HIGH DENSITY POLYETHYLENE (HDPE) LINED PRODUCED/FLOW-BACK WATER EVAPORATION PONDS

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ABSTRACT

The problem to be solved is the disposal of millions of gallons of production water (brine water) and flow-back water generated annually from the Rocky Mountain Region oil and gas industry in an environmentally safe, low cost, and efficient manner. A technology that is effective and safe is the evaporation of the water in lined containment ponds after separation and removal of the hydrocarbon component from the water.

Four projects are the case studies for this paper, located near the following cities:

- Cheyenne, Wyoming
- Cisco, Utah
- Dad, Wyoming

They were designed to evaporate water in a series of geomembrane lined ponds.

1. INTRODUCTION

Some of the aforementioned projects are complete and have been operational for a number of years, while others are currently under construction. The production and flow back water from oil and gas wells in the area local to each site is trucked to the sites for disposal. The water is evaporated in ponds lined with high density polyethylene (HDPE) as the top layer by using a combination of factors that are favorable to the evaporative process, including the following:

- Natural characteristics of the site, including the arid climate, windy conditions, and numerous sunny days,
- The top liner in the ponds is black HDPE, which creates a hot surface,
- HDPE liner was chosen to protect the surface and ground waters of the area and to assist with the evaporation of the water (evaporation is enhanced due to the black color of the liner).

The projects are interesting in that each facility provides oil and gas production companies in the area with a large commercial alternative to production water and flow-back disposal versus numerous small ponds that may service only one well pad, or expensive re-injection wells, or even more expensive water recycle treatment facilities. The regulatory agencies like it for centralization and protection of the state's waters. The facilities protect surface waters in the area due to the large capacity of the ponds, 2 feet (Utah) and 3 feet (Wyoming) of freeboard, and secondary containment in case of catastrophic berm failure (Utah).

Project Location – Cheyenne, WY

Silo Field, Wyoming

The project is located in a semi-arid region of southeastern Wyoming in Laramie County, which is situated at approximately 5,900 feet above mean sea level (amsl). The site is located approximately 15 miles northeast of the intersection of Interstates I-80 and I-25 in Cheyenne, WY.

Background and Site Conditions

The ground surface is privately owned land primarily used for arid farming and stock grazing. No residences are located within 1 mile of the site. Access to the site is over unpaved roads used primarily for agriculture, oil and gas vehicles.

Topography: The topography at the site slopes gradually from elevation 5,910 ft amsl to 5,890 ft amsl to the east. There are no major watercourses on the site.

Geology and Hydrology: The site is located above the High Plains Formation underlain by Pierre Shale at approximately 5,700 feet thick which is dominant throughout the region. The primary aquifer includes the High Plains Aquifer, consisting of the Ogallala, Arikaree, and White River formations, which total approximately 1,480 feet thick. The Ogallala is the first instance of usable groundwater at approximately 160 to 300 feet below the site.

Climatological Data

According to the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) map, the average annual precipitation is 15.17 inches. The climate survey for Cheyenne, WY (closest weather station to site) according to the Western Regional Climate Center (WRCC) is offered in the following table (re-created from WRCC information).

Table 1. Climate Survey, Cheyenne, WY

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Max. Temperature (F)	32.6	36.1	47.6	58.7	68.3	79.3	86.3	83.6	73.9	60.7	43.0	33.8	58.7
Average Min. Temperature (F)	5.2	8.9	20.7	27.9	34.7	41.5	48.1	46.4	37.9	27.6	16.8	7.4	26.9
Average Total Precipitation (in.)	0.44	0.39	0.51	0.87	1.44	0.85	1.16	0.92	1.19	1.35	0.66	0.51	10.29
Average Total Snowfall (in.)	8.4	5.4	5.3	1.9	0.2	0.0	0.0	0.0	0.0	2.0	6.1	8.8	38.2

Design Evaporation Data

The National Weather Service developed an isopleths map of the Free Water Surface Evaporation (shallow lake evaporation) based on 24 years of data. The free water surface evaporation rate is the amount expected to evaporate from the disposal ponds, which is 45 inches per year. Approximately 35 inches of that rate occurs from May to October. The remaining 10 inches would evaporate from November to April. This is based on a water containment that is not lined with black HDPE.

Project Location – Cisco, UT

Danish Flats, Utah

The project is located in an arid region of eastern Utah in the area known as Danish Flat, which is situated at approximately 4,610 feet above mean sea level (amsl). The site is located in Grand County approximately 3.5 miles north of Interstate 70 interchange exit number 214, and approximately 43 miles west of the Utah-Colorado state line.

Background and Site Conditions

The ground surface is privately owned land primarily used for stock grazing and oil and gas transmission piping. No residences are located within 10 miles of the site. Access to the site is over unpaved roads used primarily for oil and gas vehicles.

Topography: The topography at the site slopes gradually from elevation 4,615 ft amsl to 4,600 ft amsl to the southeast. There are no major watercourses on the site.

Geology and Hydrology: The site is located in the Mancos Shale lowland area including the Greater Cisco area. The Mancos Shale Formation is the predominant outcrop in this area. Due to the preponderance of fine-grained sediments and water soluble minerals found in this formation, it does not usually contain any fresh water. Groundwater that comes in contact with the Mancos Shale Formation almost always contains high levels of dissolved solids. Groundwater is usually limited to alluvial deposits along streams and drainages or to sandstone units, some of which are very localized with low recharge rates. Wells in the area are usually drilled with air with little or no water encountered until the Dakota Formation is penetrated (Hunt et al. 1996).

The underlying Mancos shale is a dark grey to black soft shale with sandstone beds at various horizons. The maximum thickness of the Mancos shale is approximately 900 to 1,000 feet. The Mancos shale is considered a confining unit and is a thick barrier to vertical and lateral groundwater flow. Below the Mancos shale is the lower to upper Cretaceous Dakota Sandstone, which are a yellow-brown and gray friable to quartzitic sandstone and conglomerate sandstone and interbedded gray to black carbonaceous shale with occasional lenticular coal beds (Cashion et al. Map I-736). The Dakota Sandstone is considered to be the first aquifer in the area.

Climatological Data

According to the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) map, the average annual precipitation is six inches. The climate survey for Cisco, UT (closest weather station to site) from 1952 to 1967 according to the Western Regional Climate Center (WRCC) is offered in the following table (re-created from WRCC information).

Table 2. Climate Survey, Cisco, UT

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Avg. Max Temp (F)	37.2	45.7	56.6	68.7	80.3	91.8	98.7	94.3	85.5	72.5	53.4	40.2	68.7
Avg. Min Temp (F)	8.8	17.7	24.0	33.5	43.7	52.1	60.7	58.4	47.3	35.2	22.5	12.5	34.7
Avg. Total Precip. (in.)	0.48	0.50	0.52	0.61	0.61	0.26	0.37	1.03	0.80	0.86	0.63	0.43	7.11
Avg. Total Snow (in.)	4.3	2.1	1.1	0.3	0.0	0.0	0.0	0.0	0.0	0.2	0.9	2.1	11.0

Design Evaporation Data

The National Weather Service developed an isopleths map of the Free Water Surface Evaporation (shallow lake evaporation) based on 24 years of data. The free water surface evaporation rate is the amount expected to evaporate from the disposal ponds, which is 50 inches per year. Approximately 35 inches of that rate occurs from May to October. The remaining 15 inches would evaporate from November to April. This is based on a water containment that is not lined with black HDPE.

Project Location – Dad, WY

Southern Cross, Wyoming

The project is located in an arid region of southwest Wyoming in the area known as Mexican Flat, which is situated at approximately 6,540 feet above mean sea level (amsl). The site is located in Carbon County approximately 5 miles west of Wyoming State Highway 789, approximately 30 miles south of the intersection of highway 789 and Interstate 80 at Wamsutter, and approximately 22 miles north of Baggs, Wyoming.

Background and Site Conditions

The ground surface is privately owned land primarily used for stock grazing and oil and gas transmission piping. No residences are located within 20 miles of the site. Access to the site is over unpaved roads used primarily for oil and gas vehicles.

Topography: The topography at the site slopes gradually from elevation 6,546 ft amsl to 6,536 ft amsl to the northeast. There are no major watercourses on the site.

Geology and Hydrology: The site is located in the Wasatch/Claron Formation. The Claron Formation also referred to as the "Pink Cliffs," and forms the highest "step" of the Grand Staircase. This formation is also known as the Wasatch Formation. The site is located in the Cathedral Bluffs Tongue of the Wasatch Formation. This outcropping consists of claystone, mudstone and sandstone. The field investigation and laboratory analysis confirmed the published description to the depth of the deepest boring.

The only known groundwater is at a depth of approximately 700 feet based on a recent boring by Devon Energy. This boring is on the north side of the property.

Climatological Data

According to the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) map, the average annual precipitation ranges between ten and twelve inches. The climate survey for Baggs, WY (the closest weather station to site) from 1948 to 2007 according to the Western Regional Climate Center (WRCC) is offered in the following tables (re-created from WRCC information).

Table 3. Climate Survey, Baggs, WY

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Max. Temperature (F)	32.6	36.1	47.6	58.7	68.3	79.3	86.3	83.6	73.9	60.7	43.0	33.8	58.7
Average Min. Temperature (F)	5.2	8.9	20.7	27.9	34.7	41.5	48.1	46.4	37.9	27.6	16.8	7.4	26.9
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2. PROJECT DETAILS

Purpose

The main purpose of the projects is to evaporate the production water and flow back water as quickly as possible while maintaining environmental controls and containment. The projects were planned and built in order to service the oil and gas industry for the disposal of production water and flow back water from oil and gas production in the service areas local to each facility location.

Several water disposal options exist, including reinjection wells, frac injection, treatment for surface discharge, and evaporation. The evaporation technology was chosen for these projects due to the ideal site conditions for evaporation, including low precipitation, windy conditions, high ambient temperatures and sun. Other factors that made the project sites ideal include the following; little or no residences within several miles of the site (other than consenting land owners), easy access to/from a major highway, long distance to open water at several miles, deep groundwater, and impermeable formations below the sites.

Selection of Technology

To enhance the evaporative quality of the projects and to adequately contain the brine water, the top layer of the pond lining needs to be a durable long-lasting product that is cost-effective and helps to enhance evaporation while being acceptable to the regulatory agencies involved. Some of the liner technologies considered include compacted clay, geosynthetic clay liner (GCL), polyvinyl chloride (PVC), polypropylene (PPE), and high density polyethylene (HDPE). While several lining technologies exist and are allowed by the regulatory agencies, the HDPE liner was chosen for the top layer for several reasons, including, durability, resistance to ultraviolet (UV) degradation, chemical resistance, black color, and ease of construction.

HDPE is designed to be the top layer of ponds and be exposed to the elements (sun, freeze/thaw, and physical impact), therefore, the material needs to be resistant to UV degradation and be durable. The addition of the proper amount of high quality carbon black to the geomembrane during manufacturing is universally accepted as being resistant to significant deterioration caused by weathering. In addition to high quality carbon black, highly effective chemical UV stabilizers further extend the life of the liner. These additives absorb incident radiation and/or terminate free radical production, thus protecting the HDPE against thermal degradation and possible chemical reactions with surrounding materials. Other factors that affect the potential UV resistance of a material include average density, density range or dispersion, chemical stabilizer system, catalyst type and amount of residue, copolymer type, combined chemical exposures, and failure criteria (GSE 2003). HDPE was chosen for this application due to these characteristics.

Implementation

To enhance the evaporative quality of each facility, and to adequately contain the brine water, high density polyethylene (HDPE) was chosen as the top layer. The top or primary liner was designed and constructed with 60-mil thick textured HDPE to help ensure a durable long-lasting containment. The liner was textured to increase the safety factor for personnel using the facility (i.e. the textured surface increases traction and gripping to enable easier egress in case of someone falling into the pond.

The facilities have been or are currently being constructed. The facilities consist of the following components (refer to Figures 1 and 2 for details):

- Access road and truck off-loading pad
- Piping and valves
- Acceptance Pits (vaults) or advanced oil/water separation equipment
- Sludge Pond covered with bird control netting or no sludge pond if oil/water separation equipment used
- Evaporation ponds (constructed or planned):
    - Silo Field, WY has 3 ponds out of the permitted 10 ponds in the process of being built at approx. 5.2 acres each and 25 feet deep (double lined HDPE with leak detection in between the liners)
    - Danish Flats, UT has 14 ponds built at approx. 5.2 acres each and are 12 or 22 feet deep (single HDPE liner underlain by compacted clay layer)
    - Southern Cross, WY has 4 ponds built at approx. 5.2 acres each and are 12 feet deep (double lined HDPE with leak detection in between the liners)

General: Production water and flow back water is delivered to the sites via tanker trucks from well sites located within the geographic area local to each site, and depends on transportation costs and disposal fees when compared to other alternatives for water disposal in the area. The tanker trucks are off-loaded and the water is sent through a treatment process, including separation vaults, gun-barrel tanks, or state-of-the art equipment.

The Danish Flats facility's plan view is shown on the following Figure 2. The operation units include one set of 14,000 gallon three-stage concrete receiving tanks, a sludge pond, and a series of five-acre evaporation ponds. All of the structures are connected via gravity or force-main fed via an underground piping system. The Southern Cross and Silo Field facilities process is similar to the Danish Flats layout.

Pond Inlet: Various methods exist for the separation of the oil and water prior to placement in the ponds for evaporation, and the proper removal of the oil from the water will dictate whether or not the ponds should be covered with bird control netting.

The incoming water at the Danish Flats and Southern Cross sites flows through the three-stage concrete settling tank systems and pretreatment tanks (Danish Flats) or one of the three-stage concrete settling tank systems (Southern Cross) and each site uses a the sludge pond before entering the evaporation ponds. The pre-treatment facilities and the evaporation ponds have been designed to follow the topography, allowing for gravity flow throughout the system, and the Danish Flats site is equipped with force-mains to allow pumping of the water from the lower Phase 1 ponds to the upper Phase 2 ponds.

Volatile organic compound (VOC) emissions from the separation equipment and ancillary tankage are controlled to maintain air quality.

Shut-off valves have been installed on the crossover piping to allow for proper flow management. If necessary, portable gasoline powered pumps will be used to transfer liquid to ponds that are not in the gravity flow line or to empty a pond for maintenance or liner repair.

Slope Design: At Danish Flats and Southern Cross the sludge ponds and evaporation ponds have an interior slope of 3 horizontal to 1 vertical, and a maximum exterior slope of 2 to 1.

At Silo Field, the pond interior and exterior slopes were designed with 4 to 1 slopes.

The HDPE chosen has a textured surface, which will increase the safety characteristics of the facility by making it easier to walk on, especially on the interior slopes.

Berm Design: Surface water will not be allowed to enter the ponds because the constructed berms are several feet higher than the surrounding ground surface and also diversion and control ditches are used to direct the run-on and run-off for minimizing impact of storm water. The interior berm walls are covered with a protective layer of 60-mil high density polyethylene (HDPE). The HDPE will provide erosion control. The area between the evaporation ponds has been covered with HDPE or compacted clay to prevent erosion, control dust and enhance evaporation. The exterior sides of the berm have been seeded as necessary.

Leak Detection System: As described in the geology/hydrology section of this paper, each site is underlain by impermeable layers of shale or clay, including at Danish Flats approximately 1,200 feet thick of Mancos Shale, and at Southern Cross the Wasatch Formation. The first usable aquifers for human use are below these formations for these sites. The geological investigations did not detect perched groundwater.

At the Silo Field site the first usable aquifer will be protected by the three layers of liner in the pond, as well as natural clay aquitards below the pond bottoms at approximately 30 and 60 feet below the ground surface, which also includes the leak detection under the primary liner.

In addition to the ideal natural conditions at each site, a 60-mil HDPE liner has been installed as the top layer in all of the ponds. The pond floors slope toward sumps that are fitted with a riser monitoring pipe and leak detection equipment.

The leak detection system is inspected and data recorded as required. A summary of the inspections are reported to the regulatory agencies as needed. Liquid from the sump can be pumped back into the pond, if excessive amounts accumulate then specific protocols for repairing the liner are required if the volume of the leak exceeds certain thresholds.

Livestock/Wildlife Protection Measures: The entire facility area at each site has been fenced and gated to help prevent cattle or other animals from entering. Since the sludge ponds could have oily material on the surface, netting has been used to deter the entry of birds or other wildlife at the Danish Flats and Southern Cross sites.

Capacity: The volume of water able to be stored for evaporation in the ponds is as follows:

- Silo Field – Ponds 1 -3 are 25 feet deep of water holding capacity and nearly 582,000 barrels each for a total water holding capacity of approximately 1,746,000 barrels.
- Danish Flats - Ponds 1 through 8 are 12 feet of water holding depth and nearly 240,000 barrels each (at 42 gallons per barrel) for a total capacity of approximately 2,000,000 barrels. Ponds 9 through 13 are 22 feet of water holding depth at Danish Flats and nearly 632,000 barrels each for a total capacity of 3,160,000 barrels.
- Southern Cross - Ponds 1 through 4 are 12 feet of water holding depth and nearly 240,000 barrels for a total capacity of approximately 960,000 barrels.

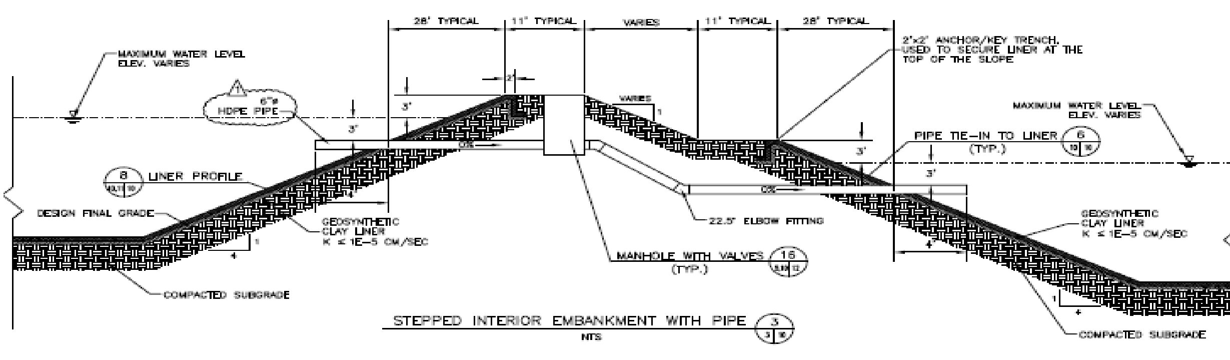


Figure 1. Silo Field Pond Liner Details

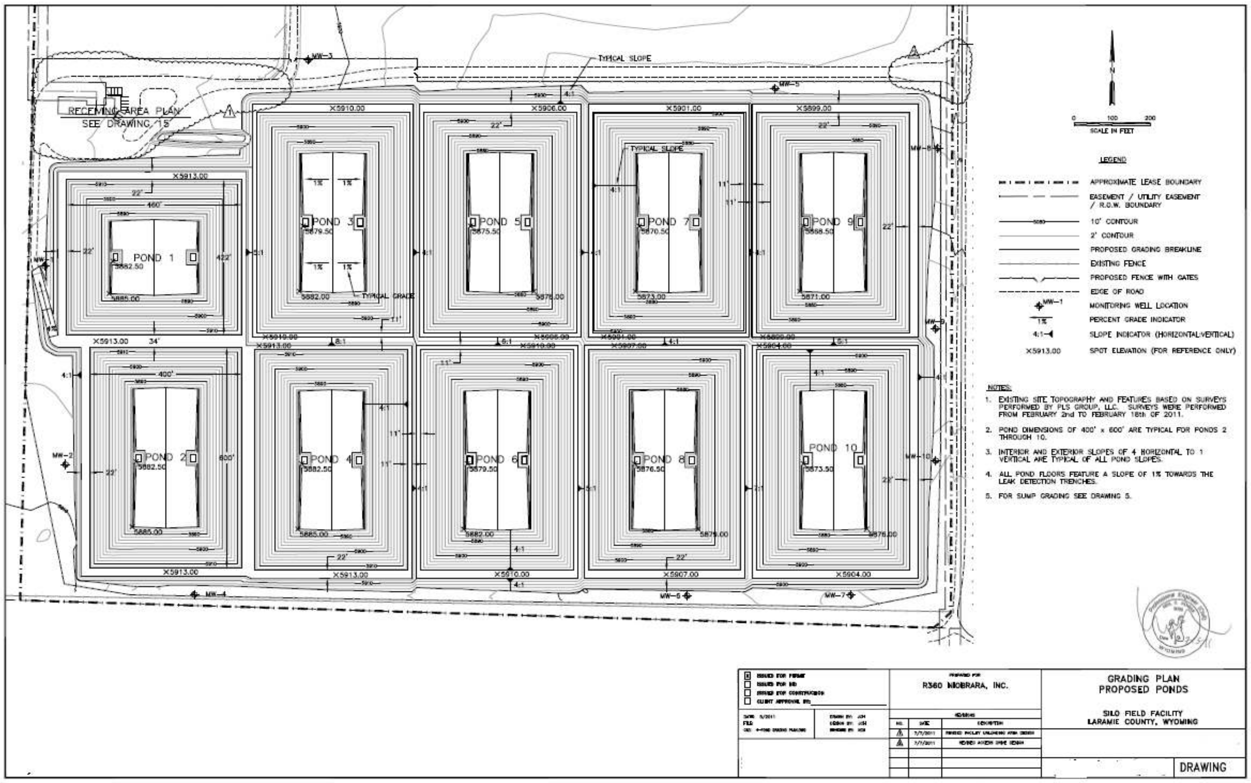


Figure 2. Silo Field - Facility Design Plan View – Permit Approved Layout

Figure 3. Aerial Photo of Completed Project at Danish Flats, UT

The partially completed and partially operational project at Danish Flats was photographed from the air on June 29, 2009 and is shown above. The water was distributed from the sludge pond to the Ponds 1 through 12, which appear as “black”. The Ponds 13 appears to have “brownish” water, which includes some construction water is shown in the background and was not yet approved for water disposal at the time of the photography, but has since been put into operation. Currently, 14 evaporation ponds are operational at Danish Flats.

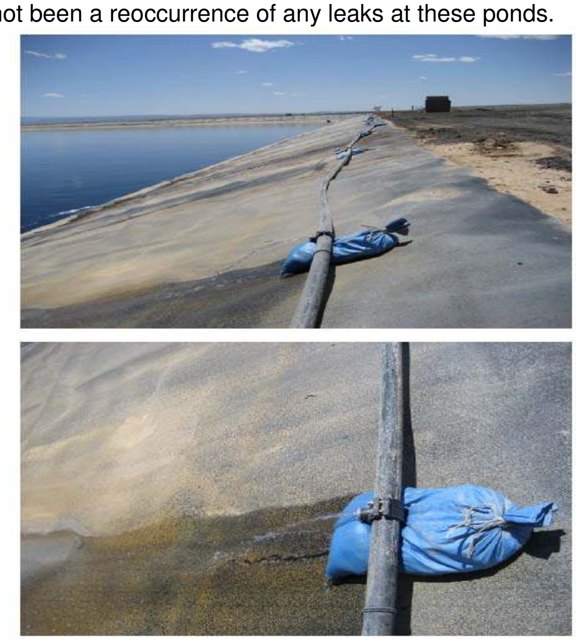
Operational Data

At Danish Flats they have experienced various quantities of water deliveries ranging from 10,000 barrels to 35,000 barrels per day. Each barrel is equal to 42 gallons. The water is moved from the off-loading area through the sludge pond and to the evaporation ponds by gravity or via force main for distribution to Phase 2. Each pond at Danish Flats, Utah has a free board requirement of 2 feet, and each pond for the projects in Wyoming at Southern Cross and Silo Field has a free board requirement of 3 feet.

When an individual evaporation pond was brought on-line, such as Ponds 5 through 8 at Danish Flats, and the water was allowed to flow into the empty pond lined with HDPE, the water was observed as “disappearing” due to the evaporative nature of the HDPE when in combination with the hot sun and arid climate in Utah in July and August.

In Cisco, UT in July and August the ambient air temperatures often exceeds 100 degrees Fahrenheit and the wind normally blows to some extent. The actual evaporation encountered during the months of July and August 2008 at the site was measured to be approximately 15 and 18 inches per day, respectively. The facility operators observed very favorable evaporation of the water and measured the total evaporation for the year 2008 above the estimate of 50 inches for approximately 6 months of operation. In year 2009, the Danish Flats facility was measured to have 60 inches of evaporation, which took place mostly in the months from April 1 to October 31, and again in year 2010 the evaporation total has exceeded 60 inches over the entire water surface of the ponds. The deeper ponds at Danish Flats experienced an approximately 30 percent lower evaporation rate due to the deeper water depth, therefore, the entire depth of water was not able to be achieve warmer temperatures as did the shallower ponds.

Each site is equipped or designed with leak detection systems that are monitored on a monthly basis or continuously, depending on the equipment chosen. Two ponds at Danish Flats were adversely affected by shifting ice at the HDPE pipe boots when the liquid level in the ponds were adjusted, which resulted in leaks at the pipe boots. The liner was easily repaired and there has not been a reoccurrence of any leaks at these ponds.



Figures 4 and 5. Weep system to enhance evaporation

In an effort to increase evaporation with low costs in mind, a “weep” system was added to the allow water to flow and fan out over the surface of the HDPE liner that is above the water line. This system utilizes the exposed HDPE liner to increase evaporation by using the heat generated from the exposed HDPE liner in combination with the increased surface area of the water fanning out over the liner. Please refer to the photographs of the “weep” system. This system has been used at Silo Field, Southern Cross, and Danish Flats.

3. CONCLUSIONS

The use of HDPE as the primary liner in the ponds appears to be favorably enhancing the evaporation of the water. At Danish Flats, the estimate of 50 inches of evaporation per year was far exceeded given the 33 inches of evaporation experienced in only July and August 2008, which may have totaled 70 inches for 2008. In years 2009 and 2010, the evaporation rate was over 60 inches. In 2012, the evaporation rate was 42 inches from May through August. The “weep” system was an enhancement to increase evaporation, which was not quantitatively measurable, but may have been a factor in the total evaporation. The deeper ponds at Danish Flats experienced approximately a 30 percent lower evaporation rate due to cooler water at depth. Similarly, the actual evaporation experienced at the Southern Cross project was also more than the pan evaporation estimate based on ponds without the HDPE liner effects, including the increase in evaporation from the estimate of 45 inches per year to nearly 55 inches.

The evaporation rates at Silo Field has been enhanced with the use of the HDPE liner as the top layer and the use of the “weep” system along the exposed liner too.

The durability and resistance to UV degradation due to the proper amount of carbon black in the geomembrane and other factors as discussed above are the major reasons for the use of the HDPE geomembrane liner as the top layer. The increase with the rate of evaporation due to the black color of the HDPE has been a great benefit and in combination with the “weep” system has realized an increase with the total evaporation at each facility.

Some of the liner was installed during the summer months and due to the expansion and contraction of the liner with ambient air temperature gradients, the anchor trenches were only filled during the coolest part of the day to reduce bridging.

The leak detection system is used to capture leaks through the primary liner, which worked as designed at the Danish Flats site when a leak was propagated due to ice on the water and the level in the ponds changing which resulted in the ice grabbing onto the pipe and pulling on the pipe boot. The liner was repaired and the leak did not appear again.

An existing study was conducted on an HDPE liner installed at a site in Colorado after 20 years of service where the liner was not buried and exposed to weathering, UV light and cooling tower blow-down water. The material was tested for various properties and was found to have no significant reduction in the primary physical properties of the HDPE (Ivy 2002).

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