Potential for Beneficial Use of Oil and Gas Produced Water

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Abstract

Technology advancements and the increasing need for fresh water resources have created the potential for desalination of oil field brine to be a cost-effective fresh water resource for the citizens of Texas. In our state and in other mature oil and gas production areas, the majority of wells produce brine water along with gas and oil. Many of these wells produce less than 10 barrels of oil a day (bbl/day) along with substantial amounts of water. Transporting water from these stripper wells is expensive, so much so that in many cases the produced water can be treated on site, including desalination, for less cost than hauling it away. One key that makes desalination affordable is that the contaminants removed from the brine can be injected back into the oil and gas producing formation without having to have an EPA Class I hazardous injection permit. The salts removed from the brine originally came from the formation into which it is being re-injected and environmental regulations permit a Class II well to contain the salt "concentrate".

This chapter discusses key issues driving this new technology. Primary are the costs (economic and environmental) of current produced water management and the potential for desalination in Texas. In addition the cost effectiveness of new water treatment technology and the changes in environmental and institutional conditions are encouraging innovative new technology to address potential future water shortages in Texas.

Introduction

Who in their right mind would ever try to purify and re-use oil field brine? The very nature of the material produced along with oil and gas would seem to make such practices uneconomical. Produced brines emanate from formations deep beneath the earth's surface and can be very salty, up to four times higher than seawater. This brine also contains crude petroleum that can be partially soluble in the water. It contains metal salts leached from rock formations millions of years old. Even with all these obstacles, however, the oil and gas industry today is developing new technology to treat this byproduct and to make it available as a resource for landowners and environmental programs needing a new source of fresh water. This report describes the economic, technological, environmental and institutional changes that are making this process viable and creating an alternate fresh water resource for the citizens of Texas.

There are a number of reasons for this interest in oil field brine desalination. First, there is a lot of water produced in Texas. The state has more than 200,000 producing wells, and while not all of them make water, most of them do. The average ratio of water produced to oil produced in Texas (known as water-oil ration or WOR) is greater than 7 to 1. Water represents by far the

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largest byproduct produced in the fossil energy industry and essentially all of it is re-injected back into the formation from whence it came.

Handling this large amount of water is expensive. First, the operator incurs the cost of bringing it to the surface. (Despite the efforts of engineers for more than 50 years, when we produce oil and gas, we produce water.) Second water re-injection is expensive. The water must be transported to the injection well, often by a pipeline to a well on the same production lease that the water came from. But in many instances, especially in leases producing low volumes of oil, the water is stored in tanks and hauled by truck to a commercial disposal facility in the vicinity of the field. Because transporting water from these stripper wells is so expensive, the produced water can be treated on site, including desalination, for less cost than hauling it away.

The key that makes desalination of produced brine viable however, is that the contaminants removed from the brine can be injected back into the formation without having to have an EPA Class I hazardous injection permit. The salts removed from the brine originally came from the formation into which it is being re-injected and thus environmental regulations permit a Class II well to contain the salt "concentrate". This alternate deep well disposal of brine is regulated by the Texas Railroad Commission (TRC) just as field produced water is monitored and regulated. In fact, because of pre-treatment of theses fluids, such brines are more easily disposed of than untreated brine.

At the current time any produced water that is being treated to make it usable for beneficial purposes, is using membrane treatment and reverse osmosis (RO) desalination to remove contaminants. This chapter discusses four key issues that drive this new technology; (1) the cost (economic and environmental) of current produced water management, (2) the potential for desalination in Texas, and (3) the cost effectiveness of such practices, and (4) the changes in environmental and institutional conditions that encourage innovative new technology that may help to solve the potential water shortage in Texas's future.

Produced Water Management Practices; Costs and Consequences

The World Energy Investment Outlook, published by the International Energy Agency (IEA) in November 2003, concluded that more than **$6 trillion dollars** of upstream investment will be required to meet world demand for oil and gas over the period to 2030[2]. (The total debt of the United States in 2004 is approximately $6 trillion dollars.) The IEA study assumed that demand for oil will grow at 1.6% per year and that the amount of production lost to decline will lie in the range of 5% to 11% per year. Under these assumptions, approximately three-quarters of this investment will be needed to replace lost production, and only one-quarter to meet the increase in demand. As much as **$1 trillion dollars** of this total will be spent on maintaining production, and much of that will be to handle the industry's largest byproduct, brine water.

The increased volume of produced water handled in both onshore and offshore petroleum production operations is becoming a major concern, especially with the possibility of further reduction in the oil content allowed in the discharged water (offshore operations), as well as the fact that produced water contains a number of undesirable toxic components. Handling this volume of water is of prime concern to all oil companies wherever they operate. (Shell Oil is now producing 2 barrels of water for each barrel of oil and oil equivalent, worldwide[2].)

Veil et al[4] describe produced water as any water that is present in a reservoir with the hydrocarbon resource that is produced to the surface with the crude oil or natural gas. The composition of this produced fluid is dependent on whether crude oil or natural gas is being produced and generally includes a mixture of either liquid or gaseous hydrocarbons, produced water, dissolved or suspended solids, produced solids such as sand or silt, and injected fluids and additives that may have been placed in the formation as a result of exploration and production activities.

Oil and gas operators routinely inject water into petroleum formations to maintain reservoir pressure and to displace oil to production wells. Twenty five years ago, this was called "secondary recovery (primary recovery referred to oil and gas produced by its own internal energy). As reservoirs matured, and more and more petroleum was produced from the formation, most water injection fell into the category of pressure maintenance and water disposal. Operators employ a number of techniques to minimize water production and control WOR in mature fields. Despite best efforts, more and more water is being injected, and produced to recover the remaining oil reserves.

If oil and gas companies were to provide fresh water to ranchers who coexist with exploration and production activity, one of the major complaints and reasons for resistance to development is removed. This is particularly true in coal bed methane (CBM) production. CBM production represents almost 10% of the daily natural gas produced in the United States. Much of it is from federal lands. But environmental issues often prevent economic growth on these lands. At Otero Mesa, CBM production represents more than $30 million tax revenue[5] to New Mexico in a portion of the state with little economic development.

Produced Water in Texas; Potential for Desalination

Produced water disposal is common in most of the regions of the state. There are approximately 300,000 wells in Texas, 2/3 of these are producing wells[6]. Figure 1 shows oil production in Texas, wells that are active, and are producing both crude oil, gas, and produced brine.

In 2002, approximately 84% of Texas production came from the Permian Basin (Texas State Land Commissioner Patterson, March 2004). Since the average well in the Permian Basin produced 7 bbls of water for each barrel of oil, this represents more than 400 million gallons of water per day. Oil and gas operators in the Permian Basin (and other parts of Texas as well) must re-inject this brine into the reservoir or pay to transport it to commercial salt-water disposal wells.

The Texas Railroad Commission (TRC) keeps records of oil, gas, and water production in each district. However, TRC does not track water chemistry. Detailed formation water analysis for this report came from two references, the West Texas Geological Society compilations and the United States Geological Society on line database[7,8]. The USGS database contains information for the past 50 years on formation waters representing the type of brine that is being produced. Such analyses are suitable for statistical data, but for exact analysis, one should refer to regional water laboratories.

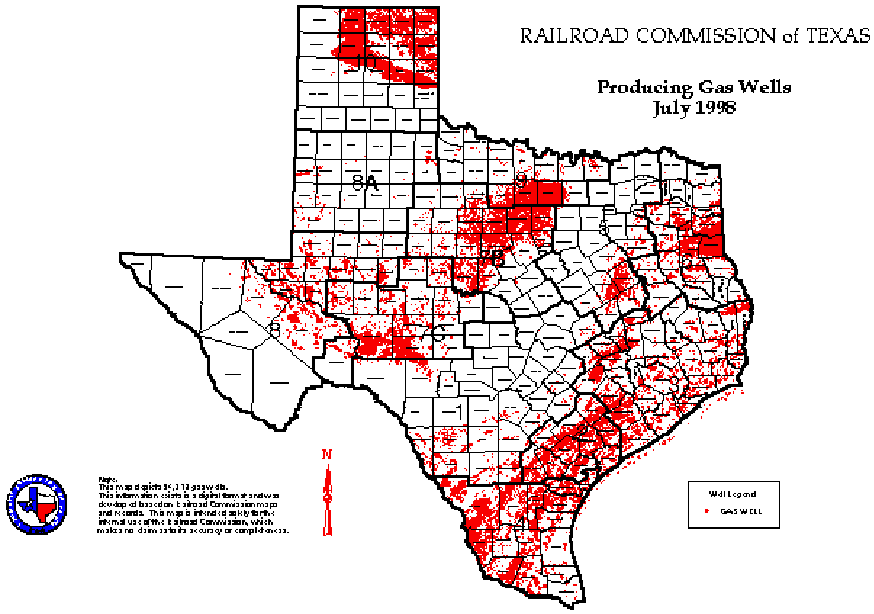

Figure 1 shows producing gas wells in the state in July 1998. Production from these wells normally includes brine water as well.

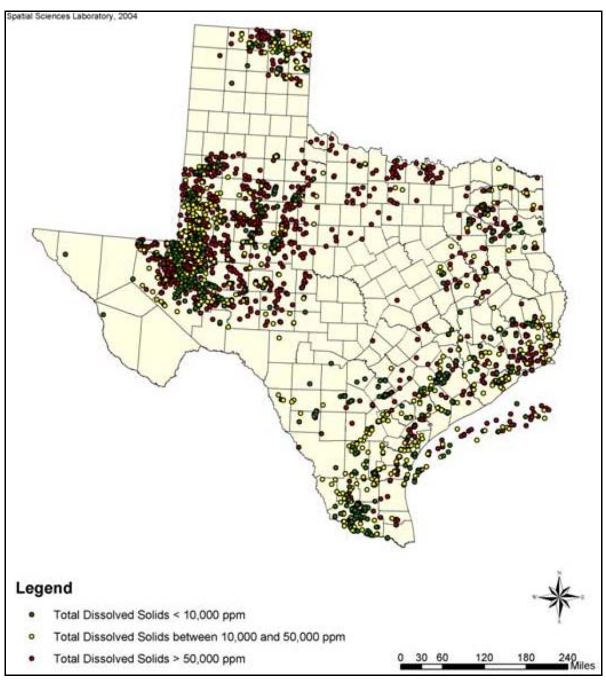

Figure 2 shows the distribution of produced water sites in the USGS database for Texas. The brines are separated into three categories based upon salinity.

Since desalination costs are a function of water salinity, produced water less than 10,000 TDS (total dissolved solids) will be the best candidate for treatment. For this reason, the USGS database was divided into three types, 10,000 TDS and less, between 10,000 and 25,000 TDS and above 50,000 TDS. The results were then charted on a map of Texas as shown in Figure 2. Approximately 1/3 of the brine produced in Texas is less than 10,000 TDS.

A typical operator in the Permian Basin producing 1,000 bbl of oil per day is estimated to spend almost $2,000 per day on produced water management and disposal. This is second only to utility costs in the case of field production operations. A 50% savings in water disposal costs translates to a savings of more than $1.00 per barrel of oil, or more than a quarter of a million dollars a year potential net profit for that individual operator.

Such benefits are magnified substantially when it is seen that as many as 2,000 of the 20,000 oil leases in Texas are potential candidates for the new technology. Table 1 shows a breakdown based on TRC data for produced water management in West Texas Districts. Water disposal values are shown in Acre-Feet/Yr. In the TRC districts 7C, 8, 8A, and 10, yearly produced water disposal is more than 265,000,000 bbls. Alternative water management represents a potential cost savings to operators of more than $3.5 million dollars annually even if only 10% of the operators take advantage of the technology.

This area includes the Barnett Shale development in North Texas. The field is already the largest natural gas field drilling play in the state, extending over parts of 12 Texas counties[9]. Tax rolls in these counties are seeing the benefit. Denton County Texas is expecting more than $24 million dollars in tax revenues from just one company (Devon Energy) in 2004. Development in the Barnett Shale depends upon well completion techniques using large amounts of fresh water to fracture the formation (a technique developed by Mitchell Energy in the early 1990s). This water, upon its return to the surface must be transported off-site to disposal wells for re-injection. Most of this brine could be recovered as fresh water if there were companies available with the facilities to provide desalination.

Table 1. Brine Production Statistics of West Texas RRC Districts (courtesy Oxy Permian)

TRRC Districts	Produced Brine, Ac. Ft.	Produced Brine, bbls
7C	7,678	57,585,000
8	16,585	124,387,500
8A	9,003	67,522,500
10	2,142	16,065,000

Cost Effective Technology for Desalination of Produced Water

The oil and gas industry has been working for several years to identify technology to utilize produced water in a beneficial manner. In the early 1990s, Marathon Oil Company evaluated, then abandoned a plan to use desalinated water on the Yates Field in West Texas[10]. In 2001, GE Water Technologies (Osmonics Desal)[11] found that membrane pre-treatment and RO desalination could effectively remove impurities from water produced from heavy crude oil field production near Bakersfield California.

Recently the Texas Water Development Board (TWDB) funded research to answer the question whether desalination of produced brine offers promise as a source of fresh water resources. Specific research needs are harder to prioritize. TWDB funded the Texas Water Resources Institute (TWRI) to report on the feasibility of new technology to treat produced brine. TWRI found that the technology is available to desalinate certain brines produced in petroleum operations. However that technology needs to be improved, the value of fresh water and local water supply needs must be established, and the environmental and regulatory issues associated with beneficial use must be addressed. A more thorough study is contained in a report by Burnett and Pankratz to the TWDB[12].

For the past four years a team from Texas A&M University has been working to find cost effective technologies to employ in desalination and to find ways to establish a value for the resource that is recovered by this treatment. Their laboratory studies and field trials show that the most significant difference in the desalination of oil field brine and brackish ground water or surface water is the "conditioning" or "pre-treatment required. Oily water is difficult to treat whether it is an industrial water (bilge water, water from contaminated bays, etc.) or oil field brine. Oil in water tends to coat particulate matter, making it "sticky" and prone to adhering to piping, suspended solids in the brine (scale, biological products, etc.), and to filter surfaces. Getting pre-treatment "right" is paramount, whether the water being treated is industrial water or oil field brine. A recent field test of a mobile produced water treatment unit[13] provided estimates of the cost of operating such a unit. Total operating costs during the daily 7 hour runs averaged less than $10 for 2,300 gallons of brine processed.

RO has been the technique of choice for essentially all pilot tests conducted in the last decade[14] because RO produces fresh water from a wide variety of saline systems. RO facilities are scalable and in general have a small footprint and fit into the environment. A disadvantage of small scale RO facilities in the oil field is the need to have the units designed so that they can run unattended with regular maintenance at regular intervals. More work is needed before dependable commercial desalination units are available.

Historically, one of the major impacts of desalination has been the problem of the disposal of the salts ("concentrate") and other materials removed from the source water. This brine contains concentrated dissolved salts and other materials. Disposing of this brine concentrate for traditional RO processes can represent a significant fraction of the cost of operating the unit to recover fresh water. However, in the oil and gas industry, high salinity brines are routinely injected into formations for pressure maintenance and secondary recovery by water flooding. Since water from desalination operations may be injected into these oil- and gas-containing formations, the estimated cost savings can be as much as 30% of the cost of operating the desalination unit. This represents a significant cost savings for RO technology that offsets any added pre-treatment needed for the oil field brine and should make fresh water available to communities in need of this valuable resource. Subsurface disposal of salts and other materials from water treatment processes is being considered for a number of industries[15].

For independent operators to employ desalination and beneficial use, they must be able to acquire robust systems that can be custom designed for specific field conditions and systems that can operate with minimal supervision. Since the chief advantage of desalination comes from not having to transport water, a desalination unit should be of sufficient size to treat water on-site, and to do so safely and in a way that meets environmental standards.

Figure 3 illustrates the A&M desalination trailer during its trial run at the water treatment plant on the A&M campus in College Station. The unit is removing diesel and combustion byproducts from water at a waste treatment plant used for fire fighter training.

Figure 3. GPRI desalination trailer at the water treatment plant on the A&M campus.

Figure 4 shows a 160 disposal well truck carrying oil field brine. A single SWD facility may receive as many as 80 trucks daily carrying brine from drilling, completion and production operations.

The unit can produce from 2,000 to 5,000 gallons per day of RO high quality water free of organics or salts. Filter efficiency and filter cleanup can be readily measured for a number of agents, and oil/water systems with the mobile unit and an on-board electrical meter keeps track of power usage. The unit is scheduled to be deployed in Wise County Texas to treat water being trucked from gas well fracturing operations in the Barnett Shale, one of the most active drilling areas in the U.S.

Environmental and Institutional Issues; Laws, Barriers, and Suggested Changes

Why would oil and gas companies assume the responsibility for treatment and re-use of a byproduct with no value? In fact, the consequences of inappropriate management of produced water can become a significant environmental expense. For example, the United Estates Environmental Protection Agency (EPA) and the Department of Justice recently announced a $5.5 million settlement with Mobil Exploration and Producing U.S. Inc to compensate the Navajo Nation in southeastern Utah for oil and produced water spills from Mobil's oil production activities[16]. The settlement included a $515,000 penalty and requires the company to spend about $4.7 million on field operation improvements to reduce spill incidences. The settlement calls for Mobil to spend approximately $327,000 on environmental projects that include sanitation facilities and construction of a drinking water supply line extension that will provide running water to 17 of the remote residences located on the oil production fields.

One reason for the number of litigations addressing such environmental matters is that the regulations applicable to this type of source water are not clearly defined. According to the Texas Commission on Environmental Quality (TCEQ) staff, this water would be considered an Industrial Reclaimed Water, and would, therefore, be subject to all rules relevant to the use of an industrial reclaimed water (Texas Administrative Code, Chapter 210, Subchapter E, Special Requirements for use of Industrial Reclaimed Water).

Additionally, any proposed use of industrial reclaimed water not considered "on-site" must comply with numerous other general reclaimed water requirements, including the sampling and analysis frequency. The nature of how the resource is being used is a factor as discussed below.

Potable Uses. The highest level of water treatment is associated with human ingestion. Discussions with TCEQ staff indicate that a project involving potable use of treated brine produced by oil and/or gas wells would receive extreme scrutiny by the State. However, if the requirements of the applicable regulations were met, the State would review the information submitted to confirm there were adequate safeguards. The applicable TCEQ Rule pertaining to public drinking water systems is TAC Chapter 290, Section 42(g). This section states that "other" treatment processes will be considered on an individual basis.

Discharge to Supplement Instream Flow Discharges to surface water designated as Waters of the State must meet Texas Surface Water Quality Standards (TSWQS) as contained in Texas Administrative Code Chapter 307.Without a specific stream or amount of discharge set, it is difficult to outline all necessary regulations one must follow. The permitting process, done through the TCEQ Water Quality Division, is conditional on two key variables, the receiving stream ambient quality and the volume of the discharge. The TSWQS identify individual water quality standards for each stream in the State, and these standards are based on the use category a particular stream is assigned. A discharge, once dilution has occurred, must not hinder the water quality standards set for the receiving stream

Livestock Uses Another potential use of the brine-produced water is livestock drinking water. There are very little, if any, regulations to follow here. If the owner of the livestock is amenable to using a water supply, he is allowed to do so. A typical rule of thumb, though, is a TDS limit of 6,000 mg/L for this purpose. This is the TDS concentration TCEQ employees use when gauging if a particular stream is suitable for livestock use.

There are other factors, not directly associated with water purity that also must be addressed when evaluating a potential project. Burnett and Veil discuss how "hard" engineering data can be combined with "soft" data from subjective observations to asses the risk of a project[17]. Two of the key issues are the project's effect on the environment and the health and safety of the populace and the workers near a facility.

Environmental. The efficiency, availability, and reliability of the individual systems, including the frequency of overboard discharges include the following:

- Additional atmospheric discharges caused by well operation
- Additional atmospheric discharges caused by increased power demand.
- Additional well operation in terms of well intervention, either workover or stimulation
- The generation of waste streams which can cause environmental handling problems either caused by well operation and / or produced water treatment prior to the re-injection process.
- The use of additional chemicals caused by either well intervention and stimulation or to compact problems caused directly by the re-injection option

Health and Safety Personnel safety and whether or not there will be an increase in the risk caused by any additional operation directly related to the alternative option. Safety limitation must be considered in the operation and the maintenance of the alternative options directly related to the facility installation and excluding any well related activities. Finally there is the risk assigned to alternative desalination operations compared with the transportation of large quantities of brine on public roads. The risk is magnified when these trucking operations are often on rural and county roads in the state, not the large freeways.

Conclusions and Recommendations

The oil and gas industry understands that it makes sense to commercialize technology to recover fresh water resources from oil field brine. The technology is available and as prototype desalination units get field experience, costs of the water produced will become more competitive with alternate sources of fresh water.

From the perspective of the potential user of the fresh water, it makes sense to encourage the practice of converting the byproduct to fresh water rather than to spend more money to re-inject it back into the oil or gas reservoir from whence it came. Field demonstration programs are recommended to show the public and local and state officials that, desalination of oil field brine is essentially the same opportunity as desalination of any other impaired water source.

Presently, the injection of RO concentrate into depleted oil and gas fields is not a common practice. If the practice becomes more common in the future, states or the EPA may adopt new policies or regulations to govern concentrate injection. We recommend a concerted effort to encourage those who are considering desalination of impaired byproduct water or brackish ground water to consider injection into depleted oil and gas zones.

Finally we recommend that the leaders of the state of Texas encourage advanced desalination technology by offering funding for research and incentives for field demonstrations of commercial projects. There is ample water for Texas in brackish ground water aquifers and in brackish oil field produced brine operations. There are cost effective solutions to the disposal of concentrate from treating those brines. Here is an opportunity to "drought proof" Texas communities.

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