JV TASK 7 – FIELD APPLICATION OF THE FREEZE–THAW/EVAPORATION (FTE®) PROCESS FOR THE TREATMENT OF NATURAL GAS PRODUCED WATER IN WYOMING

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FIELD APPLICATION OF THE FREEZE–THAW/EVAPORATION (FTE®) PROCESS FOR THE TREATMENT OF NATURAL GAS PRODUCED WATER IN WYOMING

ABSTRACT

The freeze–thaw/evaporation (FTE®) process treats oil and gas produced water so that the water can be beneficially used. The FTE® process is the coupling of evaporation and freeze-crystallization, and in climates where subfreezing temperatures seasonally occur, this coupling improves process economics compared to evaporation alone. An added benefit of the process is that water of a quality suited for a variety of beneficial uses is produced. The evolution, from concept to successful commercial deployment, of the FTE® process for the treatment of natural gas produced water has now been completed. In this document, the histories of two individual commercial deployments of the FTE® process are discussed.

In Wyoming, as in many other states, the permitting and regulation of oil and gas produced water disposal and/or treatment facilities depend upon the legal relationship between owners of the facility and the owners of wells from which the water is produced. An “owner-operated” facility is regulated by the Wyoming Oil and Gas Conservation Commission (WOGCC) and is defined as an entity which only processes water which comes from the wells in fields of which they have an equity interest. However, if a facility processes water from wells in which the owners of the facility have no equity interest, the facility is considered a “commercial” facility and is permitted and regulated by the Wyoming Department of Environmental Quality. For this reason, of the two commercial FTE® process deployments discussed in this document, one is related to an “owner-operated” facility, and the other relates to a “commercial” facility.

Case 1 summarizes the permitting, design, construction, operation, and performance of the FTE® process at an “owner-operated” facility located in the Jonah Field of southwestern Wyoming. This facility was originally owned by the McMurry Oil Company and was later purchased by the Alberta Energy Company (now EnCana). Case 2 summarizes the permitting, design, construction, operation, and performance at a “commercial” FTE® facility located in the Great Divide Basin of south central Wyoming.

Permits required for the construction and operation of each facility are described in detail. The respective qualities of each feed water, treated water, and concentrate stream are presented along with the relative yields of treated water and concentrate at each facility. Treated water from the owner-operated facility has been beneficially used in drilling and dust abatement, and treated water from the commercial facility has been used for dust abatement, construction, and land application. The permitting requirements and evaluation of beneficial use of the water at each facility are discussed.

The results of this research confirm that the FTE® process is economic at a commercial-scale for the treatment and disposal of natural gas produced water in Wyoming. Further, the treated water produced from the process is of a quality suitable for beneficial uses such as irrigation, drilling mix, wildlife or livestock watering, and/or dust abatement on local roads.
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FIELD APPLICATION OF THE FREEZE–THAW/EVAPORATION (FTE®) PROCESS FOR THE TREATMENT OF NATURAL GAS PRODUCED WATER IN WYOMING

1.0 PROJECT SUMMARY

Evaporation is an economical method to dispose of oil and natural gas produced water in warm, arid climates. During colder seasons, evaporation is not effective. The freeze–thaw/evaporation (FTE®) process economically couples freezing with evaporation. By combining these natural processes, produced water can be treated economically on a year-round basis in colder climates. Another feature of the FTE® process is that treated water purified to a quality suitable for beneficial use is produced from the freezing process. The FTE® process is applicable in regions where subfreezing temperatures seasonally occur, such as the Rocky Mountain States of Wyoming, New Mexico, Utah, Colorado, and Montana and much of Canada. The FTE® process is capable of successfully treating most wastewater containing mixtures of salts, organic compounds, and/or heavy metals.

The concept of combining the natural processes of freezing and evaporation to provide an economical technology to treat oil and natural gas produced water was proposed in 1992. Personnel of Resource Technology Corporation (RTC), Inc., developed numerical process design and economic models and laboratory-scale simulation procedures during the time period from 1992 to 1995. In 1995, RTC formed B.C. Technologies (BCT), Ltd., with the objective of commercially developing the process. Also in 1995, BCT and the University of North Dakota’s Energy & Environmental Research Center began a collaborative research effort directed toward the commercial development of the process. During the period of 1995 to 1997, the FTE® process was successfully field-tested in New Mexico’s San Juan Basin. The results of this previous research are documented in the literature (Boysen et al., 1996).

The success of the FTE® process during the field test in northern New Mexico led to the decision to deploy the process at a commercial scale. McMurry Oil Company (MOC), a producer with gas wells in the Jonah Field of the Green River Basin in Wyoming, agreed to convert a conventional evaporation site into an FTE® facility. In 1998, a 1-acre brine pond and a 1-acre treated water pond were added. The owner-operated deployment of the FTE® process at the MOC Jonah FTE® Facility was initiated in February 1998 with approval from the Wyoming Oil and Gas Conservation Commission (WOGCC). Since that time, the MOC Jonah FTE® Facility has remained in operation. Alberta Energy Company (AEC) purchased MOC in 2001. In 2002, AEC became EnCana Oil and Gas USA, Inc., through merger.

Following the success of the deployment of the FTE® technology at the owner-operated Jonah Facility, Crystal Solutions (CS), LLC (a joint venture of BCT and GRI International), was formed in May 1999. In October 1999, the Wyoming Department of Environmental Quality (WDEQ) issued a construction permit to CS for a commercial FTE® produced water treatment facility. In December 1999, a commercially permitted FTE® produced water treatment facility with a 600 bbl/day capacity began operation in the Great Divide Basin of Wyoming. In 2001, the CS FTE® Facility expanded to a capacity of 1000 bbl/day.
The commercial development of the FTE® process occurred in the last decade as a result of research sponsored by Amoco Production Company (now BP), MOC (now EnCana), GRI (now Gas Technology Institute) and the U.S. Department of Energy (DOE). The authors wish to thank the personnel of these organizations for their support.

1.1 Objectives

The objective of this report is to document, evaluate, and communicate the performance results of two commercial-scale FTE® technology applications. This involved deploying and demonstrating a commercially economic natural FTE® process for the treatment and purification of water produced in conjunction with oil and natural gas.

1.2 Project Description

This report documents the ongoing FTE® technology application at two produced water treatment facilities in Wyoming. It further disseminates FTE® technology as a viable emerging produced water management option.

1.2.1 Case 1 – The Owner-Operated Jonah FTE® Facility

An existing evaporative disposal facility, owned by MOC, was converted to an FTE® produced water treatment facility. The Jonah FTE® Facility is now owned by EnCana and is operated by CS personnel. Details regarding permitting the facility, site development/construction, daily operational activities, and performance results are provided. Figure 1 is provided to illustrate the location of the Jonah Facility.

1.2.2 Case 2 – The Commercial CS Wamsutter FTE® Facility

A new FTE® produced water treatment facility was permitted, constructed, and placed in operation. Details regarding permitting the facility, site development/construction, daily operational activities, and performance results are provided. The location of the CS Wamsutter Facility is also illustrated in Figure 1.

1.3 Background

The fundamental concepts of the FTE® process are simple. Evaporation takes place seasonally when the temperatures and climatic conditions promote it. Freezing occurs when the ambient temperature drops below 32°F. Constituents in the produced water lower the freezing point below that of pure water. However, when the produced water is cooled below 32°F, relatively pure ice crystals form, along with an unfrozen solution (brine) that contains elevated concentrations of constituents. The brine’s density is greater than that of the ice, and the purified ice and brine are easily separated. Coupling the natural processes of freezing and evaporation makes the FTE® process an effective and economic method for treatment and disposal of produced water and allows for year-round operation of the facility.
When the ambient temperature drops below 32°F, produced water is pumped from a holding pond and sprayed onto a freezing pad. The freezing pad consists of a framework of piping with upright spray heads similar to those used to water lawns. As the spray freezes, an ice pile begins to form. The high-salinity brine, identified by its high electrical conductivity, is separated and pumped to a pond where it can be utilized as an additive in deep drilling applications. As the ice pile increases in height, the sprayers are extended. When the ice on the freezing pad melts, the purified water is pumped from the freezing pad and discharged or stored for later beneficial use. No new wastes are generated by the use of the FTE® process, and no chemicals are added at any point in this treatment process. In Wyoming, the freezing period may begin as early as October and continue into April. Evaporation can occur from April through October. Because of the similarity between an FTE® facility and a conventional evaporation facility, retrofitting an existing conventional evaporation facility can be easily accomplished. Equipment required for the FTE® process consists of evaporation ponds, pumps and sprays, a temperature controller, conductivity-activated flow controllers, and electrically actuated valves.

1.4 Project Rationale

Case histories of the FTE® process are essential for natural gas producers to provide a long-term view of the effectiveness of the technology and a demonstration of its successful application. The State of Wyoming is the location of both of these commercial-scale deployments because the climate is ideally suited for the process and the high level of natural gas activity in the state has resulted in a need for increased water disposal capacity.
Two case histories are provided in this document that reflect differences with respect to regulatory and permitting issues that exist. In Wyoming, as in many other states, the permitting and regulation of oil and gas produced water disposal and/or treatment facilities depend upon the legal relationship between owners of the facility and the owners of wells from which the water is produced. An “owner-operated” facility is regulated by WOGCC and is defined as an entity which only processes water which comes from the wells in fields of which they have an equity interest. However, if a facility processes water from wells in which the owners of the facility have no equity interest, the facility is considered a “commercial” facility and is permitted and regulated by the WDEQ. Thus two commercial FTE\textsuperscript{©} process deployments are discussed in this document: one related to an “owner-operated” facility and the other related to a “commercial” facility.

Specific outcomes gained from water treatment where the FTE\textsuperscript{©} technology has been applied are not currently available from other sources at the level of detail documented in these two case histories. Information regarding the volume of produced water evaporated and/or treated and beneficially reused is critical to the decision-making process used by natural gas producers when developing long-term produced water management plans. The information provided in the two case histories presented in this document can be applied to produced water management planning in many western states in the United States and much of Canada.

1.5 Benefits of the Research

The results of this research are valuable to producers for long-term water management planning. Data provided in this report facilitate analyses of the benefit of potential FTE\textsuperscript{©} technology application at specific producing locations throughout the Rocky Mountains and Canada. This technology can be used to both dispose wastewater (through evaporation and direct reuse) and to purify wastewater for reuse. Specific volumes of water that were evaporated or treated and reused are provided in the document. Performance data provide additional details. Information regarding permitting, construction, and daily operation is of use to producers converting an existing evaporation facility or building a new FTE\textsuperscript{©} facility.

Further, the FTE\textsuperscript{©} technology application in these two cases has resulted in a reduction of produced water management costs for operators. Thus a reduction in natural gas production costs results from application of this technology at properly selected and operated locations. In the future, this cost reduction can result in extended production from marginal operating wells and development of economically marginal resources.

2.0 EXPERIMENTAL

2.1 Work Plan

This research effort examined deployment of two FTE\textsuperscript{©} produced water treatment and disposal facilities in Wyoming: one owner-operated and one commercially licensed.
2.1.1 Case 1 – Scope of Work

Case 1 describes the process deployment at the owner-operated Jonah FTE® Facility. The following tasks were successfully completed in the deployment of the FTE® process at the Jonah Facility.

2.1.1.1 Task 1.1 – Agreement with Commercial Partner

This task involved finding a producer to utilize the FTE® process for treatment and disposal of its produced water. For a facility to be classified as owner-operated in the State of Wyoming, it must be owned by a producer, and all produced water a facility processes must come only from wells in a single field that the owners of the facility have an equity interest in.

2.1.1.2 Task 1.2 – Acquisition of Regulatory Approval

Owner-operated produced water disposal facilities are regulated by the WOGCC in the State of Wyoming. This task involved applying for and obtaining “Approval to Treat Pit Water in the State of Wyoming” from the WOGCC. Further, it was necessary to obtain approval from the WOGCC for construction of new ponds and sprays at the Jonah Site.

2.1.1.3 Task 1.3 – Construction and Modification of the Jonah Facility

This task involved requesting and obtaining approval for construction of two quarter-acre freezing pads at the Jonah Facility. Approval was granted by the WOGCC in February 1998. In addition, two one-acre evaporation ponds were constructed for treated water storage and brine storage and evaporation. Approval was granted by the WOGCC in the fall of 1998 contingent on an increase in bond for the facility. The construction of these ponds was completed in November of 1999.

2.1.1.4 Task 1.4 – Operation of the FTE® Process – Evaporation

Beginning in March 1998, the Jonah FTE® Facility was placed in operation. Since that time, the facility has operated continuously. Evaporation operations are typically conducted from April through October.

2.1.1.5 Task 1.5 – Operation of the FTE® Process – Freezing

Beginning in March 1998, the Jonah FTE® Facility was placed in operation. Freezing operations were conducted in March during 1998 and from November into March in the following years.

2.1.1.6 Task 1.6 – Beneficial Use of Treated Water

In September 2001, a one-time National Pollutant Discharge Elimination System (NPDES) permit for using treated water for dust abatement by road spray in the Jonah Field was applied for to the WOGCC and approved by the WOGCC and WDEQ.
2.1.2 Case 2 – Scope of Work

Case 2 describes the process deployment at the commercial CS Wamsutter FTE® Facility. The following tasks were successfully completed in the commercial deployment of the FTE® process at the CS Wamsutter Facility.

2.1.2.1 Task 2.1 – Negotiations and Agreement with Commercial Partner

This task involved finding a producer, or producers, to utilize the FTE® process for treatment and disposing of significant volumes of produced water. In addition, the location must have a favorable climate and disposal economics for successful commercial process deployment.

2.1.2.2 Task 2.2 – Acquisition of Regulatory Approval

All permitting and regulation of commercially operated produced water disposal facilities, like the CS Wamsutter FTE® Facility, is handled through the WDEQ. Approval of a construction permit by the WDEQ is required for a facility of this nature. In addition, any modification to the facility also requires the issuance of a construction permit. The construction permit allows two years for facility construction to be completed but can be extended by request and subsequent approval if necessary. For each construction permit, documentation of completion of construction is required.

2.1.2.3 Task 2.3 – Construction of the CS Wamsutter Facility

Construction of the 600 bbl/day FTE® produced water treatment facility began in November 1999. In December 1999, facility oil/water separation system, ponds, fence, and basic structures were completed, and CS was given approval to begin accepting produced water. In June 2001, expansion of the facility to 1000 bbl/day was initiated.

2.1.2.4 Task 2.4 – Operation of the FTE® Process – Evaporation

Beginning in December 1999, the CS Wamsutter FTE® Facility was placed in operation. Since that time, the facility has remained in operation. Evaporation operations are typically conducted from April through October.

2.1.2.5 Task 2.5 – Operation of the FTE® Process – Freezing

Beginning in November 2000, the CS Wamsutter FTE® Facility began freezing operations. Freezing operations are conducted from November into March each year.

2.1.2.6 Task 2.6 – Beneficial Use of Treated Water

As previously discussed, a construction permit to expand the CS Wamsutter FTE® Facility to 1000 bbl/day capacity was applied for and received in May of 2001. At this time, the facility ponds were also permitted by the Wyoming State Engineer’s Office as water storage reservoirs to allow the sale of treated water for reuse in drilling or for reuse on site for soil compacting and
dust abatement during the facility expansion. In the future, CS intends to acquire an NPDES permit for discharge or approval for land application if appropriate.

2.2 Work Performed

2.2.1 Case 1 (Jonah FTE® Facility) Work Performed

2.2.1.1 Task 1.1 – Agreement with Commercial Partner

In November 1997, negotiations began with personnel of MOC to modify and expand its existing produced water disposal facility in southwestern Wyoming. The facility was originally operated as a conventional evaporation facility in the Jonah natural gas field in Wyoming’s Greater Green River Basin. It was converted to an FTE® facility in 1998. The facility is now owned by EnCana and operated by CS personnel.

2.2.1.2 Task 1.2 – Acquisition of Regulatory Approval

In January 1998, BCT applied for approval from the WOGCC to treat pit water in the State of Wyoming and received approval in February 1998. The process involved mailing a letter to the Commission that briefly described the FTE® process and its intended application, along with an application fee of $25.00. The letter was read, evaluated, and approved at the next Commission meeting in February 1998. If there had been concerns about the FTE® technology or its application, BCT would have been asked to provide additional information to the Commission. This permit enables BCT personnel to treat pit water at any owner-operated location in the State of Wyoming pending approval of WOGCC personnel. The approval requires annual renewal by BCT. The original approval notice from the WOGCC is provided in Appendix A. The notice provides details regarding all terms and conditions of the approval.

This task also involved requesting and obtaining approval for construction of two freezing pads, each one a quarter acre in size at the Jonah Facility. Approval was requested in January of 1998 and was granted by the WOGCC in February 1998. In addition, approval was requested to construct two evaporation ponds, each one an acre in size, for treated water storage and brine storage and evaporation. Approval was requested in August of 1998 and granted by the WOGCC in October 1998. This approval was contingent upon an increase in bond for the facility.

2.2.1.3 Task 1.3 – Construction and Modification of the Jonah Facility

In Case 1, MOC converted an existing produced water evaporation facility into an FTE® produced water treatment and disposal facility. Initial modification of the MOC facility was conducted in February 1998 after approval was received by the WOGCC. The Jonah FTE® Facility is located at NW/4 Sec. 36 T29N R108W, and its location is illustrated in Figure 1.

Figure 2 illustrates the plant layout of the Jonah FTE® Facility. Prior to modification, the facility initially included two 400-bbl vertical oil/water separator tanks with natural gas heated fire tubes for removing residual oil from off-loaded produced water, and a 400-bbl vertical condensate storage tank for oil storage: one synthetically lined one-quarter-acre oil/water
separation pond with duck netting to ensure free oil containment and a 1-acre synthetically lined holding pond for water storage. In February 1998, two synthetically lined quarter acre freezing pads, an office trailer, living trailer, three pump sheds, and related piping and instruments were added to convert the site to an FTE® treatment facility. In November 1998, two additional 1-acre
synthetically lined holding ponds, for treated water and brine storage, were constructed. Following are details regarding the ponds at the facility:

- **Separation Pond.** The separation pond is 100’ × 100’ × 6’ deep and is lined with an high-density polyethylene (HDPE) liner. It is completely covered with duck netting. The purpose of this pond is to provide additional residence time for increased oil/water separation. No chemicals are added to the pond, and the pond is not equipped with aeration or sprays.

- **Holding Ponds.** Holding Pond #1 is approximately 230’ × 230’ × 10’ deep and is lined with an HDPE liner. The purpose of this pond is to store and evaporate produced water fed from the separation pond by gravity. It is equipped with a pump for transferring produced water to the freezing pads. Sprays were also added to Holding Pond #1 in September 1999. Holding Ponds #2 and #3 are each 200’ × 200’ × 13’ deep and are also lined with HDPE liners. These ponds are equipped with sprays and a pump. Water is fed to these ponds from the freezing pads or Holding Pond #1. Holding Pond #2 is used for storage of the brine from the process and also for spray evaporation in the warmer months. Holding Pond #3 is used for storage of the treated water produced from the FTE\textsuperscript{®} process and also used as a freezing pad for the creation of an ice pile in the winter. No chemicals are added to any of these ponds.

- **Freezing Pads.** Freezing Pads #1 and #2 are each 100’ × 100’ × 4’ deep and are lined with HDPE liners. During the winter, these pads are used for the creation of an ice pile, and during the summer, they are used for spray evaporation. Produced water is fed to these ponds from Holding Pond #1. They are equipped with sprays and pumps for recirculation of the water in the pads, recirculation of water from one pad to the other, or transfer of water to or from Holding Ponds #1, #2, and #3. No chemicals are added to these pads.

In addition to the ponds, four sheds were built to house electrical connections, pumps, temperature and conductivity flow controllers, and electrically actuated valves. Properly operating and maintaining this FTE\textsuperscript{®} facility requires one full-time person, with 24-hour monitoring and maintenance activities during the freezing months.

2.2.1.4 Task 1.4 – Operation of the FTE\textsuperscript{®} Process – Evaporation

During the time period from April 1998 through October 1998, the Jonah FTE\textsuperscript{®} Facility was operated in the evaporation mode. During this time period, 23,000 bbl of water was evaporated from Holding Pond #1 using no sprays, and 9000 bbl was evaporated from Freezing Pads #1 and #2 using the spray system.

During the time period from May 1999 through October 1999, the facility was again used to evaporate water. In September 1999, sprays were added to Holding Pond #1 to enhance evaporation from the pond. A total of 51,580 bbl of water was added to the holding pond, and 24,600 bbl of this water was transferred from the holding pond to the freezing pads. Based upon water level measurements in the holding pond, 47,150 bbl of water was either evaporated or
removed from the holding pond for drilling. The net evaporation from the two freezing pads was 20,885 bbl.

During the time period from May 2000 through October 2000, the facility was operated in the evaporation mode. A total of 91,626 bbl of water was added to the holding pond, and 17,252 bbl of water was transferred from the holding pond to the freezing pads. An additional 8220 bbl of water was transferred directly to the brine storage pond. The accumulation of water in the holding pond, evaporation of water in the holding pond, and water removed from the holding pond for drilling totaled 66,154 bbl during this time period. The increase in the volume of water retained in the holding pond is estimated to be approximately 15,000 bbl. Based upon this estimate, 51,154 bbl of water was either evaporated or removed from the holding pond for drilling. The net evaporation from the two freezing pads was 11,171 bbl during this time period.

During the time period from May 2001 through October 2001, a total of 79,665 bbl of water was added to the holding pond, and 16,306 bbl of this water was transferred from the holding pond to the freezing pads. The accumulation of water in the holding pond, evaporation of water from the holding pond, and water removed from the holding pond for drilling totaled 169,135 bbl during this time period. The net evaporation from the two freezing pads was 10,300 bbl during this period. In August 2001, a pump shed was constructed between Holding Pond #2 and Holding Pond #3. It is designed to feed Holding Pond #2 evaporative sprays during the summer months and feed Holding Pond #3 freezing sprays during the winter months.

### 2.2.1.5 Task 1.5 – Operation of the FTE® Process – Freezing

As previously stated, the Jonah FTE® Facility was placed in operation March 1, 1998, which allowed a 2-week period for shakedown of the freezing system. During this time period, 1280 bbl of ice was created. Detailed chemical analyses of the ice were conducted, and the results of these analyses indicated that the treated water was suited for a variety of beneficial uses.

During the winter of 1998–1999, a total of 17,300 bbl of produced water was fed to the two freezing pads. Over half of this water (55% – 9500 bbl) was converted to a treated water with a total dissolved solids (TDS) concentration of 1210 mg/L compared to the 22,800 mg/L TDS concentration of the feed (95% reduction in TDS). Approximately one-third of the feed (34% – 5900 bbl) was converted to concentrated brine with nearly 3 times the TDS concentration of the feed (66,900 mg/L). Slightly more than one-tenth of the feed (11% – 1900 bbl) was disposed of by sublimation and/or evaporation when water was sprayed during the winter months. Figure 3 shows the Jonah Site during the winter of 1998–1999. The freezing pads and ice piles are in the left background of the picture. Holding Pond #1 is in the right foreground, and Holding Pond #2 is partially visible in the right middle of the picture. Ice piles created during the winter of 1998–1999 are illustrated in Figure 4.

During the 1999–2000 winter, a total of 20,903 bbl of produced water was fed to the two freezing pads. Again, over half of this water (55% – 11,462 bbl) was converted to treated water with a TDS concentration of 924 mg/L compared to 14,000 mg/L TDS concentration of the feed (93% reduction in TDS). Approximately one-seventh of the feed (14% – 3006 bbl) was
Figure 3. Jonah FTE® Facility during the winter of 1998–1999.

Figure 4. Ice piles at the Jonah FTE® Facility during the winter of 1998–1999.
converted to concentrated brine with 4.6 times the TDS concentration of the feed (64,300 mg/L). Slightly less than one-third of the feed (31% – 6435 bbl) was disposed of by sublimation and/or evaporation when the water was sprayed during the winter months. Ice piles created during the winter of 1999–2000 are illustrated in Figure 5.

During the 2000–2001 winter, a total of 31,256 bbl of produced water was fed to the two freezing pads. Over half of this water (63% – 19,642 bbl) was converted to treated water with a TDS concentration of 589 mg/L compared to the 9750 mg/L TDS concentration of the feed (94% reduction in TDS). Approximately one-third of the feed (29% – 9004 bbl) was converted to concentrated brine with 5 times the TDS concentration of the feed (48,800 mg/L). Slightly more than 8% (2610 bbl) of the feed was disposed of by sublimation and/or evaporation when the water was sprayed during the winter months. Ice piles created during the winter of 2000–2001 are illustrated in Figure 6.

2.2.1.6 Task 1.6 – Beneficial Use of Treated Water

In the summer of 2001, CS personnel assisted AEC in the acquisition of a permit for road application of waste and wastewater from the WOGCC. The process involved first gaining the written approval of all landowners where spraying would occur. In the case of road spray application in the Jonah Field, all lands involved are owned by the U.S. Government and managed by the Bureau of Land Management. Then the commission required a completed application form including a detailed water quality analysis of the treated water that would be applied. The permit was issued by letter on September 6, 2001, and filed by BCT on August 31, 2001. This permit enabled AEC (who had purchased the MOC operations in the Jonah field) to spray the treated water on public roads in the Jonah Field in an effort to abate dust. A stipulation of the permit was that limited analyses of road-bed samples were required before and after the treated water was applied. A total of 6840 bbl of treated water was removed from Holding Pond #3 (treated water pond), for road spray, under the permit from WOGCC.

2.2.2 Case 2 (Crystal Solutions Wamsutter FTE® Facility) Work Performed

2.2.2.1 Task 2.1 – Negotiations and Agreement with Commercial Partner

The Great Divide Basin of south central Wyoming was identified as a location where significant natural gas development will occur during the next decade. Natural gas producers in the basin were identified and contacted based upon the volume of produced water reported to the WOGCC. In March 1999, one independent producer with over forty wells in the area contracted to utilize the facility for disposal of produced water. This agreement was sufficient to site the CS Facility in the Wamsutter area and acquire necessary financing. The commercial CS FTE® facility was located in the Echo Springs gas field of south central Wyoming’s Great Divide Basin. Thirty-five acres of land was purchased approximately 9.5 miles southeast of Wamsutter, Wyoming. This location was selected to reduce the water transportation costs for the independent producer under contract. Actual purchase of the land was contingent on obtaining a permit from the WDEQ to construct the facility and acquire necessary easements to access the property. Land owners were identified and agreements formulated for purchasing easements. The easement purchases were also contingent on obtaining the construction permit.
Figure 5. Ice piles at the Jonah FTE® Facility during the winter of 1999–2000.
Figure 6. Ice piles at the Jonah FTE® Facility during the winter of 2000–2001.
2.2.2.2 Task 2.2 – Acquisition of Regulatory Approval

In August 1999, an application for a permit to construct an FTE® produced water treatment facility was submitted with a complete plant design to the WDEQ. The plant was originally designed with a capacity of 600 bbl/day. In addition, the facility was permitted for expansion to 1000 bbl/day capacity in May 2001. The construction permit application required site-specific information in an Engineering Design Report according to instructions provided in Chapter 3 and Section 6 of Chapter 11 of the WDEQ Water Quality Rules and Regulations. The following information is required when applying for a construction permit, and all items below must be stamped and certified by a professional engineer registered in the State of Wyoming:

A) WDEQ Application Form for Permit to Construct, Install, or Modify Water Supplies, Wastewater Facilities, or Groundwater Pollution Control Systems in Wyoming.

B) Engineering Design Report.
1. Scope and purpose for the facility: Discuss existing conditions, problems, and proposed solutions. In addition, discuss proposed facility and its operation.
2. Facility location: This section must include the present and proposed facility location, flood protection plans, present and proposed facility access, distances from current habitations, prevailing wind direction, fencing and security, topographic features and contours, and soil and subsurface geological characteristics.
3. Description of the project service area.
4. Effluent and solids disposal from the process.
5. Effluent water quality considerations for the design of the facility: This section must discuss any current or future plans for surface discharge or beneficial use along with a discussion regarding plans for groundwater protection.
6. Design conditions: This section must include proposed effluent standards, design population, projected flows and flow variations, shock loads with cause and frequency, projected wastewater characteristics, projected flow, proposed quantity and frequency of septic discharges, site climate conditions, proposed water supply, theory of operations, odor control features, existing facilities, and requirements of water quality management plans.
7. All figures and drawings required for clarification.

C) Equipment and Parts Specifications.


E) Site Reclamation Plans and Financial Assurance. Plans for site closure were prepared and bids for complete site reclamation were obtained. Following acceptance of the site closure plans by WDEQ personnel, financial assurance requirements were negotiated. Financial assurance must be in the form of bond, certificates of deposit from a Wyoming bank, or letter of credit from a Wyoming Bank.

The items included above are separate from any permit requirements to discharge or beneficially use facility waters. Also, once approval for a construction permit was received, it
was necessary to obtain approval from the Carbon County Commissioners for a land use variance from agricultural use to produced water treatment. This required a request to the commission, public hearing, and commission approval. Upon approval by the commission for the land use variance, a building permit was applied for and received from the Carbon County Planning and Zoning Department. The building permit required payment of a $500 fee.

2.2.2.3 Task 2.3 – Construction of the CS Wamsutter Facility

In Case 2, CS was building a new commercial FTE® produced water treatment and disposal facility. The CS Wamsutter FTE® Facility is located at SE 1/4 Sec. 19 T19N R93W, and its location is illustrated in Figure 1. The property encompasses 35 acres. Construction activities at this location began in October 1999.

Figure 7 illustrates the initial plant layout of the 600 bbl/day CS Wamsutter FTE® Facility. The facility includes two 400-bbl vertical oil/water separator tanks with propane-heated fire tubes for removing residual oil from off-loaded produced water and one 300-bbl vertical condensate storage tank. The facility also features one synthetically lined one-quarter acre oil/water separation pond with duck netting to ensure containment of free oil. The facility includes two 1-acre synthetically lined holding ponds for feed water and brine storage, respectively. In addition, the facility includes two 1-acre synthetically lined freezing pads used for both evaporation and freezing. The facility is completely fenced for security. A building is provided for operator living quarters, shop, laboratory, office, and storage. Five pump sheds are also provided along with facility piping, instruments, and controls. Following is a description of the ponds initially constructed at the CS Wamsutter FTE® Facility:

- **Separation Pond.** Separation Pond #1 is 100’ × 100’ × 13’ deep. It is lined with a HDPE liner, is completely covered with duck netting, and is equipped with a leak detection and collection system. The purpose of this pond is to provide additional residence time for increased oil/water separation. No chemicals are added to the pond, and the pond is not equipped with aeration or sprays.

- **Holding Ponds.** Holding Pond #1 and Holding Pond #2 are each 210’ × 210’ × 13’ deep and are each lined with an HDPE liner and equipped with a leak detection and collection system. Holding Pond #1 is used to store and evaporate produced water fed from Separation Pond #1. It is equipped with sprays and pumps for recirculating the water in the pond or for transferring the water to other ponds. Holding Pond #2 is used for storing brine that results after the produced water has been treated using the FTE® process. This pond is equipped with sprays and pumps for recirculating the water in the pond.

- **Freezing Pads.** Freezing Pad #1 and Freezing Pad #2 are each 300’ × 150’ × 13’ deep. Each of these ponds are lined with HDPE liners and are equipped with two leak detection and collection systems. During the winter, these pads are used for the creation of an ice pile, and during the summer, they are used for spray evaporation. Produced water is fed to these ponds from Holding Pond #1. No chemicals are added to the pads. These pads are equipped with sprays and pumps for recirculation of the water in the
Figure 7. CS Wamsutter 600 bbl/day FTE® facility layout.

pads, recirculation of water from one pad to the other, or transfer of water to Holding Ponds #1 and #2.

In April 2001, CS submitted an application to the WDEQ – Water Quality Division for a permit to allow construction of additional pits for the CS Wamsutter FTE® Facility. It was approved in May 2001, and construction activities for expansion of the Wamsutter facility began shortly thereafter. This expansion consisted of the construction of an additional separation pond, two additional holding ponds (Holding Pond #3 and Holding Pond #4) and respective pump sheds, and two additional freezing pads (Freezing Pad #3 and Freezing Pad #4) with pump sheds, and leak detection systems for all five new ponds. In addition, fencing was added to enclose the ponds in the expansion area. Figure 8 illustrates the plant layout after the 1000 bbl/day facility expansion. The following is a discussion of the pits added to the facility:
• Separation Pond. Separation Pond #2 is 100’ × 50’ × 8’ deep. It is lined with an HDPE liner, is completely covered with duck netting, and is equipped with a leak detection and collection system. The purpose of this pond is to provide additional residence time for increased oil/water separation.

• Holding Ponds. Holding Pond #3 is 208’ × 208’ × 13’ deep, and Holding Pond #4 is 161’ × 254’ × 13’ deep. They are both lined with HDPE liners and are each equipped with a leak detection and collection system. The purpose of these ponds is to store and evaporate produced water fed from the separation pond. They are both equipped with sprays and pumps for recirculating the water in the pond.

• Freezing Pads. Freezing Pad #3 is 135’ × 300’ × 13’ deep, and Freezing Pad #4 is 161’ × 254’ × 13’ deep. Both pads are lined with an HDPE liner and are equipped with a leak detection and collection system. During the winter, these pads are used for the creation of ice piles, and during the summer, they are used for spray evaporation. Produced water is fed to these pads from Holding Pond #1. These pads are equipped with sprays and pumps for recirculating the water in the pad.

Figure 8. CS Wamsutter 1000 bbl/day FTE® facility layout.
2.2.2.4 Task 2.4 – Operation of the FTE® Process – Evaporation

During the time period from April through October 2000, the CS Wamsutter FTE® Facility was incrementally operated in the evaporation mode. In June 2000, the installation of pumps, piping, sprays, and related controls and instruments was completed for Holding Ponds #1 and #2. During the April to October time period, 16,216 bbl of water was evaporated using Holding Pond #1, and 16,536 bbl of water was evaporated using Holding Pond #2. In August 2000, the installation of pumps, piping, sprays, and related controls and instruments was completed for Freezing Pads #1 and #2. During the April to October time period, 2493 bbl was evaporated using Freezing Pad #1, and 2868 bbl was evaporated using Freezing Pad #2. The total volume of produced water evaporated during the 2000 evaporation season was 38,113 bbl.

During the time period from April 2001 through October 2001, the CS Wamsutter FTE® Facility was expanded and incrementally operated in the evaporation mode. Holding Ponds #1 and #2 and Freezing Pad #1 were operated during the entire evaporative season. Freezing Pad #2 was used to hold treated water that was used in facility expansion construction and in drilling operations in the area and saw only limited use in evaporation. Construction of Holding Ponds #3 and #4 and Freezing Pads #3 and #4 was completed in July of 2001. In August 2001, the installation of pumps, piping, sprays, and related controls and instruments was completed for Holding Ponds #3 and #4 and Freezing Pads #3 and #4. During the April to October time period, 11,052 bbl of water was evaporated using Holding Pond #1; 23,585 bbl of water was evaporated using Holding Pond #2; 5015 bbl of water was evaporated using Holding Pond #3; and 943 bbl of water was evaporated using Holding Pond #4. During the same time period, 22,275 bbl was evaporated using Freezing Pad #1; 2414 bbl was passively (not sprayed) evaporated from Freezing Pad #2; 3265 bbl was evaporated using Freezing Pad #3; and 1379 bbl was evaporated using Freezing Pad #4. The total volume of produced water evaporated during the 2001 evaporation season was 69,928 bbl.

2.2.2.5 Task 2.5 – Operation of the FTE® Process – Freezing

Beginning in November 2000, the CS Wamsutter FTE® Facility began freezing operations. Freezing operations are conducted from November into March each year.

During the 2000–2001 winter, a total of 88,797 bbl of produced water was fed to Freezing Pads #1 and #2. Over half of this water (66% – 58,588 bbl) was converted to treated water with a TDS concentration of 1000 mg/L compared to the 9790 mg/L TDS concentration of the feed (88% reduction in TDS). Approximately one-third of the feed (32% – 28,649 bbl) was converted to concentrated brine with 4.6 times the TDS concentration of the feed (44,900 mg/L). Slightly less than 2% (1,560 bbl) of the feed was disposed of by sublimation and/or evaporation when the water was sprayed during the winter months. Ice piles created during the winter of 2000–2001 are illustrated in Figure 9.

2.2.2.6 Task 2.6 – Beneficial Use of Treated Water

In April 2001, all the facility ponds were permitted by the Wyoming State Engineer’s Office as water storage reservoirs to allow the sale of treated water for reuse. CS also applied to
the Office of the State Engineer for a “Permit to Appropriate Surface Water.” Receipt of this permit enables the owner to sell water contained in the permitted water storage reservoirs. In this case, CS planned to sell its treated water to local producers for dust abatement and for drilling mix. In addition, as previously discussed, a construction permit to expand the CS Wamsutter FTE Facility to 1000 bbl/day capacity was applied for and received in May of 2001. With this construction permit, CS also received approval from WDEQ Water Quality Division granting permission to use the treated water in construction related to expansion of the Wamsutter Facility. This primary use of the treated water was for compacting the secondary clay liners for each pit, compacting soils supporting newly installed fence posts, and dust abatement. During the summer of 2001, 11,624 bbl of treated water was utilized in plant expansion construction, and 2180 bbl of treated water was sold for nearby drilling operations. In the future, CS intends to acquire an NPDES permit for discharge or approval for land application if appropriate.

3.0 RESULTS AND FINDINGS

3.1 Jonah FTE® Facility Performance Evaluation

Since the Jonah FTE® Facility was constructed in February 1998, the first months of activity were considered to be shakedown operations. As such, a discussion of the results of the 1998 winter operation is not included in this document. The reader is referred to the literature for information regarding the 1998 winter operation (Boysen et al., 1998).
There are two key issues with respect to evaluation of the FTE® process performance at either site. The first is the quality of the water produced, and the second is the increased facility capacity resulting from application of the process. Table 1 provides a summary of the results of analyses of the FTE® process feed, treated water, and brine resulting from the operation at the Jonah Site during the winter of 1998 and 1999. Table 2 provides a similar summary for the FTE® process operation at the Jonah Site during the winter of 1999 and 2000, and Table 3 provides similar information for the 2000 and 2001 winter. The data illustrate that the Jonah FTE® Facility operated as expected based on previous FTE® demonstrations (Boysen et al., 1996), yielding treated water with significantly lower inorganic and organic constituents than the feed water.

Table 1. Treated Water Quality – FTE® Deployment in the Jonah Field of Wyoming During the Winter of 1998–1999 – Analytical Results Summary

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Feed</th>
<th>Treated Water</th>
<th>Brine</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDS, mg/L</td>
<td>22,800</td>
<td>1210</td>
<td>66,900</td>
</tr>
<tr>
<td>Total Alkalinity (as CaCO₃), mg/L</td>
<td>400</td>
<td>33.4</td>
<td>694</td>
</tr>
<tr>
<td>pH</td>
<td>5.4</td>
<td>6.5</td>
<td>5.4</td>
</tr>
<tr>
<td>Oil and Grease, mg/L</td>
<td>19.2</td>
<td>&lt;0.1</td>
<td>69.2</td>
</tr>
<tr>
<td>Barium, mg/L</td>
<td>3.08</td>
<td>0.62</td>
<td>3.18</td>
</tr>
<tr>
<td>Boron, mg/L</td>
<td>14</td>
<td>0.88</td>
<td>44</td>
</tr>
<tr>
<td>Chloride, mg/L</td>
<td>10,700</td>
<td>586</td>
<td>34,000</td>
</tr>
<tr>
<td>Phenols, mg/L</td>
<td>10</td>
<td>1</td>
<td>31</td>
</tr>
<tr>
<td>Potassium, mg/L</td>
<td>6100</td>
<td>314</td>
<td>17,400</td>
</tr>
<tr>
<td>Sodium, mg/L</td>
<td>3280</td>
<td>171</td>
<td>9250</td>
</tr>
<tr>
<td>Sulfate, mg/L</td>
<td>224</td>
<td>15.8</td>
<td>638</td>
</tr>
</tbody>
</table>

Table 2. Treated Water Quality – FTE® Deployment in the Jonah Field of Wyoming During the Winter of 1999–2000 – Analytical Results Summary

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Feed</th>
<th>Treated Water</th>
<th>Brine</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDS, mg/L</td>
<td>14,000</td>
<td>924</td>
<td>64,300</td>
</tr>
<tr>
<td>Total Alkalinity (as CaCO₃), mg/L</td>
<td>520</td>
<td>41.6</td>
<td>2770</td>
</tr>
<tr>
<td>pH</td>
<td>5.3</td>
<td>6.6</td>
<td>6.7</td>
</tr>
<tr>
<td>Oil and Grease, mg/L</td>
<td>116.5</td>
<td>7.4</td>
<td>46.6</td>
</tr>
<tr>
<td>Barium, mg/L</td>
<td>5.4</td>
<td>0.7</td>
<td>18.5</td>
</tr>
<tr>
<td>Boron, mg/L</td>
<td>4.7</td>
<td>0.6</td>
<td>21.9</td>
</tr>
<tr>
<td>Chloride, mg/L</td>
<td>7250</td>
<td>320</td>
<td>35,200</td>
</tr>
<tr>
<td>Phenols, mg/L</td>
<td>7.8</td>
<td>0.2</td>
<td>19.2</td>
</tr>
<tr>
<td>Potassium, mg/L</td>
<td>2790</td>
<td>120</td>
<td>15,100</td>
</tr>
<tr>
<td>Sodium, mg/L</td>
<td>2690</td>
<td>125</td>
<td>13,100</td>
</tr>
<tr>
<td>Sulfate, mg/L</td>
<td>89.2</td>
<td>4.9</td>
<td>398</td>
</tr>
</tbody>
</table>
Table 3. Treated Water Quality – FTE® Deployment in the Jonah Field of Wyoming During the Winter of 2000–2001 – Analytical Results Summary

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Feed</th>
<th>Treated Water</th>
<th>Brine</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDS, mg/L</td>
<td>9750</td>
<td>589</td>
<td>48,800</td>
</tr>
<tr>
<td>pH</td>
<td>6.0</td>
<td>5.8</td>
<td>5.3</td>
</tr>
<tr>
<td>Total Recoverable Petroleum Hydrocarbons, mg/L</td>
<td>11</td>
<td>4.2</td>
<td>4.9</td>
</tr>
</tbody>
</table>

The analytical results illustrate that the Jonah FTE® Facility effectively concentrated inorganic constituents while producing a high-quality treated water. In the brine, TDS and the salt constituents were essentially triple that of the feed water. Treated water constituents were all at least an order of magnitude lower than the feed water.

The Jonah Facility throughput volume is also a key measure of the plant’s effectiveness. The facility performance for the time period from 1999 to 2001 is provided in Table 4. Produced water has been successfully used for drilling at depths greater than 2200 ft in the Jonah field since 1999. The use of this water in drilling has resulted in considerable cost savings; however, more water is produced than can be used for drilling, and the use of water in drilling is only a satisfactory method for produced water management as long as drilling continues. If only the performance of the two freezing pads, each one-quarter acre in size, is considered, these data indicate that over 60,000 bbl/acre-year was processed in the small freezing pads. This is substantial.

Table 4. Jonah FTE® Facility Performance (1999–2001)

<table>
<thead>
<tr>
<th></th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Volume, bbl</td>
<td>TDSa</td>
<td>Volume, bbl</td>
</tr>
<tr>
<td>Total Feed to Facility</td>
<td>89,050</td>
<td>22,800</td>
<td>174,830</td>
</tr>
<tr>
<td>Holding Pond #1 Evap. or Removed for Drilling</td>
<td>47,150</td>
<td>—</td>
<td>128,735</td>
</tr>
<tr>
<td>Evaporation from Freezing Pads</td>
<td>22,780</td>
<td>—</td>
<td>17,326</td>
</tr>
<tr>
<td>Winter Brine from Freezing Pads</td>
<td>5900</td>
<td>66,900</td>
<td>3006</td>
</tr>
<tr>
<td>Summer Brine</td>
<td>3720</td>
<td>56,000</td>
<td>14,301</td>
</tr>
<tr>
<td>Treated Water from Freezing Pads</td>
<td>9500</td>
<td>1210</td>
<td>11,462</td>
</tr>
</tbody>
</table>

a TDS = Total dissolved solids concentration (mg/L).

3.2 Crystal Solutions Wamsutter FTE® Facility Performance Evaluation

The second deployment of the FTE® process under this project was conducted south of Wamsutter, Wyoming, in the Great Divide Basin region. In contrast to the Jonah Site, where an
existing evaporation facility was modified and expanded for the implementation of FTE®, the site near Wamsutter was built “from the ground up.” In early 1999, CS was formed by GRI International and BCT to provide turnkey produced water management service to operators in the Great Divide Basin region. CS purchased undeveloped land southeast of Wamsutter and designed a 600 bbl/day FTE® facility on which construction began in the fall of 1999.

Delivery of produced water to the Wamsutter site began in December 1999. While produced water was delivered to the site on a continuous basis throughout the winter of 1999–2000, the facility was only able to operate in a storage mode because insufficient water was available for continuous freezing operations. The facility operated in the evaporation mode throughout the spring and summer of 2000.

In November 2000, the CS Facility began its first full season of operation as a commercial FTE® facility. The CS Wamsutter FTE® Facility operated throughout the winter of 2000–2001. By the end of February 2001, each pile had achieved an average height of approximately 30 feet above the bottom of the freezing pad. The thaw began in early March, and samples of the feed water, treated water, and brine were collected in late March for analysis. The constituents in the treated water meet the requirements outlined in the WDEQ water quality standards. The results for key parameters are shown in Table 5. These analytical results show that the CS Wamsutter FTE® Facility is effective in concentrating constituents into a brine solution while producing treated water of a quality suitable for a variety of beneficial uses.

**Table 5. Treated Water Quality – FTE® Deployment at the CS Wamsutter Facility During the Winter of 2000–2001 – Analytical Results Summary**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Feed</th>
<th>Treated Water</th>
<th>Brine</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDS, mg/L</td>
<td>9790</td>
<td>1000</td>
<td>44,900</td>
</tr>
<tr>
<td>Total Alkalinity (as CaCO₃), mg/L</td>
<td>1580</td>
<td>177</td>
<td>7390</td>
</tr>
<tr>
<td>pH</td>
<td>7.9</td>
<td>8.4</td>
<td>8.2</td>
</tr>
<tr>
<td>Oil and Grease, mg/L</td>
<td>39.1</td>
<td>3.1</td>
<td>63.2</td>
</tr>
<tr>
<td>Barium, mg/L</td>
<td>7.2</td>
<td>0.5</td>
<td>4.2</td>
</tr>
<tr>
<td>Boron, mg/L</td>
<td>9.4</td>
<td>1.2</td>
<td>38.8</td>
</tr>
<tr>
<td>Chloride, mg/L</td>
<td>4720</td>
<td>472</td>
<td>19,900</td>
</tr>
<tr>
<td>Phenols, mg/L</td>
<td>4.1</td>
<td>0.4</td>
<td>15.1</td>
</tr>
<tr>
<td>Potassium, mg/L</td>
<td>152</td>
<td>30.7</td>
<td>901</td>
</tr>
<tr>
<td>Sodium, mg/L</td>
<td>3340</td>
<td>342</td>
<td>14,100</td>
</tr>
<tr>
<td>Sulfate, mg/L</td>
<td>38.1</td>
<td>7.8</td>
<td>247</td>
</tr>
</tbody>
</table>

The CS Wamsutter FTE® Facility operations are summarized in Table 6 for the time period from November 2000 through October 2001. During the time period from November 2000 to April 2001 (freezing operations), 96,186 bbl of produced water was delivered to the facility, and 2441 bbl of condensate had to be removed prior to introduction of this water into the facility ponds. The total feed to Freezing Pads #1 and #2 was 88,797 bbl. This water was recirculated within the freezing pads to form the ice pile and brine. The brine solution was placed in Holding Pond #2 when concentrated. During the freezing operation, 58,588 bbl (66% of the feed) of melt

<table>
<thead>
<tr>
<th></th>
<th>bbl</th>
<th>% of Feed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed to Facility</td>
<td>263,611</td>
<td>—</td>
</tr>
<tr>
<td>Condensate</td>
<td>5974</td>
<td>2.3</td>
</tr>
<tr>
<td>Evaporation</td>
<td>71,560</td>
<td>27.2</td>
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<tr>
<td>Treated Water</td>
<td>58,588</td>
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<tr>
<td>Accumulation</td>
<td>127,489</td>
<td>48.3</td>
</tr>
</tbody>
</table>

was treated water, which had a TDS concentration of 1000 mg/L compared to the 9790 mg/L TDS concentration of the feed (90% reduction in TDS). Approximately 32% (28,649 bbl) of the feed was converted to brine with 4.6 times the TDS concentration of the feed (44,900 mg/L). Sublimation and/or evaporation disposed of approximately 2% (1,560 bbl) of the feed when spraying the water during the winter months.

During the time period from April 2001 to November 2001 (evaporation operations), 167,425 bbl of produced water was delivered to the facility, and 3533 bbl of condensate had to be removed prior to introduction of this water into the facility ponds. A total of 70,000 bbl of water were evaporated using Holding Ponds #1 and #2 and Freezing Pad #1. Freezing Pad #2 was used to store the treated water from the winter operation. 11,624 bbl of treated water was used for on-site dust control and soil compacting related to facility expansion, and 2180 bbl of treated water was sold to producers for use in drilling. In addition, 127,489 bbl of water accumulated in the facility. This accumulation was primarily in the new facility expansion ponds.

Performance data for the CS Wamsutter FTE® Facility indicate potential for significant increase in evaporation rates, treated water production, and concentrated brine production with all facility evaporation ponds and freezing pads fully operational. The construction, shakedown, and optimization of a new plant typically takes on the order of three years. Personnel of CS are confident that the plant will be operating at design performance within the expected time frame.

4.0 MAJOR ACHIEVEMENTS OF THE PROJECT

4.1 Permits/Approvals

The following permits and/or approvals for the Jonah Site have been obtained from the WOGCC as a result of this project:

- “Pit Water Treater” approval since 1998
- Approval to construct two one-quarter-acre freezing pads
- Approval to construct two 1-acre evaporation ponds
- A one-time NPDES permit for road spray application of treated water
The following permits and/or approvals for the CS Wamsutter Site have been obtained from the WDEQ as a result of this project:

- Permit to Construct a 600 bbl/day FTE® Produced Water Treatment and Disposal Facility
- Permit to Construct an Expansion to a 1000 bbl/day FTE® Produced Water Treatment and Disposal Facility
- Approval to use treated water in plant construction
- Approval to sell treated water for drilling

In addition, the following permits and/or approvals for the CS Wamsutter Site have been obtained from the Wyoming State Engineers Office as a result of this project:

- Permit all facility ponds as water storage reservoirs
- Permit to appropriate water for use and sale
- Permit to drill a water well for facility use
- Three agreements to sell treated water for drilling

4.2 Beneficial Uses for Treated Water

The following beneficial uses of produced water and treated produced water have been successfully achieved in an environmentally acceptable fashion as a result of this project:

- Produced water at the Jonah Site has been used in drilling.
- Treated water produced at the Jonah Site has been used for road spray dust abatement.
- Treated water produced at the CS Wamsutter Facility has been used on-site for soil compacting.
- Treated water produced at the CS Wamsutter Facility has been used on-site for dust abatement during construction.
- Treated water produced at the CS Wamsutter Facility has been used in drilling.

4.3 Commercial Economic Success

Since its formation, CS has operated profitably.
5.0 MAJOR TECHNICAL PROBLEM AREAS ENCOUNTERED

No unusual technical problems were encountered during this research. However, problems integral to spraying water at temperatures below 0°F were often encountered and overcome.

6.0 CONCLUSIONS

The FTE® process has been clearly demonstrated as a technology that, when properly located and operated, can provide significant water management cost savings to natural gas producers. It is most effective in arid climates with seasonal subfreezing temperatures. This process of coupled evaporation and freezing allows producers an economic alternative to manage produced water on a year-round basis.

The FTE® process is capable of economically producing significant quantities of water of a quality suitable for beneficial uses such as road spray, livestock watering, irrigation, and reuse in drilling and production operations. Treated waters with TDS concentration reductions of 90% or more can be readily produced using the FTE® process. Results of sample analyses indicate that salts, organics, and heavy metals are efficiently removed from produced waters.

Two benefits of the FTE® process that make it a good environmental choice are 1) the treated water may be beneficially used and 2) freezing, thawing and evaporating are natural processes that do not require chemical enhancements.

7.0 RECOMMENDATIONS

The results of this research confirm the FTE® process has significant commercial economic potential and is technically feasible. Aggressive technology transfer is needed to maximize use of the process where applicable. Further, research related to the development of the process should continue to investigate feasibility of the process in its vast number of other potential water treatment applications.

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9.0 REFERENCES AND RELATED PUBLICATIONS


