High Density Polyethylene (HDPE) Lined Produced/Flow-back Water Evaporation Ponds

Neil C. Nowak[1], John Briest[2]

[1]Weaver Boos Consultants, LLC, 7340 East Caley Ave., Centennial, CO, 80111, USA, nnowak@weaverboos.com
[2]Weaver Boos Consultants, LLC, 7340 East Caley Ave., Centennial, CO, 80111, USA, jbriest@weaverboos.com

Abstract The problem to be solved is the disposal of millions of liters (gallons) of production 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. One such technology used is the evaporation of the water in lined containment ponds after separation and removal of the hydrocarbon component from the water. Three projects in Cisco, Utah; Dad, Wyoming; and Cheyenne, Wyoming as case studies were designed to evaporate water in a series of geomembrane lined ponds. The projects use high density polyethylene (HDPE) as the top layer to help protect the groundwater, and enhance evaporation.

Keywords Evaporation Ponds, Evaporation, Impoundments, Produced Water, Geomembrane

Introduction

The three projects are complete and have been operational for a number of years. 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 liner 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 layer in the ponds is black HDPE, which creates a hot surface hence evaporation is enhanced,
- HDPE liner was chosen to protect the surface and groundwaters of the area; it is durable and chemical resistant.

Also, these sites are favorable due to other factors, such as, remoteness from populated areas, accessible from highways for trucks, far depth to groundwater, and geology.

The projects provide 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 recycling or treatment facilities. The regulatory agencies are favorable to these type commercial facilities for centralization and protection of the state's waters. The facilities protect surface waters in the area due to the liner, large capacity of the ponds, and the freeboard that is above the maximum water level, which is 0.61 m (2 ft; Utah) and 0.91 m (3 ft; Wyoming). Also, secondary containment is used in case of catastrophic berm failure in Utah.

Project Location – Silo Field, Cheyenne, WY

The project is located in a semi-arid region of southeastern Wyoming in Laramie County, which is situated at approximately 1,738 m (5,900 ft) above mean sea level (amsl). The site is located above the High Plains Formation underlain by Pierre Shale at approximately 1,737 m (5,700 ft) 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 451 m (1,480 ft) thick. The Ogallala is the first instance of usable groundwater at approximately 48.8 to 91.4 m (160 to 300 ft) 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 38.1 cm (15.17 in). 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 114.3 cm (45 in) per year. Approximately 88.9 cm (35 in) of that rate occurs from May to October. The remaining 25.4 cm (10 in) would evaporate from November to April. This is based on a water containment that is not lined with black HDPE.

Project Location – Danish Flats, Cisco, UT

The project is located in an arid region of eastern Utah in the area known as Danish Flat, which is situated at approximately 1,405 m (4,610 ft) amsl. 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 and little or no water encountered until the Dakota Formation is penetrated (Hunt 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 274.3 to 304.8 m (900 to 1,000 ft). The Mancos shale is considered a confining unit and provides 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 Map I-736). The Dakota Sandstone is considered to be the first encountered or shallowest 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 15.2 cm (6 in). 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 127 cm (50 in) per year. Approximately 88.9 cm (35 in) of that rate occurs from May to October. The remaining 38.1 cm (15 in) would evaporate from November to April. This is based on a water containment that is not lined with black HDPE.

Project Location – Southern Cross, Dad, WY

The project is located in a semi-arid region of southwest Wyoming in the area known as Mexican Flat, which is situated at approximately 1,993 m (6,540 ft) amsl. 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 213.4 m (700 ft) based on a recent boring 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 25.4 and 30.5 cm (10 and 12 in). 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 114.3 cm (45 in) per year. Approximately 88.9 cm (35 in) of that rate occurs from May to October. The remaining 38.1 cm (15 in) would evaporate from November to April. This is based on a water containment that is not lined with black HDPE.

Methods

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. 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 solar radiation. Other factors that made the project sites ideal include the following; little or no residences within several kilometers (miles) of the site (other than consenting land owners), easy access to/from a major highway, long distance to open water at several kilometers (miles), deep groundwater, and relatively impermeable formations below the sites.

Selection of Technology: To enhance the evaporative quality of the projects and to adequately contain the production water, the primary/top layer of the pond lining needs to be a durable long-lasting material 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 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.

The design properties of HDPE make it acceptable to be the primary/top layer of ponds. This material can 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 making the HDPE more 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, which is estimated to be approximately 20 years. These additives absorb incident radiation as well as 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). 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 power plant 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).

To enhance the evaporative quality (*i.e.* pan rates versus actual) of each facility, and to adequately contain the brine water, high density polyethylene (HDPE) was chosen as the top layer. The top/primary liner was designed with 1.5 mm (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 generally consist of the following components:

- 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 at Danish Flats and Southern Cross, or no sludge pond, if advanced oil/water separation equipment used at Silo Field,
- Evaporation ponds (constructed or planned):

1. Silo Field, WY has 3 ponds out of the permitted 10 ponds in the process of being built at approx. 2.1 ha (5.2 ac) each and 7.6 m (25 ft) deep (double lined HDPE with leak detection in between the liners) with a water holding capacity and nearly 922 ML (24 Mgal) each for a total water holding capacity of approximately 277 ML (73 Mgal).
2. Danish Flats, UT has 14 ponds built at approx. 2.1 ha (5.2 ac) each (single HDPE liner underlain by compacted clay layer) shallow 3.7 m (12 ft) deep ponds 1–8 with nearly 38.2 ML (10 Mgal) each for a total capacity of approximately 317.9 ML (84 Mgal). Ponds 9 through 13 are 6.7 m (22 ft) of water holding depth and nearly 100.5 ML (26.5 Mgal) each for a total capacity of 502.4 ML (132.7 Mgal).
3. Southern Cross, WY has 4 ponds built at approx. 2.1 ha (5.2 ac) each and are 3.7 m (12 ft) deep (double lined HDPE with leak detection in between the liners) have 3.7 m (12 ft) of water holding depth and nearly 38.2 ML (10 Mgal) for a total capacity of approximately 152.6 ML (40.3 Mgal).

General Production water and flow-back water is delivered to the facilities via tanker trucks from well sites located within the geographic area local to each disposal facility, and dilivery 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 an oil/water separation process, including separation vaults, gun-barrel tanks, or state-of-the practice treatment equipment. Shut-off valves have been installed on the crossover piping to allow for proper flow management. If necessary, portable gasoline powered pumps are used to transfer liquid to ponds that are not in the gravity flow line or to empty a pond for maintenance or liner repair. 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 varying slopes are due to soil subgrade stability based on soil geotechnical characteristics.

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. Also diversion and control ditches are used to direct the run-on and control run-off for minimizing impact of storm water. The interior berm walls are covered with the liner system. The HDPE provides erosion control.

Leak Detection System Each site has a 1.5 mm (60 mil) thick HDPE primary liner 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 to monitor leaks through the primary liner. Double liners are installed at Silo Field and Southern Cross, and a single primary liner at Danish Flats. The leak detection system is inspected monthly and data recorded as required. A summary of the inspections are reported to the regulatory agencies on an annual basis, unless excessive water quantities in the leak sump indicate large leaks(s). Liquid from the sump can be pumped back into the pond, if excessive amounts accumulate then specific protocols for repairing the liner in place (*i.e.* the ponds need to be emptied to point of the liner leak) are required if the volume of the leak exceeds certain thresholds, such as, greater than 3,785 (L/d)/ha (400 (gal/d)/ac) of liner.

Project Results As an example, the Danish Flats data is presented in this results section. The partially completed and partially operational project at Danish Flats was photographed from the air on June 29, 2009 and is shown in Fig. 1 above. The water is distributed from the truck offloading area through the sludge pond to the evaporation Ponds 1 through 13, which appear as "black". Currently, 14 evaporation ponds are operational at Danish Flats.

In Cisco, UT in July and August the ambient air temperatures often exceeds 37.8 °C (100 °F) and it is the windy. The actual evaporation during the months of July and August 2008 at the site was estimated to be approximately 38.1 and 45.7 cm (15 and 18 in) per month, respectively. The facility operators observed very favorable evaporation of the water and measured the total evaporation for the year 2008 above the estimate of 127 cm (50 in) during approximately 6 months of operation. In year 2009, the Danish Flats facility was estimated to have 152.4 cm (60 in) 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 152.4 cm (60 in) over the entire water surface of the ponds. The deeper ponds at Danish Flats experienced an approximately 30 % lower evaporation rate due to the deeper water depth and the entire depth of water not able to be achieve warmer temperatures as did the shallower ponds. The water level in the ponds was estimated by site personnel with tape measure and the change in water level recorded over time.

In an effort to increase evaporation with low costs in mind at Danish Flats and Southern Cross, a "weep" system was added to the allow pumped water from the ponds to flow and fan out over the surface of the HDPE liner that is above the water line (*i.e.* within the freeboard liner area on the berms). 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 as sheet-flow over the liner.

Additional: Some of the liner was installed during the summer months and due to the expansion and contraction of the liner with am-

***Fig. 1**. Aerial Photo of Completed Project at Danish Flats, UT*

bient 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.

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 127 cm (50 in) of evaporation per year was far exceeded given the 83.8 cm (33 in) of evaporation experienced in only July and August 2008, which may have totaled 177.8 cm (70 in) for 2008. In years 2009 and 2010, the evaporation rate was over 152.4 cm (60 in). In 2012, the evaporation rate was 106.7 cm (42 in) from May through August.

The "weep" system was an enhancement to increase evaporation, which was not quantitatively measurable, but was a factor with increasing the total evaporation. The deeper ponds at Danish Flats experienced approximately a 30 % 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 114.3 cm (45 in) per year to nearly 139.7 cm (55 in). It is anticipated that the evaporation rates at Silo Field will also be 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.

Acknowledgments

Thank you to R360 Environmental Solutions/ Waste Connections, Danish Flats Environmental Services, and Southern Cross Environmental Services for the use of their projects in this paper and to John Heap of Colorado Lining, Inc. who provided his installation expertise and also performed the construction of the HDPE liners at the ponds in field, which all are performing exceptionally well and without leaks due to construction.

References

Cashion WB. Geologic and Structure Map of the Grand Junction Quadrangle, Colorado and Utah, USGS Miscellaneous Geologic Investigations, Map I-736.

Gundle/SLT Environmental, Inc (GSE) (2003) Technical Note – HDPE, UV Resistance for GSE Geomembranes

Hunt GL (1996) Environmental Handbook, Environmental Regulations for the Oil & Gas Exploration and Production Industry.

Ivy N (2002) HDPE geomembrane after 20 years of service, GFR Magazine June/July 2002.