The Use of Coal Bed Methane Product Water to Enhance Wetland Function

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Wetlands have long been known as nature's kidneys because of their ability to absorb large amounts of nutrients and filter some materials considered to be toxins and pollutants (Anonymous, 1998; Gopal, 1999). With the exception of peat bogs, natural wetlands are very productive systems that support high biodiversity and perform a variety of ecological functions (Gopal, 1999). Constructed wetlands (CW) have been gaining acceptance as replacements of natural systems which have been lost or degraded and as treatment systems because of their ability to improve water quality (Cunningham et al., 1995; Gopal, 1999; Peterson and Teal, 1996; Tanner, 1996). The EPA and U.S. Army Corps of Engineers drafted section 404 of the Clean Water Act in order preserve and maintain natural and constructed wetlands.

Wetlands are defined as areas which are inundated for a sufficient amount of time to develop hydric soils and vegetation. Section 404 provides the rules and regulations governing who may construct a wetland, how the discharge of water and fill from the wetland is to be handled, and how to deal with replacing or rehabilitating natural systems. Once a wetland has been created, it must be maintained in perpetuity with the exception of treatment wetlands, holding ponds, or other systems designed specifically for water treatment (Section 404 Clean Water Act). Constructed wetlands have several constraints on their usefulness: 1) Wetlands require a large amount of land per unit volume of water. 2) A sufficient supply of water is necessary to support the wetland. 3) The source and quality of wastewater may require pretreatment; in some agricultural and municipal cases wastewater must be pre-treated before entering a treatment wetland (Gopal, 1999).

A limitation of wetlands in cold climates is that primary function may be minimal during winter months. A possible solution to this problem would be to spray the inflow water in the air. This would cause the fresh water to freeze (some would evaporate as well), and the remaining water would be more concentrated in respect to the salts (Available from: Crystal Solutions, LLC).
A selection of various research projects involving CW's and heavy metal removal, dairy and agricultural effluent treatment, and municipal wastewater treatment are summarized in Table 1. However, limited research on constructed wetlands for use and treatment of product water from oil and gas wells can be found in the scientific literature.

Many researchers have considered the concept of using plants to accumulate salt through plant uptake or through water volume reduction. However, few efforts have been followed through to the point of publication of promising results. Probably one of the first studies to show reasonable success was that reported by Settle et al. (1998) which highlights the potential use of halophytic species to reduce the volume of product water and concentrate salts. Several attempts with greenhouse studies were conducted between 1990 and 1995 and subsequently in 1996 the first field studies were instituted.

Settle et al. (1998) reference two sources of information defining the characteristics of halophytes (Aronson, 1989; Sutcliffe, 1962). Halophytes are plants found growing under saline conditions and are generally defined as salt and/or sodium tolerant plants. As reported by all three of these sources, halophytes have two mechanisms for tolerating high external salt concentrations, either by accumulating salt in high levels in plant tissue or by excluding salt from plant uptake.

The process proposed by Settle et al. (1998) uses natural plant processes of evapotranspiration and salt accumulation to reduce the volume of product water requiring treatment or disposal while simultaneously reducing the total salt load by plant accumulation. Settle et al. (1998) defined their proposed process as a "bioreactor" which incorporates saltmarsh processes with salt tolerant wetland plant species in a hydroponic growth environment.

Salt concentration of water in which these plants were grown ranged from 2 to 6 % (corresponding to 20,000 to 60,000 ppm, EC 30 - 90 dS/m). According to the authors, the ideal plant is a large, vigorous, salt tolerant species. Volume reduction is dependent on the evapotranspiration rate established by local climatic conditions. To incorporate plant processes to remove salt concentrations from water, finding the right native plant species, determining sustainable plant communities, and scaling the "bioreactor" to size to accomplish the task is necessary. The one additional step is the consideration of water managment during the non-growing season.

Numerous approaches to dealing with saline product water from conventional oil and gas wells have been explored. Lessons learned have potential applications to addressing issues of management, utilization, and disposal of large volumes of coal bed methane (CBM) product water. With respect to CBM product water, the significant issues which must be dealt with are large volumes of modestly saline-sodic water and lack of
suitability of disposal of such water on the landscape or to ephemeral channels and streams due to concerns about potential adverse impacts to down-stream irrigable soils, ephemeral stream channels, stream corridors and plants and aquatic organisms in these channels.

Photo courtesy of http://english.epochtimes.com/news_images/2004-3-3-3-oil-well.jpg

Generally, the significant limiting factor to management or disposal of saline product water is cost of treatment or the cost of disposal, particularly when disposal involves deep injection of large volumes of water. The other significant determinant to product water treatment is management of concentrated waste. Most individuals dealing with the environmental issues associated with product water management would concur that processes which minimize potential consequences and volumes of product water to be managed are preferred. Processes such as reverse osmosis, resin exchange, and distillation all require concentrated waste product management. A treatment process which incorporates volume reduction and concentration antecedent to deep reinjection would be preferred. In addition, any water utilization which, in practice, creates beneficial use, added value, or product enhancement potentially reduces the net cost, thereby making the overall operation more profitable.

In 1990 the Argonne National Laboratory began examining the possibility of using biological methods to optimize metal uptake and reduce the volume of water produced by oil and gas wells (Negri et al., 1999). The main purpose of the study was to examine the effectiveness of a plant-based system in reducing the volume of water requiring treatment, effectively concentrating the salts. Six species were evaluated for salinity tolerance at three salt concentrations (0, 15000, 30000 ppm). The mean evapotranspiration (ET) rates for all six species exceeded evaporation of open water up to a salt concentration of 20,000 ppm, and several of the species maintained high ET rates in salt concentrations up to 60,000 ppm.

Two species were selected for further study based on the results of the laboratory screening. Spartina alterniflora (Saltwater cordgrass) was selected for its high salt tolerance, and Scirpus validus (common great bulrush) because of its high ET rates. A model of plant dynamics which the researchers termed a ‘bioreactor’ was developed using
approximately 40% of the ET rates of the Spartina alterniflora and Scirpus validus. The bioreactor was designed to treat 66.6 m³ (~18,300 gallons) per day of product water using a surface area of 300 m² (~3300 ft²), and predicted a 75% reduction in the volume of water in less than 8 days with the resulting water having a higher concentration of salts due to the reduction in volume.

In cooperation with Devon Energy Corporation and the Gas Research Institute, Argonne National Laboratory scientists established several on-site studies in Oklahoma. They used the basic model developed in the laboratory to reduce the volume of water produced at an oil/gas lease in Oklahoma (Negri et al., 1999; Settle et al., 1997). The model CW consisted of two cattle watering troughs filled with pea gravel as a growth substrate and planted with *Scirpus validus* in the first compartment to maximize ET and the more salt tolerant *Spartina alterniflora* in the second. The system was gravity operated, required no external power, and the only maintenance cost was fertilizer to maintain optimum growth of the plants. The volume of water in the tanks was reduced by 75% in four days, and within seven days the leaves of *Spartina* were coated in salt crystals. Subsequently, a second site was constructed with a third trough containing no plants to compare the evaporation rate of open water to ET rates where plants were present. The troughs with plants reduced the volume of water 30% faster than the open water troughs. The role of plants in bioremediation:

Phytoremediation is the concept of using plant-based systems and microbiological processes to counteract or eliminate contaminants in nature. These remediation techniques, which utilize specific planting arrangements, constructed wetlands, reed beds, floating-plant systems and numerous other configurations, have been common in the treatment of many types of wastewater, and lately, contaminated soils and atmospheric pollutants as well (Cunningham et al., 1995; Anonymous, 1998). One of the main advantages in phytoremediation is that the systems are generally low-cost and low-tech with little maintenance expense, although there are some limitations. Remediation is best considered a long-term process since it is usually slower than chemical treatments; the levels of parameters targeted must be within the tolerance limit of the selected plants; and containment may be needed in the case of highly soluble contaminants which may leach out of the root zone (Cunningham et al., 1995).
Plants utilize one of three basic phytoremediation strategies: phytoextraction/bioaccumulation- plants accumulate contaminants and are harvested in order to remove the contaminants from the system, phytodegradation- contaminants are converted into non-toxic materials by plants and associated microorganisms, phytostabilization- contaminants are precipitated out of solution or absorbed/entrapped in the soil matrix or plant tissue (Cunningham et al., 1995). *Spartina alterniflora* is a phytoextractor; salts are accumulated in the leaves of the plant, and when harvested, the accumulated salts are effectively removed from the system. There is an added cost-reduction benefit in that *Spartina alterniflora* can be used as forage for cattle. The plants are readily consumed and the salt-covered leaves are not harmful to cattle (Settle et al., 1998). The drawback to *Spartina alterniflora* is that it is not a native to some areas, and utilization may constitute introduction of a potential weed species. A native cordgrass, *Spartina pectinata* (Prairie Cordgrass), may be a viable alternative in areas where *S. alterniflora* is considered a potential weed.

In a study conducted by Pauliukonis and Schneider (2001) along the southern shoreline of Oneida Lake, NY, USA, *Typha Latifolia* L. (broad-leaved cattail) had higher ET rates than open water or bare soil and used an average of 5.75 +/- 1.34 mm of water per day. In order to obtain consistent water use data across different substrates, plant forms and without the interference of meteorological conditions, the researchers used the lysimeter method to determine daily ET rates. As the summer progressed, ET increased. This could be attributed to the ability of *T. Latifolia L.* to increase the number of ramets from 5-8 in the beginning of summer to 8-20 at the end. Researchers also noted that *T. Latifolia L.* did not show the typical midday drop in ET rates. The researchers relate this to claims by Leverenze (1981), Schulze et al. (1985), and Bernhoffer and Gay, (1989), that plants with a constant supply of water do not need to regulate their stomates in order to conserve water in their leaves.

Studies by Glenn et al., (1995), Snyder and Boyd (1987), Negri et al. (1997) agree with the results obtained by Pauliukonis and Schneider that show ET from vegetated areas to exceed evaporation from open water. In 1981 Idso (1981) reviewed experiments conducted to determine whether vegetation helped or hindered evaporation. Over the years, some researchers have found evaporation from open water to exceed ET of vegetated surfaces, while others have concluded there is no difference (Idso, 1981). Some of the disagreement may be due to differences in experimental design, i.e. small, exposed lysimeters. There are also inherent differences in ET rates among plant species and communities as well as the fact that there is no common method for determining ET rates. Based on theoretical and experimental evidence, Idso concluded that evaporation from an extensive, open body of water will not significantly increase with the introduction of vegetation. In reality, the vegetation may in fact lower the evaporation rate. However, introduction of vegetation on a body of water of more limited extent may increase evaporation as long as the vegetation remains robust.

Lorenzen et al., (2000), conducted a study of seed germination of *Typha domingensis Pers.* (cattail) and *Cladium jamaicense* (sawgrass) under controlled conditions in the laboratory. The results suggest that cattail germination is dependant on light, and
enhanced by low oxygen concentrations, organic sediment, and diurnal temperature fluctuations. *Typha* reproduce by seed dispersal and vegetative propagation from rhizomes with rapid rhizomatous growth. Wild et al. (2001) found rhizomatous colonization of two *Typha* species increased the number of shoots per m² by an average factor of 8.4 in just two months. Woo and Zedler (2002) and Svengsouk and Mitsch (2000) studied the effect of nutrients on vegetative growth of *Typha spp*. The results indicated that vegetative growth of *Typha* is increased by the addition of nutrients, and that *Typha* can quickly form monotypic stands in fertile wetland systems. Options for CBM product water management:

The excess volume of water produced by a CBM well can be problematic. Economics preclude the use of traditional treatment methods to deal with such large quantities of water. Discharge restrictions disallow large volumes of questionable quality water for surface release, so containment ponds are necessary to hold the water until it can safely be discharged or utilized. In the case of CBM product water, the excess volume may be beneficial in that the constraint of having adequate water for wetland establishment and maintenance may be alleviated. CBM wells produce large initial volumes of water (up to 100,000+ gallons a day) which decrease significantly after prolonged pumping. Even with decreased volume, CBM wells should provide ample water to support a treatment wetland. The results of the study performed by Argonne scientists demonstrate how a constructed wetland system can be successful in reducing the volume of product water through plant consumptive use and evaporation.

Various plant types have been studied and identified for salt tolerance and uptake, as well as for their quality as forage for livestock. A possible strategy to aid in processing CBM product water is to construct a wetland composed of a variety of halophytic plants which have dense fibrous root systems, uptake salts and sodium, can be used as forage, have high ET and water use rates, or a combination of these traits. The purpose of the proposed study is to examine constructed wetlands as a method for utilizing and reducing excess water associated with CBM product water. It is hypothesized that through biological, chemical and physical processes, CBM product water can be utilized by plants and through evapotranspiration, concentrated for treatment. The project proposes using CBM product water to enhance wetland function and large, vigorous halophytic plants known for high evapotranspiration rates to effectively concentrate the salts and reduce the volume of water needing treatment.

Table 1. Summary of various research projects utilizing constructed wetlands and/or plant-based systems in remediation of contaminated waters.

<table>
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<tr>
<th>REFERENCE</th>
<th>PROBLEM</th>
<th>FINDINGS</th>
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<tr>
<td>Abisssy and Mandi, 1999.</td>
<td>Arid climate wastewater purification using <em>Typha latifolia</em> and <em>Juncus subulatus</em>.</td>
<td>Ammonia concentration was reduced by 31% in the <em>Typha</em> system, 17% in the <em>Juncus</em> system, and -22% in the unplanted. Phosphorus depletion of 32%, 27%, -10%, respectively. Organic matter removal due almost entirely to physical processes such as sedimentation, filtration.</td>
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<tr>
<td>Author(s)</td>
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<td>Barrett-Lennard, E.G., 2002.</td>
<td>Rising water table and subsequent secondary salinity problem due to replacement of deep-rooted native plants with shallow-rooted agricultural crops.</td>
<td>Examined tolerance levels of trees and halophytic plants to inundation and salinity. Examined efficiency of trees and plants in lowering the water table and removing excess salts.</td>
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<td>Cheng et al., 2002.</td>
<td>Decontamination of artificial wastewater polluted with heavy metals.</td>
<td>A vertical flow C.W. with <em>Cyperus Alternifolius</em> was effective in treating the wastewater.</td>
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<td>Cunningham et al., 1995.</td>
<td>Plant-based remediation of soils contaminated with organic and inorganic pollutants.</td>
<td>Discussed two contrasting approaches: pollutant-stabilization and containment; and decontamination.</td>
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<td>DeBusk et al., 1995.</td>
<td>Use of aquatic and terrestrial plants for removing phosphorus from dairy wastewaters.</td>
<td>Water Hyacinth removed more N and P from dairy wastewater than Duckweed. Increased hydraulic residence time (HRT) decreases productivity and the concentration of N in tissue. Terrestrial plants did better under drained conditions.</td>
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<td>Ernst, W.H.O., 1996.</td>
<td>Soils contaminated with heavy metals.</td>
<td>Phytoremediation is an important clean-up technique for slightly contaminated soils. For heavily contaminated soils, revegetation with highly metal-resistant plants is more efficient.</td>
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<tr>
<td>Groudeva et al., 2001.</td>
<td>Bioremediation of waters contaminated with crude oil and toxic heavy metals.</td>
<td>Oil content decreased to less than 0.2mg/l due to microbial degradation. Concentration of heavy metals decreased below permissible levels. In part due to sorption onto plants, microbial biomass, and clay minerals.</td>
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<td>Mungur et al., 1997.</td>
<td>An assessment of metal removal by a laboratory scale wetland.</td>
<td>The wetland system retained about 99% of the metals in a pre-saturated situation. Once saturated, the systems efficiency may decrease.</td>
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<td>Peterson and Teal, 1996.</td>
<td>Septage treatment- concentrated waste from anoxic septic tanks of houses or businesses.</td>
<td>Plants are effective in nutrient uptake, and can remove a significant amount of nitrogen from the system. Roots provide attachment sites for microorganisms.</td>
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<tr>
<td>Scholz and Xu, 2002.</td>
<td>Treating wastewater contaminated with lead and copper. And reduction of BODs.</td>
<td>Plant decay resulted in an increase in BODs. Filter material did not enhance copper and lead reduction. Macrophytes did not increase wetland function.</td>
</tr>
</tbody>
</table>
References Cited:


Bureau of Land Management. 1999. Excerpts from the Tongue River CBM environmental assessment which address soil or water resources impacted. Miles City Field Office, Miles City, MT.


Phelps, S.D., and Bauder, Dr. James W. 2002. The role of plants in the bioremediation of coal bed methane product water.[Online]. Available at http://waterquality.montana.edu/docs/methane


