symposium On Improved Oil Recovery in Tulsa, Oklahoma, (April 21-24, 1996) 221-226.
3. Barnett, G.B., "Engineering Aspects Of The Savonburg Class I Project", Proceedings of the Eleventh Oil Recovery Conference, Contribution No. 13, Wichita, Kansas, (March 14-15, 1995) 49-53.
4. Michnick, M.J., "Problems In The Use Of Air Flotation For Cleaning Produced Water", Proceedings of the Twelfth Oil Recovery Conference, Wichita, Kansas (March 19-20, 1997).
5. Barnett, G.B., "Savonburg Project Progress Report", Proceedings of the Twelfth Oil Recovery Conference, Wichita, Kansas (March 19-20, 1997).

## VISITORS TO THE NELSON LEASE
## AIR FLOTATION UNIT

### OIL OPERATOR REPRESENTATIVES

Belport Oil
- George Davenport

Blue Top Oil Company
- Marvin Stroble

Carmel Energy
- John Sperry

Colt Energy
- Alan Nichols and John Golston

Cryan & Associates
- Tom Cryan

Ensminger Oil
- Don Ensminger

Equinox Oil Company
- Doug Layton

Mico Oil & Gas
- John Ammerman

Northstar
- Steve Becker

Verde Oil Company
- Jeff Dale and Steve Balantyne

Westport Oil & Gas
- Ken Ogle

Wimsett Oil
- Jerry Wimsett

APPENDIX I

## VISITORS TO THE NELSON LEASE AIR FLOTATION UNIT

## SPECIALTY SERVICE & SUPPLY COMPANIES

BDM-DOE
- Winifred Ho
- Lance Cole
- Merle Grabhorn
- Rhonda Patterson

TORP
- Paul Willhite
- Don Green
- Lanny Schoeling
- Rodney Reynolds
- Tony Walton
- Stan McCool

Consolidated Industrial Services
- Mait Debois
- Dan and Fred Larson
- Ron Boquist

Cornish Wireline
- Jim Cornish

Faith Well Service
- Ed and Dave Willis

J & K Services
- Joe Goley

National Petrochem
- Mark Southerland
- Bruce Kiddoo

Oil Patch
- Merle Boone
- Gene Koester

P Chem
- Andy Herell

Petrolite
- Brad Seymour

Sabre-Chem
- Scott Beaver

Separation Specialists
- Jerry Just
- Dale McBride

Zimmerman Electric
- Max and Bob Zimmerman

APPENDIX II

## COMPANIES RECEIVING INFORMATION ON THE AIR FLOTATION UNIT

Delta Distributors, Inc.
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10319 E. 54th Street
Tulsa, OK 74146
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Dillman Services, Inc.
Gary Dillman
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Carmi, IL 62821
(618)382-4720

Esses, Inc.
Earl Schott
1917 W. Nashville
Broken Arrow, OK 74012
(918) 258-2288

Equinox Oil Company
Bryan J. Dicus
P.O. Box 31
Crossville, IL 62827
(618) 966-2101

Filtration Systems
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APPENDIX III