HDPE GEOMEMBRANE APPLICATIONS IN HIGH ALTITUDE REGION

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ABSTRACT

Geomembrane liner has been widely accepted as standard components of geosynthetic lining systems in many containment facilities. Among the plastic materials utilized for geomembranes, high density polyethylene (HDPE) geomembranes are the most widely used geosynthetic lining materials adopted for various containments applications including solid waste landfill, liquid containment and reservoirs, mining, etc. This is mainly attributed to its superior hydraulic and mechanical properties in combination with its very low permeable characteristics, greater chemical resistance and ultraviolet (UV) light degradation resistances. HDPE geomembranes serve as very low permeability barriers to stop or limit the migration of liquids and/or chemicals out of the containment area.

The paper presents the application of impervious HDPE geomembrane adopted in an industrial brine lagoon and a chemical solution pond of a mine site in Northern China and Mongolia at elevation altitude 2,600m and 1,600m, respectively. HDPE geomembrane with exceptional flexibility and outstanding mechanical properties and high durability provides an effective and economical solution as liquid containment and leakage prevention to the chemical pond. This paper also discusses the characteristic of the High Density Polyethylene (HDPE) geomembrane as waterproofing elements. Lastly, geomembrane installation under the extreme environment and related issues are discussed.

Keywords: Polyethylene, geomembrane, liquid containment, chemical solution pond, UV stability

INTRODUCTION

Geomembrane are flexible synthetic liners with very low effective permeability (less than $1x10^{-12}$ cm/sec) manufactured from base resins including high density polyethylene (HDPE), very flexible polyethylene (VFPE), chlorosulfonated polyethylene (CSPE, or Hypalon), plasticized polyvinyl chloride (PVC) and flexible polypropylene (fPP). Among the plastic materials utilized for geomembranes purpose, HDPE geomembranes, with its superior hydraulic and mechanical properties in combination with its very low permeable characteristics (hydraulic conductivity of less than $1x10^{-12}$ cm/sec), high longevity, outstanding chemical resistance and ultraviolet (UV) light degradation resistance, are the most widely adopted as geosynthetic lining materials for waste containments and other environmental engineering applications such as mining leach pads and tailing ponds. HDPE geomembranes serve as impermeable barriers to stop or limit the migration of liquids or water out of the containments.

US Environmental Protection Agency (EPA) regulations have been promulgated for 2 categories of waste disposal: (i) Hazardous Waste – The Resource Conservation and Recovery Act (RCRA) Subtitle C [as amended by Hazardous and Solid Waste Amendments of 1984], 40CFR 264; (ii) Municipal Solid Waste - The Resource Conservation and Recovery Act (RCRA) Subtitle D, 40 CFR 257 and 258. Figure 1 shows the cross section of typical composite liner systems used in the modern waste disposal facilities. The base liner system is designed to contain any leachate, detect any leakage, provide for the prompt removal of harmful liquids and avoid groundwater contamination.

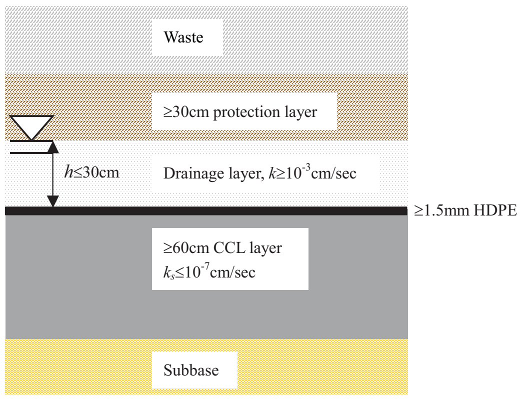

Fig. 1 A typical composite liner system for MSW landfill (US EPA RCRA Subtitle D)

The use of geosynthetics in mining is a function of economics as the mining industry, unlike landfills and other public projects, cannot pass its costs to the consumer (Van Dirk, Z. et al. 1997). In the United States, the landfill and hazardous waste industries are regulated through federal statutes and regulations. Regulations promulgated under Subtitle C and D of the Resource Conservation and Recovery Act of 1976 and subsequent amendments control, to a large extent, the design details and use of geosynthetics in solid- and hazardous-waste landfills. The mining industry has adopted much of this information as background because such prescriptive federal regulations do not exist for its applications. The state regulations passed under the Clean Water Act (1977) and other state mine reclamation acts control the design considerations for geosynthetics use in mining applications and most of them are based on performance rather than prescriptive criteria. This therefore provides engineers the flexibility to develop innovative designs and incorporate new materials when they become available. Environmental issues typically addressed in the mining industry deal with the protection of groundwater and surface water resources. Containment is therefore the most important consideration. For mining, various chemicals are used to extract metals from the minerals via commonly used hydrometallurgical process. Cyanide solutions are used as lixiviant for gold and silver, while sulfuric acid is adopted for copper mining. Geosynthetics liners have been significantly used in the mining industry since about 1970 for lining solution and evaporation ponds, tailing impoundments and heap leach pads (Breitenbach et al. 2006).

Some of the developing countries in Asia have adopted the US and European experiences by introducing the environmental regulations and guidelines on waste containments design as to reduce the environment impacts and to improve the environmental quality of their nations. In 1997, China published the "Standard for Protection Control of Municipal Solid Waste" (GB16889-1997), and subsequently the corresponding technical specifications (CJJ 17-2004, CJJ 112-2007 and CJJ113-2007) to stipulate the construction and operations requirements of waste containment facilities (Ministry of Construction, China). Many liquid containments and chemical ponds are designed in line with the US EPA's recommendation and /or adopted most of the information as background as such prescriptive federal regulations do not exist for their applications.

This paper presents the applications of HDPE geomembrane as base liner system for salt evaporation pond, mining heap leach and chemical solution ponds at high altitude in Northern China and Mongolia. HDPE geomembranes were introduced to these applications with the objectives: (i) to control and prevent seepage and leakage of liquids, (ii) to accommodate for potentially large ground settlement with the application of flexible geosynthetic membrane that exhibits outstanding mechanical properties, (iii) a cost-effective solution to the leakage and erosion problems due to its low permeation, durability and outstanding ultraviolet light resistance, (iv) an effective solution based on the proven track record in these types of applications or of similarities for decades.

POLYETHYLENE GEOMEMBRANE IN LIQUID CONTAINMENTS

With the ever-growing of population, the demand for clean water and aesthetic benefit increases significantly, hence the demand for secure water containment is growing. Until the mid of 1980s, the most common liner was a conventional low impermeable clay layer, varying in thickness and constructed by heavy mobile machineries and equipment. Geomembranes provide an alternative lining system to clay liners as the synthetic liners are generally more economical, quicker to install, and out-perform clay liners that may desiccate and crack over time due to the temperature effects. Geomembranes either alone or in conjunction with a concrete /brick covers can significantly increase the effectiveness of liquid containment. Not only erosion can be mitigated, but seepage and leakage problem shall be greatly reduced as compared to the conventional concrete lining system. It provides a cost-effective and quality method of water-proofing the earthen water impoundments with aesthetic benefits. In addition, geotextiles are sometimes recommended to be lain underneath the geomembrane to serve as cushion and protection to the rocky or uneven and protruded subgrade, when necessary. Narejo et al. (1996) proposed design methodology for the protection of geomembrane from puncture using nonwoven needlepunched geotextiles, which has been commonly served as reference by engineers today. Abramento et al. (2006) reported on the necessity of geotextile as mechanical protection of HDPE geomembranes in the Itiquira Dam Channel, which allowed for a rapid installation process with great effectiveness. Youngblood and Ng (2008) reported that the application of polyethylene geomembrane in the aquaculture ponds is widely accepted as a cost effective lining solution. The benefits of using polyethylene (includes HDPE and LLDPE) geomembranes in aquaculture applications includes lower operational and maintenance cost; maintain dissolved oxygen; secure water containment and enhanced water quality control; reduce risk of diseases; erosion control; offer the most durable containment at the most economical cost and speed the turn-around time between crops.

Today the most widely used lining systems are HDPE geomembranes, which is produced in various thicknesses and textured surfaces. The significant advantages of HDPE geomembrane includes its great flexibility, very low permeable, thermal stability, UV light resistance, exceptional chemical resistance and durability, which makes it becomes an excellent liner candidate for water containment and mining industry applications. HDPE geomembrane has been successfully adopted in many water projects around the world, and working efficiently. Ivy and Mills (2002) reported that for over 20 years, HDPE geomembranes have been successfully applied to line ponds for power generating stations, inclusive of evaporation ponds and pumped storage ponds, etc. Hsuan and Koerner (1998) reported the predicted half-life of HDPE liners achieve 109 and 712 years at the respective 20^{o}C and 40^{o}C temperature. Ivy (2002) performed testing on 2.5mm HDPE in both exposed and unexposed conditions after 20 years of service as containment for wastewater from a steam electric generating station. It is reported that no significant reduction in the primary physical properties was observed, that include tensile, tear, puncture, carbon black and density, except some reduction in OIT value caused by depletion of antioxidants. Comer *et al.* (1995) reported that the buried, exposed and concrete covered geomembranes are effectively providing seepage control in the aging water conveyance system of the Western United States. The repairing of 2.4km Tucson Aqueduct, Reach 3 cracked concrete canal lining was successfully done by using white textured VLDPE geomembrane. The white textured VLDPE liner was selected because of its excellent bi-axial elongation properties, enhanced puncture resistance and greater tear strength than PVC, which has an advantage during construction. Shotcrete was also applied to the geomembrane surface as a protection layer Polyethylene geomembranes can be designed for exposal or protected with cover soil or concrete. The outstanding UV-stabilized geomembranes can remain exposed for an extended period of time with no decline in their level of performance. However, as exposed geomembranes are relatively susceptible to damage from falling rocks, debris, machineries and vandalism, most reservoir liner systems are recommended to design with protection.

Polyethylene geomembranes as impermeable materials are widely used in a variety of applications in water containments purposes, which include canal, artificial pond, lagoon, dams and reservoirs, etc. It also provides a cost-effective and value engineering solutions for electrical power generation purposes, which includes disposal of spent fuel, storage of process water, cooling ponds, etc.

POLYETHYLENE GEOMEMBRANE IN MINING INDUSTRY

Mining uses geomembrane liners generally in three areas: evaporation (or solar) ponds for recovery of the salts, heap leaching of mineral-bearing rock, and disposal of mill tailings. Heap leaching is a mineral processing technology in which the large piles of crushed or run-of-mine rock (or even mill tailings) are leached with various chemical solutions that extract valuable minerals. Figure 2 shows the modern heap leaching process that typically involving the percolation of leach solutions through controlled lifts of stacked, low-grade ore (crushed, agglomerate or run-of-mine) in a heap for chemical extraction of precious base metals into solution. The pregnant solution is generally collected by gravity flow in lined basins, sumps and ponds for processing and recovery of the target metals (copper, gold and silver). As shown in Fig. 2, the solution dissolves the metals (copper or gold) from the mineral and the pregnant leach solution (PLS) will then pass down through the ore pile and is recovered at the bottom on the leach pad, which usually consists of a geomembrane liner, typically polyethylene geomembranes overlying clay composite liner of low-permeability characteristics as to maximize the solution recovery and protect the underground water. The metal is then extracted from the PLS using electrowining processes and the barren solution (cyanide or sulfuric acid) from the recovery facilities is recirculated to the leach pile.

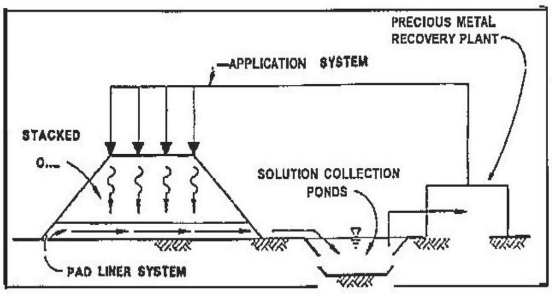

Fig. 2 Heap leach operation (Breitenbach 1994)

The first heap leach projects were copper dump leach facilities and used only natural soil containment. Until the late 1970's when cyanide was introduced to the heap leach technology (for gold and silver), natural containment was no longer viable. The low permeability soil liner was then used until 1983 when geomembrane liners became more common. Today, no modern large-scale leach pads use soil-only liners as base liner system (Breitenbach et al. 2006). With the introduction of polyethylene geomembrane to the mining industry, HDPE geomembrane starts dominate the industry in the mid of 1980's and was used in the now-famous

Summitville gold project in Colorado, USA. Very low density polyethylene (VLDPE) was the first used for small applications in the mid 1980's and for larger lined tailing impoundments like Ridgeway gold tailing dams (South Carolina, USA) in 1986. With its enhanced multi-axial elongation and improved frictional resistance provided compared to HDPE liner, linear low density polyethylene (LLDPE) geomembrane becomes popular in leach pad industry by the mid of 1990's.

Single geomembrane liners are still the most common liners for copper leach pads with composite liners more commonly adopted for gold and silver leach pads. With their outstanding mechanical properties and chemical resistance, HDPE and LLDPE liners at 1.5mm to 2.5mm thicknesses are the most common types and thicknesses of liners currently used in the mining facilities that are usually subjected to very high loads, such as heap leach facilities, mine waste facilities and tailing dam. Typical liner systems for these facilities are shown in Fig. 3.

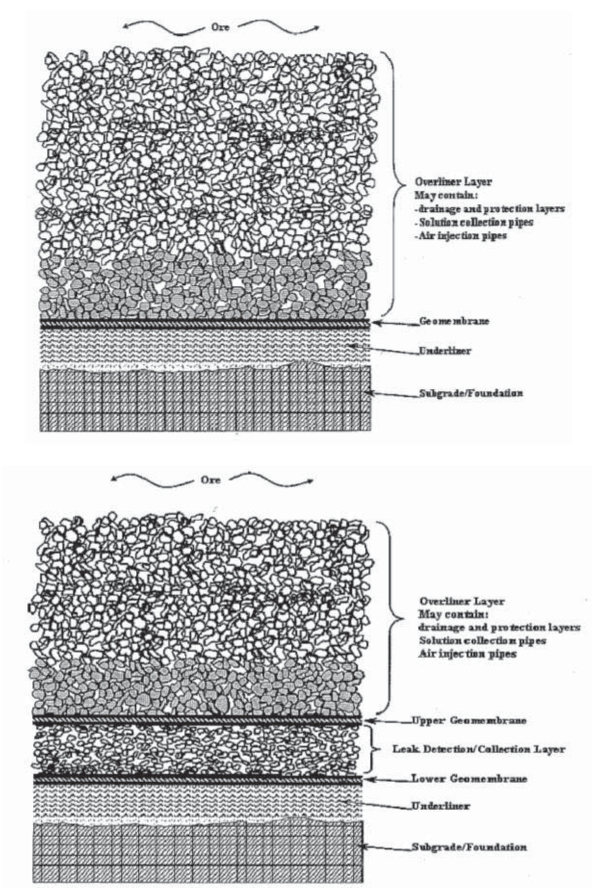

Fig. 3 Typical base liner system for mine facilities: Single composite liner system (top); double composite liner system (bottom), Lupo et al. 2005.

SUCCESSFUL CASE HISTORES

Some successful experiences on the application of polyethylene geomembranes as a primary lining component for industrial salt channel and brine pond at Northern China, heap leach pad and chemical solution pond in a mining job site at Mongolia are presented in this section.

Industrial Salt Channel and Brine Pond

Salt lakes form when the water flowing into the lake, containing salt or minerals, cannot leave because the lake is endorheic. The water then evaporates, leaving behind any dissolved salts and thus increasing its salinity, making a salt lake an excellent place for salt production. The project is located at Golmud, Qinghai province of PR China. Due to its location, Golmud appears with natural resources from nearby salt lakes. This has then brought up the development of industries involving salt lake chemicals. Qarham Salt Lake to the northeast of Golmud proper boasts an area of 5,856 km², making it the largest salt lake in China, and also the biggest inland salt lake in the world. Qarham Salt Lake is the largest production base for potassium, magnesium, and salt in Mainland China. Golmud is also claimed to be "China's Salt Lake City", with the salt thickness of about 2-20 meters. The salt lake is located at Gobi desert, about 2,670 meters above mean sea level, where the climate is hot and dry, water evaporation is much higher than precipitation. Long term exposed to wind and sunshine, the lake forms a high concentration of brine, gradual crystallizing into the salt lake. Qarhan Salt Lake is China's largest potassium and magnesium salt deposits in the total reserves of all kinds of salts more than 60 billion tons.

The site has a cold arid climate, with long and cold winters, warm summers. The daily temperature is highly fluctuating, with highest temperature at 35°C during the summer and dropped to the lowest temperature at -25°C during the winter. The mean monthly temperature drops to −9.1 °C in January and rises to 17.9 °C in July, with temperature averaging at about 5 °C for the year. Precipitation is very low, only 42 millimeters per annum, particularly during the summer. Relative humidity averages only 32%, and due to this aridity, the area is one of the sunniest in Mainland China, with nearly 3,100 hours of sunshine in a year.

As the subsoil mainly consists of high salt content, the saline soil foundation is easier to get dissolve, and potentially cause soil erosion and instability. Dissolution of saline soil lead to the potential ground erosion, cave in and collapse settlement could eventually results in severe leakage of brine. In order to prevent the losses of salts to the ground and to improve the harvest of rock salts as a long term solution, the engineers introduced geomembrane liner to serve as a barrier, erosion control and protection to the brine channels, brine ponds and reservoirs. Under the extreme ground condition and mountain plateau climate at high altitude land that experiencing low temperature, intense UV radiation, less precipitation winter and strong wind, a proper selection of high quality geomembrane liner becomes crucial to the long-term performance and functioning of the brine industry in this jobsite. With its durability, low permeability characteristics, outstanding performance in chemical resistance and UV light resistance, HDPE geomembrane has been selected as the candidate based on the proven track record in solid waste and liquid containment applications for more than two decades.

An impervious system using HDPE geomembranes was adopted and deployed by an experienced geosynthetic liner installer at the jobsite in order to secure the brine water in the channel transporting brine and brine storage ponds. Polyethylene geomembranes are certified for drinking water containments without additives and chemicals which can impact the water quality, they provide secure water containment and long term performance derived from their exceptional material properties, hence are ideal material for bottom liners in this facilities. Figures 4 and 5 are photos showing the brine pond and channel lined with HDPE geomembrane in Qinghai, China.

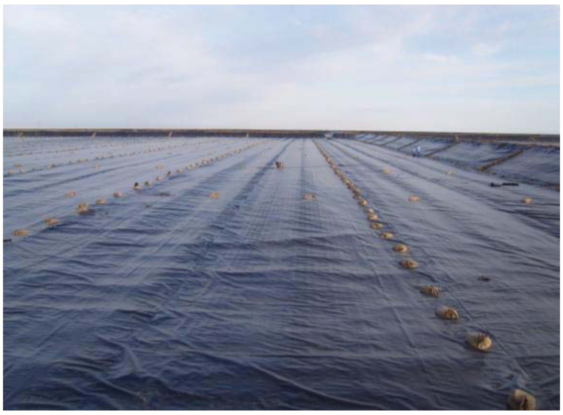

Fig. 4 HDPE lined salt brine pond in Qinghai Province, China

Fig. 5 HDPE lined channel transporting brine in Qinghai Province, China

Heap Leach Pad and Chemical Solution Pond

In mining industry, geomembranes have been adopted with a number of unique applications, which include the use as heap leach liners, solution pond liners and tailing pond liners, etc. Heap leach mining uses a lining material to catch chemicals that dissolve minerals in ore, and allow the solution to be collected and refined. Tailing dams and ponds use geomembrane liners to prevent the release of concentrated mine chemicals into the environment, which is mainly for environmental protection. The lined solution ponds retain the mining chemicals and process water to retention, reuse, or treatment for heap leach mining. In modern day, heap leach mining is commonly used for gold and copper. The chemical used for gold heap leaching is cyanide which is compatible with polyethylene geomembrane. The liquid used for the heap leach of copper is sulfuric acid which is also compatible with polyethylene geomembrane at all concentrations. The solution ponds as the collection ponds for enriched pregnant solutions are also commonly lined with polyethylene geomembranes as an exposed liner owing to its essentially impermeable characteristics, outstanding UV resistance, chemical resistance and longevity. Composite liners, which are combination of clayey soils in direct contact with geomembrane liners, become the most widely adopted and environmentally sound liner system in use. Factory manufactured geosynthetic clay liners (GCL) are sometimes used to substitute the commonly used compacted clay soils as the supplementary liner to reduce leakage through any holes or defects in the primary geomembrane liner. The composite liner system has been successfully used in mining industry since 1980's. HDPE geomembrane liners have been successfully deployed and performed satisfactorily in terms of mineral processing and environmental protection.

The development of mining industry in Asia Pacific regions is also picking up in consistent with the economic development in this region; there is no sign of slowing up in the pursuit of sustaining economic development. Figures 6 and 7 are a gold mine facility at Mongolia region, which is largely lined with HDPE geomembranes for the solution ponds and with LLDPE geomembrane as the lining component of the heap leach pad system. Textured geomembrane was lined on the slope to enhance the overall slope stability of the heap leach pad system.

Fig. 6 HDPE lined chemical solution pond

Fig. 7 Heap leach pad system was lined Polyethylene geomembrane at a mine site.

The mine is an open-pit gold mine site in Mongolia that located at the west of the capital Ulaanbaatar in Mongolia. The mine site is located in mountainous terrain with average elevation at 1,600m above mean sea level, varies from below 1,000m to 2,500m. It has a mid-continental climate, temperate to cold, with an average annual temperature of approximately 0ºC. Temperatures may drop to -40ºC during the months of December through February. Summer temperatures may exceed 40ºC, but they average approximately 20ºC. The area receives about 25 cm of precipitation per year, most of which is rainfall between July and August. The winters are relatively dry, with a moderate amount of snow from early November to April. Although the climate may present some challenges to heavy equipment operation, the mine and mill operate effectively year round. Geomembrane installation works at site is only practical for 6 months and most efficient during the months of April to October.

The lining of the chemical pregnant solution pond was completed during the summer of 2007. The lining of the pad with polyethylene geomembrane with total quantity of about 330,000 square meters was completed in 2008.

INSTALLATION AND CONSTRUCTION QUALITY ASSURANCE

A proper geomembrane installation and associated construction quality assurance and quality control (CQA/CQC) is crucial to the long-term performance of lining system. A CQA plan is usually developed before construction and used during construction to guide observation, inspection, testing and documentation of all field records. Prior to the geomembrane deployment, the subgrade should be properly prepared by removing any sharp edges objects, debris and organics matters, following with well compaction to the desired density and strength. It is necessary to be extra careful during the installation process in order to prevent equipment or personnel from damaging the liner. The geomembrane seaming always requires well-trained personnel, qualified welders and proper equipment. One of the most challenging works during installation is to allow sufficient slack for accommodating thermal contraction at low temperature. This is particularly important in the region that experiences extreme weather condition because polymeric geomembranes expand and contract as the temperature changes and thermal contraction can cause extensive damage to geomembranes. In addition, geomembrane welding is very sensitive to temperature differences, moisture and dust. Welding of geomembrane under low temperature requires special attention and procedure. During the deployment of the initial geomembrane rolls, trial welds were conducted on the same type of materials used on this project. Trial sections of seamed geomembranes are used to establish temperature settings of machine, pressure and travel rate for a specific geomembrane under a specific set of atmospheric conditions for machine-assisted seaming as well as establishing procedures to be correctly used by the installation crew. The trial welds are then subjected to destructive tests to qualify the welding and the equipment used before commencement on the field seaming works. Seaming should not be taking place when it is snowing or hailing on the geomembrane at the field to be seamed. Seaming during cold temperature requires more frequent trial seams and seam tests. GRI Test Method GM9 provides guidelines for the field seaming of thermoplastic geomembranes in cold climates and conditions. Geomembrane seaming at temperatures below -15°C is not generally recommended from both material and personnel perspectives.

Thermal wedge welding is the primary method used for the field seaming of HDPE geomembrane by qualified and experienced welders. The extrusion welding technique is adopted only for non-linear seams, patches, pipe penetrations or areas that wedge welder is impractical. After the seaming works, a series of installation quality assurance tests, inclusive of non-destructive and destructive weld testing, are carried out to ensure the weld quality at site is in full compliance with the engineer's requirements and/or the equivalent recognized testing standards. Typically, non-destructive seam tests include spark testing, air-pressure and vacuum-box tests. Hot wedge welder creates a double-track weld, leaving an air channel in between these two weld tracks which can then be used to non-destructively air pressure test the integrity of the seam. When the seam is completed, both ends of the air channel are sealed off and the seam is pressure-tested to determine its continuity. Any non-compliant seams are patched with extrusion weld before retesting. The non-destructive vacuum-box test is used to check the continuity of welded seams, repairs and patches where it is not practical to conduct air pressure test.

Destructive seam tests are used to evaluate bonded seam strength, which involves cutting out a section of the seam and tested until failure. Test strips are cut from the section and tested on site. The destructive samples are tested for shear-strength and peel-strength values, carried out in accordance to ASTM D6392. The sampling frequency is conducted as per recommendation of GRI-GM19, in which is, on average, one test location per 500 linear feet of seam for the entire project and can be reduced as per engineer's decision at site depending on the weld quality. GRI White Paper #3 provides a guide that allows a decrease in the amount of destructive seam sampling for good seams (Koerner et al. 2003). The destructive shear test involves application of a tensile stress from the edge of one sheet, through the weld to the edge of the adjoining sheet. For the peel test, the overlapping portions of the sheet are pulled in opposite directions to observe weld separation behavior.

To ensure the sealing integrity of geomembrane installation, a series of the quality assurance and quality control programs as well as the final monitoring, field leak detection survey are usually required to be implemented in order to serve as validation and verification during and after construction works. Leak Location liner, a coextruded polyethylene geomembrane with an electrically conductive layer on the base of the liner, is commonly used as liner system in mining and water containments. This is because Leak Location liner offers the quickest and most cost-effective leak detection at post-construction.

DISCUSSIONS AND CONCLUSIONS

HDPE geomembrane is an impervious synthetic material which has been widely used as a watertight lining, particularly in geoenvironmental engineering works such as hazardous and non-hazardous landfills, wastewater treatment pond; industrial tanks for chemical and toxic liquids as well as mining facilities. It forms the foundation of the modern containment system and become a cost-effective lining system. Polyethylene geomembranes have a proven track record in these types of applications, particularly in water containments and mining facilities for more than three decades.

This paper presented the successful applications of polyethylene geomembranes in environmental lining solutions for industrial salt channel and brine pond, chemical solution pond and heap leach pad liner system. HDPE geomembrane generally serves as impermeable barriers to stop or limit the migration of water and liquids out of the containment. Due to the specialty of the geomembrane liner, HDPE geomembranes are selected and have been successfully deployed with acceptable leak-proofing performance in the liquid containments and chemical ponds at various regions. The use of geomembrane liners at salt evaporation pond, heap leach pad and chemical solution pond of mining facilities in developing countries increased rapidly in these recent years. Flexible polyethylene geomembrane with its durability and low permeability characteristics has therefore become a widely accepted component of the barrier / liner systems to achieve the final protection to the environment as well as create higher profit.

Engage a proper geomembrane installation team with associated construction quality assurance and quality control (CQA/CQC) is always crucial to the long term performance of lining systems. To ensure the integrity of geomembrane at post-installation, quality assurance and quality control programs together with field leak detection survey are recommended to serve as validation and verification to the installed geomembranes. The Spark-testable conductive geomembrane is a good candidate of base liner system in mining facilities and water containments, particularly it provides a quickest, more reliable, and cost-effective leak detection at post-construction. Past experiences show that key design and performance issues must be evaluated on a project-by-project basis, in which for geomembrane liner it includes both material quality and construction quality.

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