

APPENDIX F

WATER TREATMENT TECHNOLOGIES

There are a variety of potential beneficial uses for CBM produced water that can be implemented by CBM operators to manage this resource but the quality of the produced water can be a deciding criterion for what option is chosen. The potential also exists for this water to be treated by a variety of technologies to improve the quality of this water and allow for increased beneficial use. However, there are cases, particularly in the Powder River Basin where water quality standards can be met and receiving water quality protected without treating CBM produced water. This should be carefully assessed when evaluating treatment.

To design an effective system for treating or disposing produced water it is necessary to know the following: likely quality of produced water; estimated water production rates at various phases of the project; nature of any proposed receiving waters in terms of seasonal flow rates, existing water quality, and aquatic flora and fauna; and current or proposed permitting and regulatory restrictions.

The following section presents a discussion of some of the treatment options that may be utilized. However, this list is not all-inclusive nor is it intended to show preferred treatment methods. Instead, this section is intended to provide a description of several treatment technologies that are currently being evaluated or utilized for the treatment of CBM produced water prior to beneficial use. Other methods may become available or may be developed that should also be considered.

Freeze-Thaw/Evaporation

The Freeze-Thaw/Evaporation (FTE) process involves lowering the freezing point of water containing salts or other constituents below the freezing point of pure water (32°F). Partial freezing of the solution results in the formation of higher quality ice crystals than the water from which it was derived, and the concentration of the higher density dissolved solids and other constituents in the unfrozen liquid. The ice crystals can then be collected and thawed, providing a source of high quality water with more management options, or in appropriate regions, the crystals can be allowed to evaporate. This process can be repeated until the more concentrated effluent is of a manageable volume. The smaller volume of effluent, though more concentrated, can be more easily disposed of and/or discharged with an appropriate NPDES permit, if necessary.

Reverse Osmosis

Reverse Osmosis (RO), or hyperfiltration, is a proven treatment process for the removal of TDS and other constituents such as arsenic. RO water treatment has been used extensively to convert brackish water/seawater or brine to drinking water, reclaim wastewater, and recover dissolved salts from various industrial processes. The RO treatment process separates dissolved solids or other constituents from water by passing the water solution through a semi-permeable cellophane-like membrane. Most RO

technologies utilize a cross-flow process to allow the membrane to continually clean itself. As some of the solution passes through the membrane, the remaining fluid is flushed down stream to remove constituents away from the membrane.

Ultraviolet Light

Ultraviolet (UV) sterilization is a proven technology for the treatment of water and the removal of unwanted free-floating constituents. UV light is a form of energy located in the electromagnetic spectrum region of shorter wavelength, high-energy light. UV light exists in a region between visible light and x-rays, occupying a spatial spectrum between 1 to 400 nanometers (1 nm = 10^{-9} meters). UV energy absorbed by bacteria, viruses, fungi, algae, and protozoa disrupts nucleic acids found in their cells preventing the cell's ability to multiply (Muskoka-Parry South Health Unit, 2002). The amount of UV light necessary to kill microbes depends on the type of microbe, but the minimum recommended dosage considered acceptable for treatment is 16,000 microwatts per second at a wavelength of 253.7 nm at maximum flow (Muskoka-Parry Sound Health Unit, 2002).

Chemical Treatment

Chlorination – Chlorine has been the principal water disinfectant of public water supplies, sewage, and industrial effluent for several decades. The active form of chlorine present in treated water is a hydrolysis product, hypochlorous acid (HOCL), which is formed when chlorine and water molecules interact (Committee on Groundwater Recharge, National Research Council. 1994). Chlorination effectively removes disease-causing bacteria, viruses, protozoa, and other organisms, and can be used to oxidize iron, manganese and hydrogen sulfide so these minerals can be filtered from the water. Other treatment technologies, such as UV light and RO, are often used in tandem with the chlorination process.

Iodine – Iodine water treatment is commonly used to remove pathogens, with the exception of cryptosporidia, from water. Iodine is less sensitive to pH and the organic content of water, is safe for long-term exposure, and is considered effective in lower doses. Experts however, are reluctant to recommend iodine for long-term use because the range of the average American iodine intake (0.24 to 0.74 mg/day) includes levels higher than the recommended daily allowance (0.4 mg/day) (Turner, 2002).

Silver – The use of silver to kill water pathogens has been considered, but because of the EPA's establishment of 50 ppb MCL limit on silver, its use for water treatment has been very limited. The MCL was established to prevent argyrosis, a silver specific disease characterized by staining of the eyes, skin, and mucous membranes.

Additional chemicals used to treat water include potassium permanganate, hydrogen peroxide, and coagulation/flocculation agents. Historically these reagents have been used on a very limited basis because of potential health concerns and/or cost efficiency. For the purpose of this study, as with iodine and silver, these chemicals are not considered a practical solution for treating produced water for beneficial uses.

Ion Exchange (Resin Extraction)

The process of ion exchange historically has been used to soften water for residential purposes by replacing hardness ions such as calcium and magnesium with Na⁺ and Cl⁻ ions (Filters, Water & Instrumentation, Inc., 2002). Ion exchange is also commonly used to deionize water by replacing ions, such as conductive salts (desalination), with H⁺ and OH⁻ when extremely pure water is required. The ion exchange process works by charging resins with the replacement ions, e.g., Na⁺, Cl⁻, H⁺ or OH⁻. Ions in the water are attracted to the resin and attach themselves to the resin, replacing the ions that are already attached. Once the replacement ions are exhausted, the resin is regenerated with a concentrated solution of the replacement ions. This process removes the ions concentrated in the water and effectively regenerates the resin (Osmonics, 2002b).

A residual brine containing the ions removed by this process is formed by this method. This brine is typically 1-5% of the original produced water volume. The management of this brine must be considered in advance if this technology is to be used.

Capacitive Desalination (CD) or Deionization

According to the inventor, Joe Farmer, this relatively new high water recovery treatment process has the potential to use one-thousandth to one-hundredth the energy required by typical distillation methods. Water with concentrations of salts, heavy metals, and/or radioactive isotopes is pumped through thin sheets of carbon aerogel. Each porous aerogel sheet is 3 in² with the effective surface area of a football field (600 to 900 m²/g) (Envirosense, 1996). Non-polluting electricity is applied to the aerogel sheets (electrodes) trapping ions and allowing pure water to pass through. Since the capacitive deionization process does not require the regeneration of ion exchangers with acids and bases, as with the conventional ion exchange process, any associated secondary waste would be eliminated (Lawrence Livermore National Laboratory, 1994b).

Electrodialysis Reversal (EDR)

Traditionally, electrodialysis treatment of water has been used to desalt brackish water to produce higher quality water (Damien (Solarweb), 1998). The basic principles of this treatment process are similar to ion exchange in that ions will dissolve in water and will possess either a positive charge (cation) or negative charge (anion) and will be attracted to electrodes of an opposite electrical charge. Electrodialysis differs from a normal ion exchange process by utilizing both cation and anion selective membranes to segregate charged ions from a water solution (AWWA, 1996). These membranes are arranged alternatively (cation and anion) to selectively collect charged ions. The arrangement of two membranes creates spaces of concentrated and diluted solutions and collectively is referred to as a cell (Shuler and Kargi, 1992). A typical dialysis system consists of hundreds of adjacent cells with electrodes on the outside and is referred to as a membrane stack (Damien (Solarweb), 1998). As with RO, energy, such as a small pump, is required to move the water through the membranes.

Distillation

The distillation process is capable of removing 99.5% of the impurities concentrated in raw water (Derickson, et al 1992). The distillation process is commonly used to remove nitrates, bacteria, sodium, hardness, dissolved solids, many organics, heavy metals, and in

some cases, radionucleides. Distillation involves boiling water into steam, which is then passed through a cooling chamber and subsequently condensed into a purified form. The boiling process segregates water impurities from the purified product for collection and disposal. Constituents having similar boiling points of water are not effectively removed during the distillation process. Such impurities include many volatile organic contaminants, certain pesticides, and volatile solvents (Derickson, et al, 1992).

Artificial Wetlands

Constructed wetlands were developed approximately 40 years ago to exploit the biodegradation ability of plants (Shutes, 2001). The advantage of these systems includes low construction and operation costs (Cooper, et al., 1996), approximately 1 to 2 cents/bbl, although relative to other wastewater treatment technologies these systems have a slow rate of operation and require a large area.

Table

Treatment Technologies and their Effectiveness on Reducing Certain Constituent Types Present in CBM Produced Water

Treatment Technology	Heavy Metals	SAR	TDS	Ba	Fe	EC	Organics	Na	HCO₃	Bio
FTE	√		√	√	√	√		√		
RO	√	√ ²	√	√	√	√		√	√ ¹	
UV Light							√ ³			√
Chemical										√
Ion Exchange	√	√	√	√	√	√		√	√ ¹	
CD	√	√ ²	√	√	√	√		√	√ ¹	
EDR	√	√ ²	√	√	√	√		√	√ ¹	
Distillation	√		√	√	√	√	√ ³	√		√
Wetlands	√		√	√	√	√				√

Source: ALL Consulting

√ - indicates treatment process can reduce constituent type.

1 - pH adjustment would be required prior to treatment

2 - water adjustment by addition of calcium and magnesium would be required.

3 - limited to certain organics based on volatility, boiling point, chemical composition, etc.