

LONG TERM TEMPERATURE MONITORING OF LANDFILL GEOMEMBRANES

George R. Koerner , Ph.D., P.E. & CQA
Geosynthetic Research Institute, Drexel University

Ramin Yazdani, P.E.
Yolo County Department of Public Works

Robert E. Mackey, P.E.
Post , Buckley, Schuh & Jernigan, Inc.

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ABSTRACT

An important aspect of understanding any material's long term performance is knowing the environmental conditions that it will experience during its service life. A key environmental condition for a geomembrane is its in-situ temperature. This paper discusses the installation of thermocouples on geomembranes at several landfills for the purpose of long term temperature monitoring. Of specific interest is the magnitude of the field measured temperatures, temperature fluctuations and relative temperatures with respect to ambient.

This paper presents results from three different landfills; one each in Pennsylvania, California and Florida. Insitu geomembrane temperatures have been monitored in both the liners, covers and in one case the solid waste itself. It should be noted that these are long term projects in which temperatures have been monitored from 3 months to 5 years and are all ongoing.

INTRODUCTION

Geomembranes are made of polymers and as such their physical, mechanical and endurance properties are strongly temperature dependent, Budiman (1996). Due to the critical nature of geomembranes in landfills there is keen interest in the long-term insitu temperature monitoring of these materials. Data is particularly needed to assess the role temperature plays in the degradation of geomembranes over time.

There is a concerted effort in the geosynthetic community to answer the question of how long will geomembranes last. Clearly the long time frames involved in actually investigating degradation at field-related temperatures are not providing answers fast enough for the decision-making processes of today. Thus accelerated testing at elevated temperatures is a typical protocol. Using experimental chambers that superimpose compressive stress, aqueous-oxidative environment, elevated temperature and long testing times, Koerner, Hsuan and Lord (1993) have devised an accelerated aging test for geomembranes.

In these incubation chambers, samples are removed periodically and evaluated for changes in physical, mechanical and endurance properties. The anticipated behavior is based on the knowledge that elevated temperature accelerates degradation. Therefore the concept of time versus temperature superposition can be used to determine a relationship between temperature and the reaction rate of degradation. In predicting the life of the

geomembrane one can extrapolate the experimental curve down to insitu conditions. However, there is little information as to what actual insitu temperature is to be targeted.

Hsuan and Koerner (1995) suggest that the long term lifetime of HDPE geomembranes can be predicted via the summation of three separate and distinct phenomena:

- (a) depletion of antioxidants,
- (b) induction time, and
- (c) time for half-life of property depletion.

Using the incubation chambers previously described, the depletion of antioxidants has been tracked at four elevated temperatures; 85, 75, 65 and 55°C. In each case, the time for full antioxidant depletion has been obtained. Using this data in an Arrhenius plot, the depletion time at any site specific temperature can be obtained. To illustrate the depletion times with respect to predicted lifetime at a site specific temperature, Figure 1 has been prepared. For example, at an insitu temperature of 25°C, the time for depletion of antioxidants would be 125 years. Conversely, at 15°C, the time for depletion of antioxidants would be 290 years. Clearly determining the actual temperature of insitu geomembranes is the focus of this study.

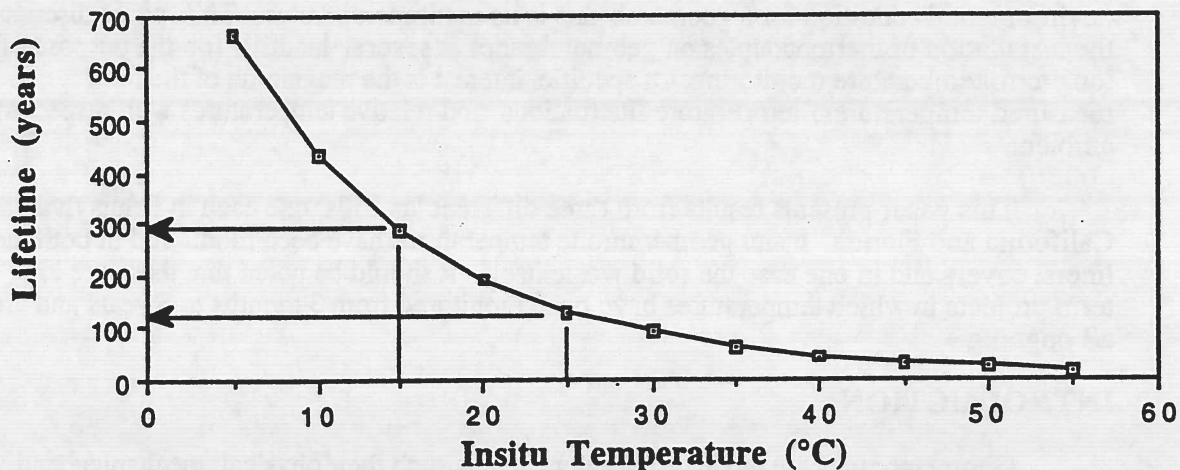


Figure 1, Theoretical HDPE Geomembrane Temperature versus Insitu Temperature Response

As a secondary issue, it was realized that in monitoring the insitu temperature of the geomembranes in landfill liners and covers, a few thermocouples could be devoted to monitoring the temperature of the solid waste itself. This data is relevant for tracking the stages of the bio-chemical processes ongoing in the waste mass, see Ham (1988) and Pohland (1989). Such monitored temperatures may be relevant when discussing the viability of the concept of landfills as bio-reactors.

EQUIPMENT AND INSTRUMENTATION

Thermocouples are commonly used to measure temperature variations in materials and are particularly useful for remote sensing of temperature over long periods of time. Thermocouple technology is based on a particular thermoelectric phenomena known as the Seebeck effect. If two different metal wires are joined at both ends and the two junctions

are held at different temperatures, a current will flow in the circuit caused by the difference in temperature between the hot and cold junctions of the circuit. An electro-motive force is developed in the circuit by the junction of two dissimilar metals which has a voltage output proportional to the difference in temperature between the hot junction and the cold junction, Pitis (1977). For common temperature ranges, the voltage is linearly proportional to temperature. The only equipment that is required is a reference junction compensation unit to accommodate environmental and geometric drift effects. Such systems are simple, robust and relatively inexpensive. Hence they are ideal for long term temperature monitoring projects.

Site #1 Landfill in Pennsylvania

The first site is a solid waste landfill located just north of Philadelphia, Pennsylvania. It is a very large 110 ha landfill that is permitted to handle 27,000 metric tons per day. The temperature investigation is being conducted on a 3.2 ha cell. The bottom liner consists of a double composite liner system of 0.6 m compacted clay, nonwoven geotextile, 1.5 mm HDPE secondary geomembrane, HDPE geonet, nonwoven heat bonded geotextile, geosynthetic clay liner, 1.5 mm HDPE primary geomembrane, nonwoven geotextile and 0.6 m leachate collection layer. An estimated 50 meters of waste was subsequently placed in the cell and then covered. The final cover system consists of 1 m of soil, textured 1.0 mm HDPE geomembrane, geocomposite consisting of two needle punched nonwoven geotextiles thermally bonded to a geonet and 0.6 m of top soil.

The climate in the region is characterized as wet with periods of high and low temperatures which seldom last for more than three or four days. Temperatures below zero or above 34°C are rare. Precipitation is distributed throughout the year with maximum amounts during the late summer. Snowfall amounts vary widely. In many cases, precipitation will change from snow to rain. The mean annual precipitation for the site is 1045 mm and the mean annual temperature is 12.6°C, Wood (1996).

Omega Type J thermocouples were used for this investigation. They are made of 20 gauge thermocouple wire. The positive lead is iron and the negative lead is Constantan. The leads are individually wrapped in Teflon and then the entire wire is sheathed in Neflon. This type of thermocouple wire is rated over a temperature range from -100 to +200°C. Over 1,000 meters of Duplex insulated TT-J-20-1000 thermocouple wire was used. All thermocouples were calibrated as per ASTM E839 prior to installation.

The thermocouples were attached to small coupons of geomembrane in the laboratory and then taped to the upper geomembrane in the field. In so doing the permanent geomembrane was not jeopardized during thermocouple installation since no welding equipment was used during installation. This precautionary step was taken so that a permit modification could be avoided and installation of the gauges could commence at the same time that the cell was being constructed. Both the regulatory agency and the geosynthetic installation contractor were made aware of the project and approved the thermocouple installation process.

Figure 2 shows the thermocouple leads just prior to installation on the geomembrane liner. The leads were brought to the edge of the landfill cell and protected by a 550 g/m² needle punched nonwoven geotextile. Figure 3 shows a close-up of the thermocouples being installed. The thermocouples were not subjected to high installation stresses due to care and quickness of installation. Figure 4 shows the control panel and data acquisition station attached to an adjacent sump house. An oversized galvanized steel mailbox permanently attached to the outside wall of the sump house was utilized at this

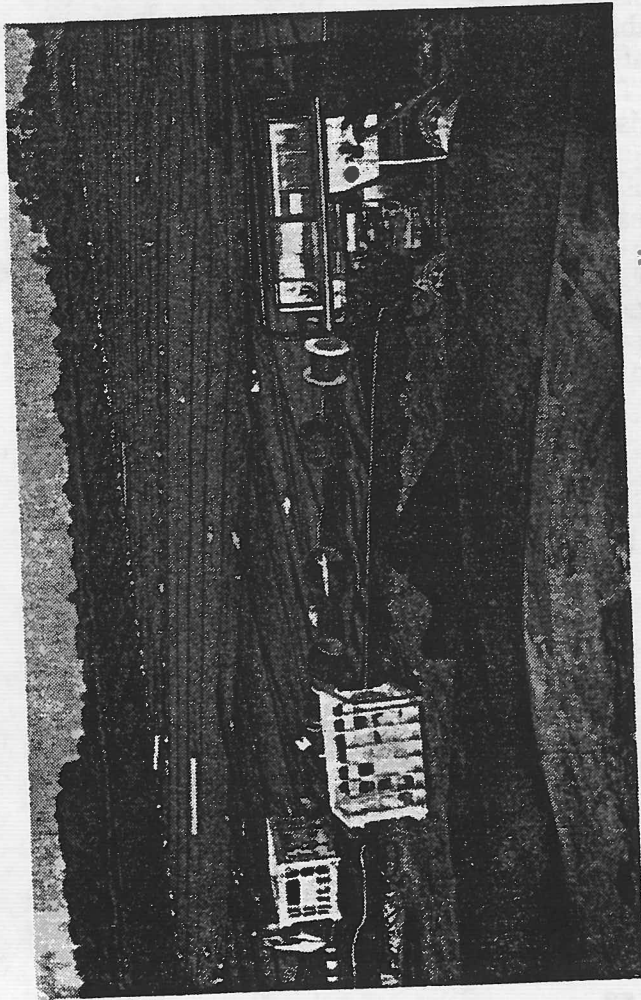


Figure 2, Overview of geomembrane liner thermocouples being installed at site #1

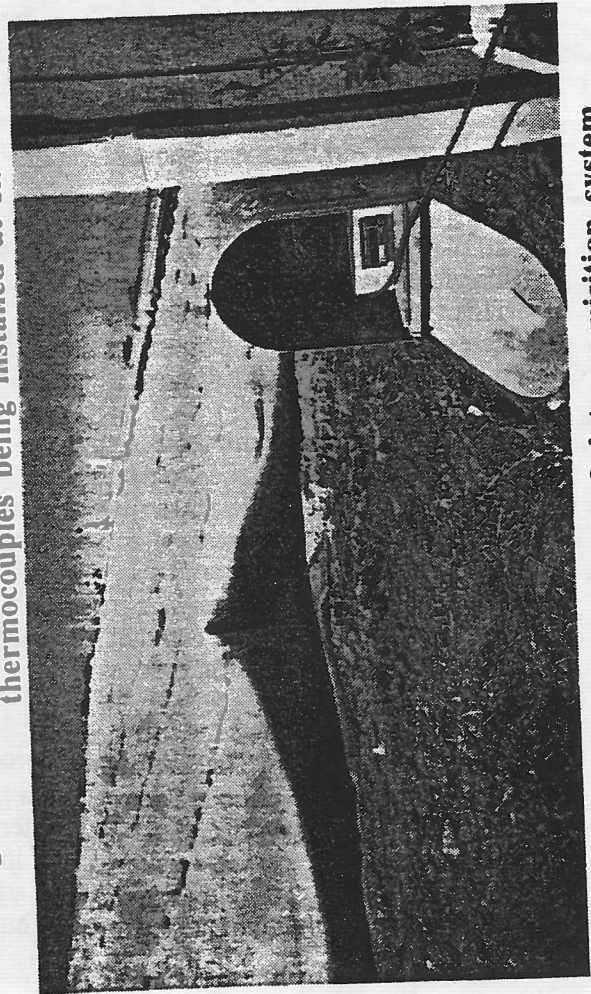


Figure 4, Photograph of data acquisition system and cover system of site #1

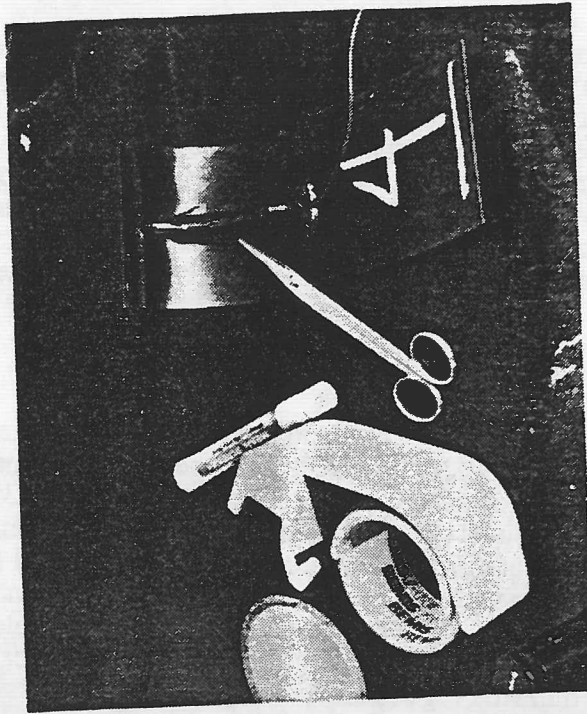


Figure 3, Photograph of a thermocouple being installed

site. This type of shelter was selected because it was small, robust, weatherproof and could be inconspicuously mounted to the exterior of the sump house for easy access. The data acquisition system did not obstruct daily operations and was near a reliable source of electric power.

Subsequent to installation of the thermocouples, gravel for the leachate collection system was placed. The thermocouple wires exited below the geotextile protection layer at the top of the berm about 8 m from the sump. The wires were taped to the top of the sump riser leading to the sump house. This was an important detail because a clay plug was placed around the sump riser in an effort to minimize the migration of landfill gases from exiting the cell.

In the cross section of Figure 5, the distance from the thermocouples on the geomembrane to the data acquisition system at the sump house are 150, 140, 120, 110, 90, 80, 60 and 50 m, respectively. Additional thermocouples were installed in the drainage gravel and in the waste mass. Thermocouples on the geomembrane cover are 20, 40, 60, 80, 100, and 120 m from the data acquisition system, respectively. Ambient temperature is measured at the sump house. The ambient temperature values are contrasted with results from a local weather station. All 20 thermocouple stations of the data acquisition system are occupied. It took approximately two and a half years to construct the liner system, fill it with waste and construct the cover system. Temperature readings were taken manually on a monthly basis since the onset of geomembrane liner placement.

The temperature response curves for this site appear in Figure 6 (a) through (d). Figure 6 (a) shows the temperature response of the geomembrane liner over a two and a half year period. After an initial unsteady response during installation, all eight of the geomembrane liner thermocouples have been approximately 20°C. There seems to be little seasonal effect and no ambient temperature effect.

The temperature response of the thermocouples in the gravel and waste mass are somewhat irregular, but still average approximately 20°C. As can be seen in Figure 6 (b) these five thermocouple have a slight seasonal effect, however no ambient temperature effect.

The temperature responses of the cover geomembrane in Figure 6 (c) are different from the other responses in that they exhibit both a seasonal and an ambient temperature effect. When contrasted against the curves in Figure 6 (d) the temperatures tend to be a few degrees centigrade below ambient temperature. The 0.6 m of cover soil which overlays this cover geomembrane buffers them but not to the extent that the thick body of waste buffers the temperature response of the geomembrane liner.

Site #2 Yolo County Central Landfill in California

The second site, Yolo County Central Landfill (YCCL) is a municipal solid waste (MSW) landfill located in Yolo County California. YCCL is permitted to handle 1,600 metric tons of MSW per day. This investigation was conducted at a 8 hectare cell. The composite liner system consisted of 0.6 m of compacted clay, 1.5 mm HDPE geomembrane, HDPE geonet, nonwoven geotextile and 0.3 m of soil acting as an operations layer.

Situated 5 km northwest of Davis, California. The site is near to geographical center of the great interior valley of California. This predominantly agricultural region has

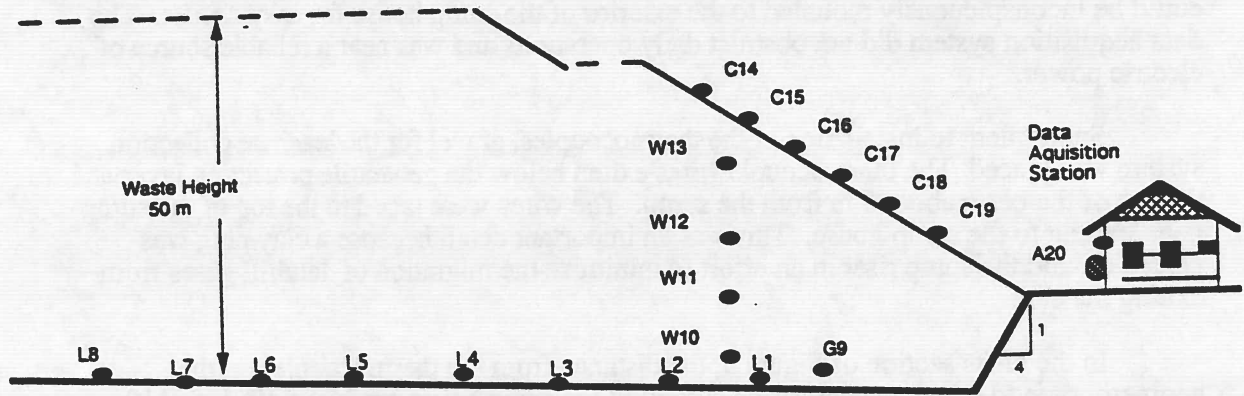
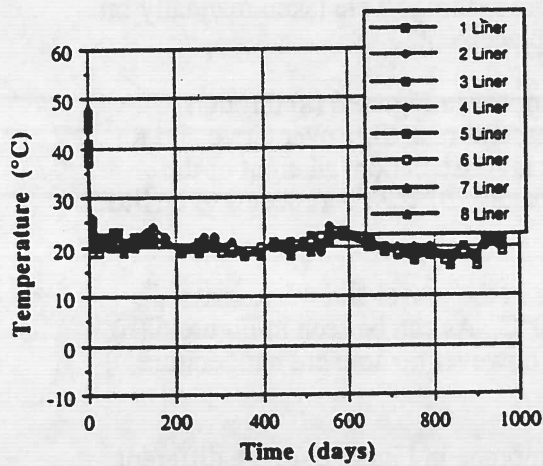
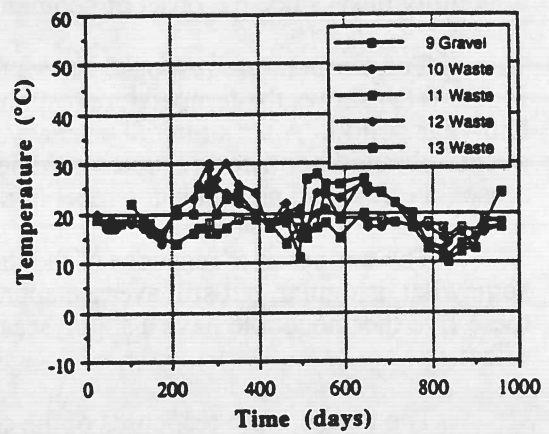


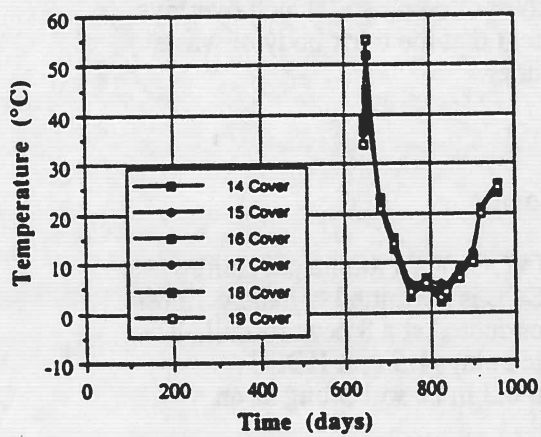
Figure 5, Schematic cross section diagram of site #1 showing the locations of the thermocouples



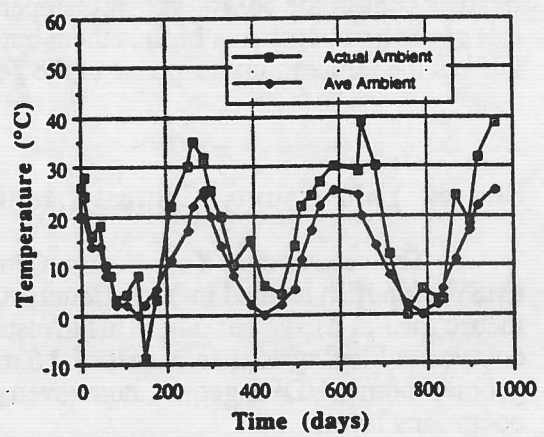
(a) Geomembrane liner results



(b) Gravel and waste results



(c) Geomembrane cover results



(d) Ambient results

Figure 6, Temperature versus time response of the thermocouples of site #1

a mild climate with sunshine most of the year. A nearly cloud-free sky prevails throughout the summer months and for much of the spring and fall. About 75 percent of the annual precipitation occurs during the rainy season extending from November through March. The climate is considered to be semiarid and the topography of the site is relatively flat. The mean annual precipitation for the site is 450 mm and the mean annual temperature is 15.9°C, Wood (1996).

Omega Type K thermocouples were used for this investigation. They are made of 20 gauge thermocouple wire. The positive lead is Chromel and the negative lead is Alumel. The leads are individually wrapped in Teflon and then the entire wire is sheathed in Neflon. This type of thermocouple wire is rated over a temperature range from -100 to +200°C. Over 145 meters of Duplex insulated TT-K-20-1000 thermocouple wire was used.

Three strings of four thermocouples (for a total of 12 thermocouples) were installed at cell module A of YCCL. Figure 7 and 8 shows an overview and close-up of the thermocouple installation process respectively. Note that the thermocouples of this site were installed in a 32 mm schedule 40 PVC pipe laid directly on the geomembrane liner. This difference in installation technique from the other sites is believed to have little effect on the actual measured temperatures of the geomembrane liner. Figure 9 shows a technician reading the temperature response of one of the thermocouples with a mobile readout unit.

Figure 10 shows a cross section view of the cell indicating the thermocouple locations. There were three strings of four thermocouples each along the north and east sides of the cell. Each string of thermocouples, at stations C, D, and E, were placed in the same four strategic locations as indicated by Figure 10. T1 was placed at the top of the slope, T2 at mid slope, T3 at the toe of slope and T4 at the bottom of the cell. It should be noted that additional instrumentation (i.e. strain gauges) was placed at the same locations as the thermocouples at this site. Details about this additional instrumentation can be found in Yazdani et al. (1995). It is important to note that this is a county landfill that has a constant, but rather low, volume of incoming waste. Hence filling operations were not nearly as fast as the previously described site.

The temperature response curves for site 2 appear in Figure 11 (a) through (d). Figure 11 (a) shows the temperature response of the geomembrane over a five year period at station C, while Figures 11 (b) and 11 (c) show the geomembrane responses of station D and E, respectively. At all three stations, three of the four thermocouples have been yielding an average temperature response of 21°C. There seems to be a little seasonal effect and the ambient temperature effect is approximately 2 to 3 °C. The temperature response of the other thermocouple, namely T1, at the top of the slope has been fluctuating at all three stations. As can be seen in Figure 10, T1 has only been covered by a thin layer soil and no waste. Hence it has both seasonal and ambient temperature effects which are very explainable.

Site #3 Orange County Landfill in Florida

The third site is the Orange County Landfill located near Orlando, Florida. It is permitted to handle 8,200 metric tons of MSW per day. The temperature investigation was conducted within a long, rectangular 1.6 hectare cell. The composite liner system consisted of 0.6 m compacted clay liner, 1.5 mm HDPE geomembrane, and 0.6 m of sand drainage layer. The cell was constructed in the spring of 1996 and has not yet received waste.

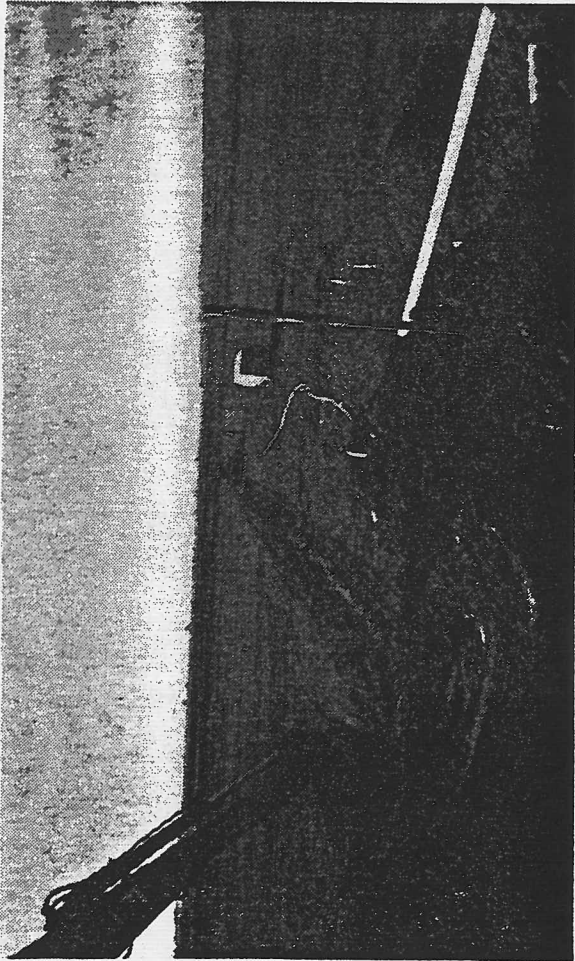


Figure 7, Overview of geomembrane liner thermocouples being installed at site #2

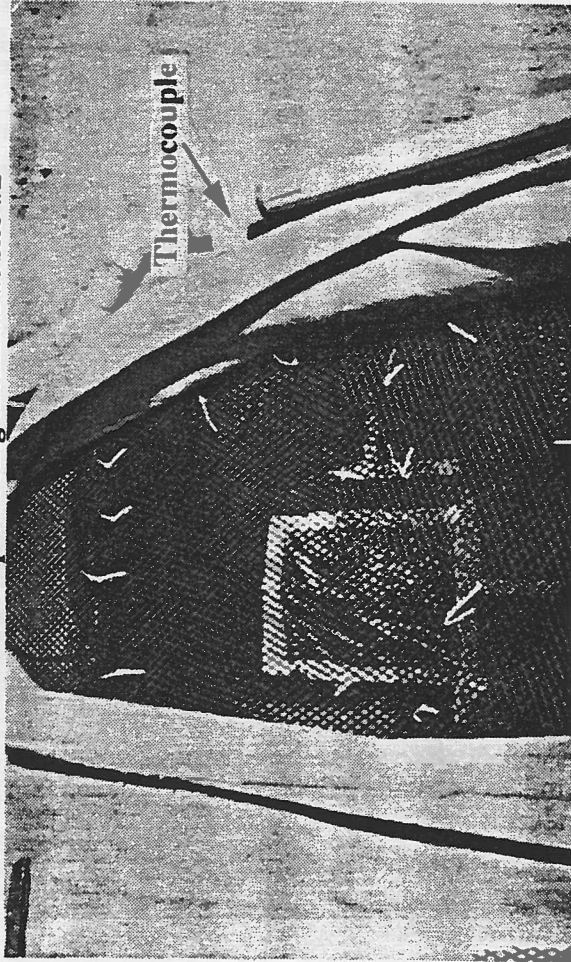


Figure 8, Close-up of geomembrane liner thermocouple being installed at site #2

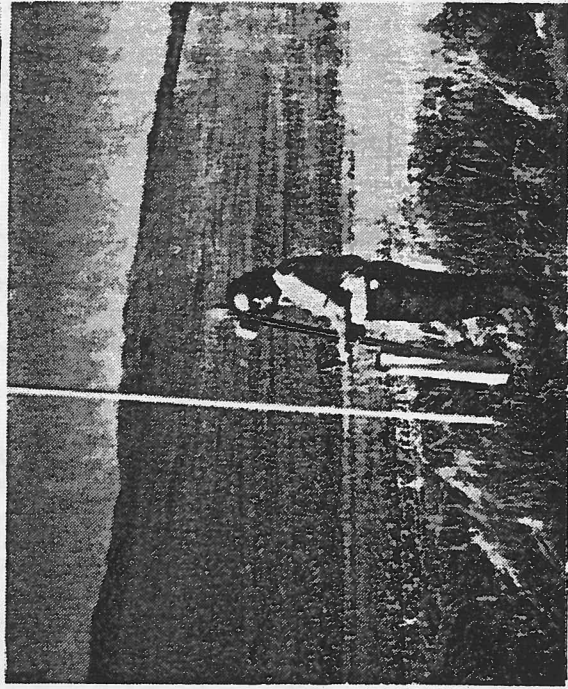
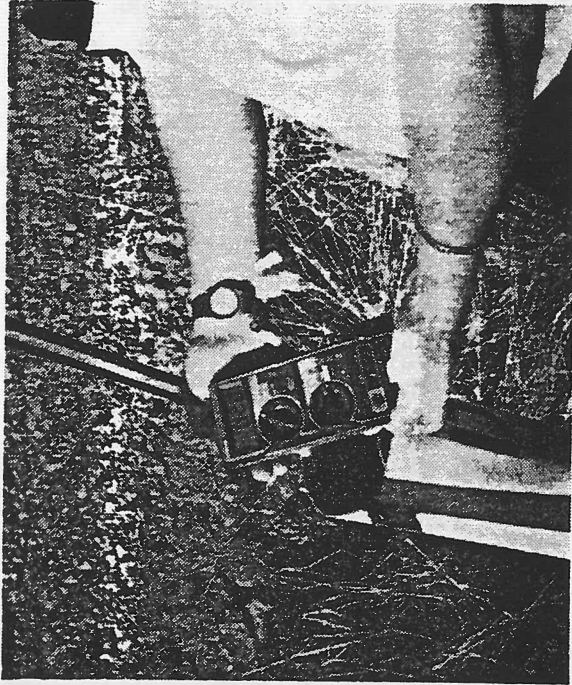


Figure 9 a & b, Photographs of David Hiatt reading the thermocouples of site #2

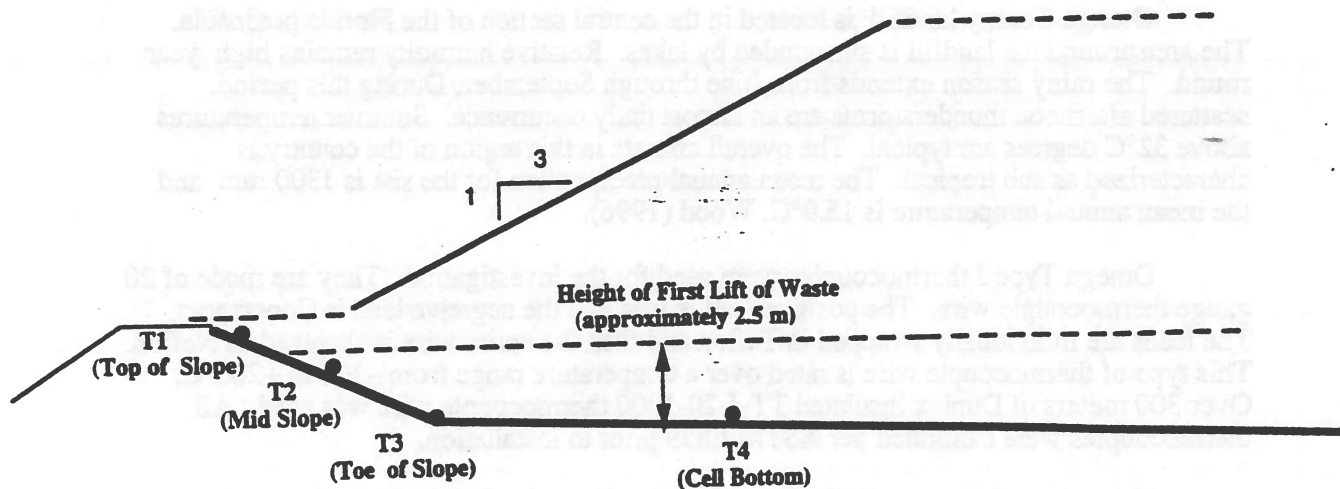


Figure 10, Schematic cross section diagram of site #2 showing the locations of the thermocouples

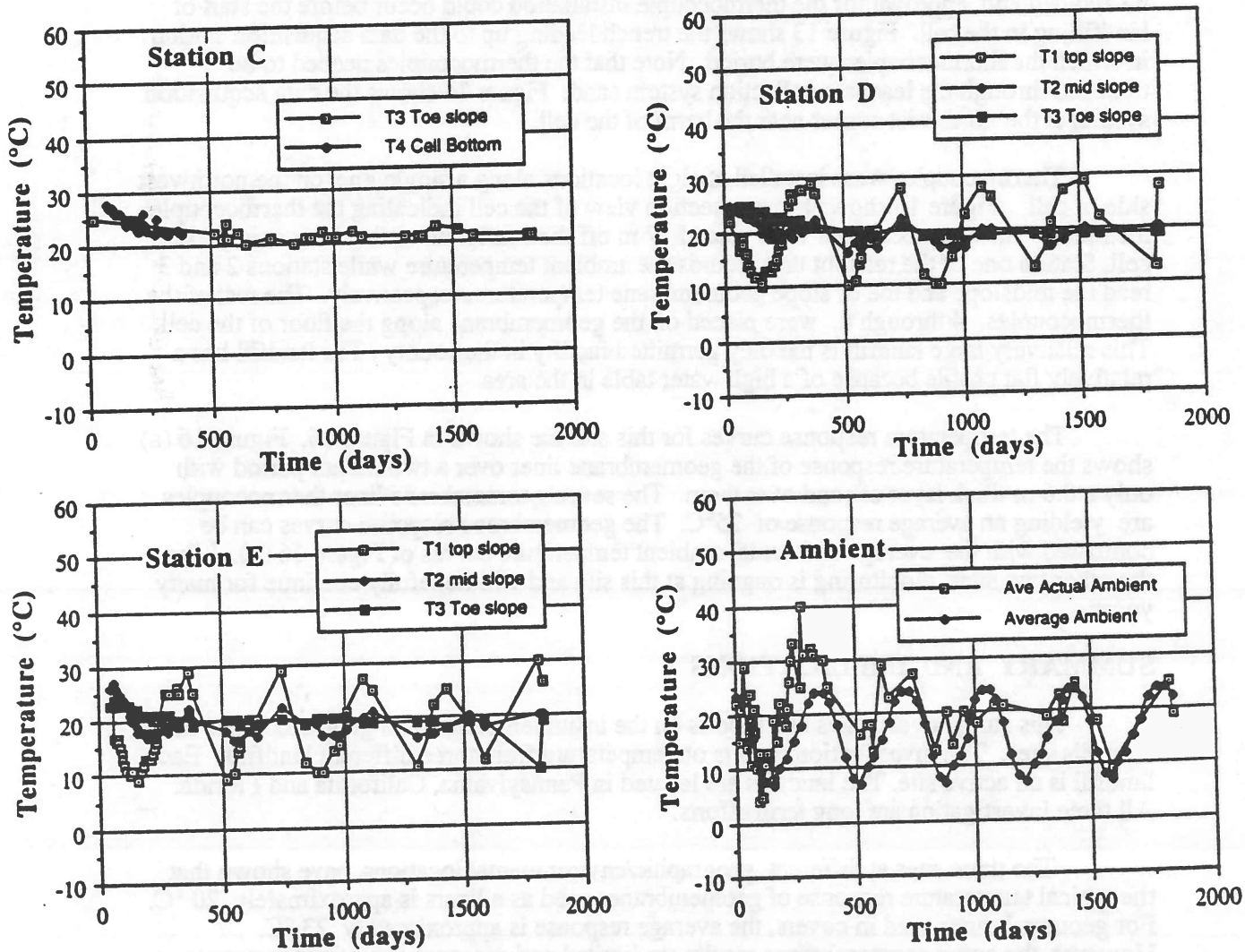


Figure 11, Temperature versus time thermocouple responses of #2

Orange County landfill is located in the central section of the Florida peninsula. The area around the landfill is surrounded by lakes. Relative humidity remains high year round. The rainy season extends from June through September. During this period, scattered afternoon thunderstorms are an almost daily occurrence. Summer temperatures above 32°C degrees are typical. The overall climate in this region of the country is characterized as sub tropical. The mean annual precipitation for the site is 1300 mm and the mean annual temperature is 15.9°C, Wood (1996).

Omega Type J thermocouples were used for the investigation. They are made of 20 gauge thermocouple wire. The positive lead is iron and the negative lead is Constantan. The leads are individually wrapped in Teflon and then the entire wire is sheathed in Nefflon. This type of thermocouple wire is rated over a temperature range from -100 to +200°C. Over 300 meters of Duplex insulated TT-J-20-1000 thermocouple wire was used. All thermocouples were calibrated per ASTM E839 prior to installation.

Thermocouples were attached to coupons of geomembranes in the laboratory and then taped to the geomembrane in the field as shown in Figure 12. In so doing the geomembrane was not jeopardized during installation for no welding equipment was used during installation. This precautionary step was taken so that a permit modification could be avoided and approval for the thermocouple installation could occur before the start of landfilling in the cell. Figure 13 shows the trench leading up to the data acquisition station in which the thermocouples were buried. Note that the thermocouples needed to be trenched through the leachate collection system sand. Figure 14 shows the data acquisition system at the northwest corner near the berm of the cell.

Thermocouples were installed at eight locations along a single line on the northwest side of cell. Figure 15 shows a cross section view of the cell indicating the thermocouple locations. The thermocouples were placed 17 m off the centerline of the long axis of the cell. Station one of the readout unit records the ambient temperature while stations 2 and 3 read the midslope and toe of slope geomembrane temperature, respectively. The rest of the thermocouples, 4 through 8, were placed on the geomembrane along the floor of the cell. This relatively large landfill is the only permitted facility in the county. The landfill has a relatively flat profile because of a high water table in the area.

The temperature response curves for this site are shown in Figure 16. Figure 16 (a) shows the temperature response of the geomembrane liner over a two month period with only a 0.6 m thick layer of sand over them. The seven geomembrane liner thermocouples are yielding an average response of 25°C. The geomembrane response curves can be compared with the average and actual ambient temperature curves of Figure 16 (b). Like the other two sites, monitoring is ongoing at this site and will hopefully continue for many years.

SUMMARY AND IMPLICATIONS

This study investigates and reports on the insitu temperature of geomembranes at landfills sites. The investigation reports on temperature from three different landfills. Each landfill is an active site. The landfills are located in Pennsylvania, California and Florida. All three investigation are long term efforts.

The three sites at different geographic/environmental locations, have shown that the typical temperature response of geomembranes used as a liners is approximately 20 °C. For geomembranes used in covers, the average response is approximately 23 °C. However, the cover geomembranes results are limited and seasonal conditions appear to effect the temperature response of geomembranes in covers more than in liners. It was



Figure 12 Close-up of geomembrane liner thermocouples being installed at site #3

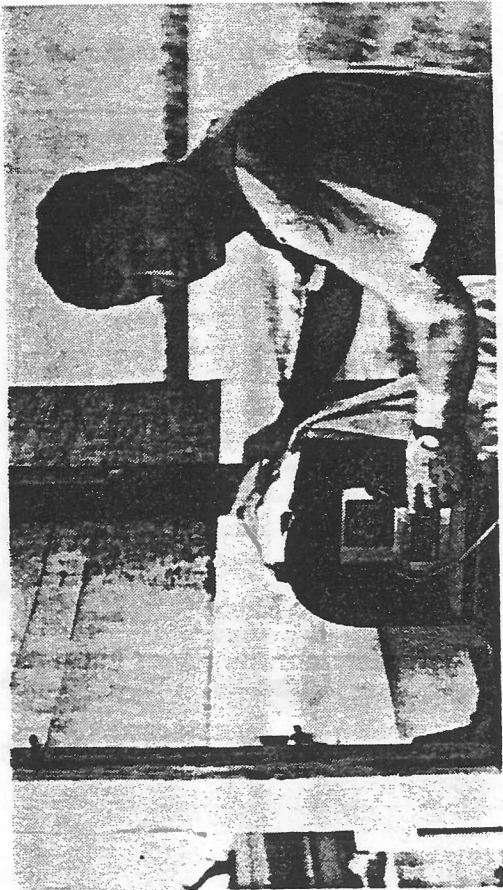


Figure 14, Photograph of technician reading thermocouples of site #3

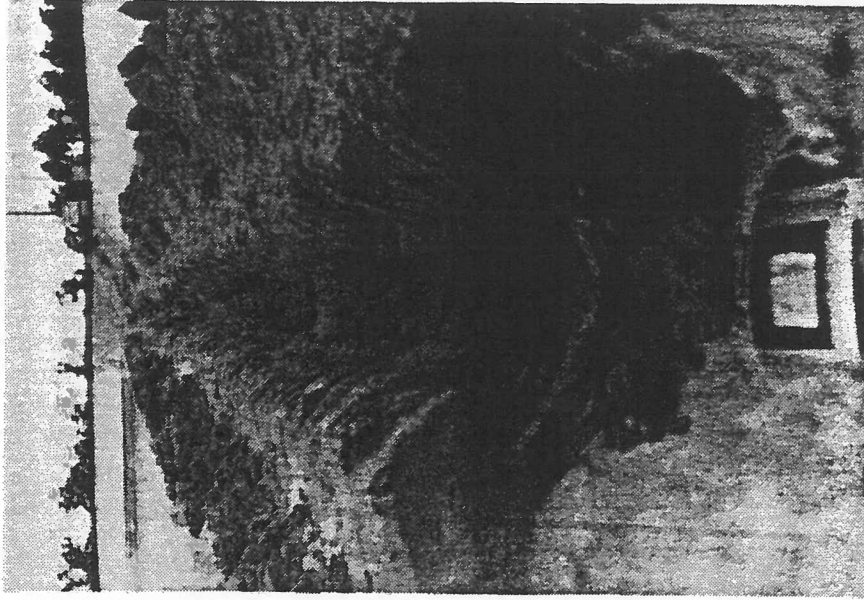


Figure 13, Overview of geomembrane liner thermocouples being installed at site #3

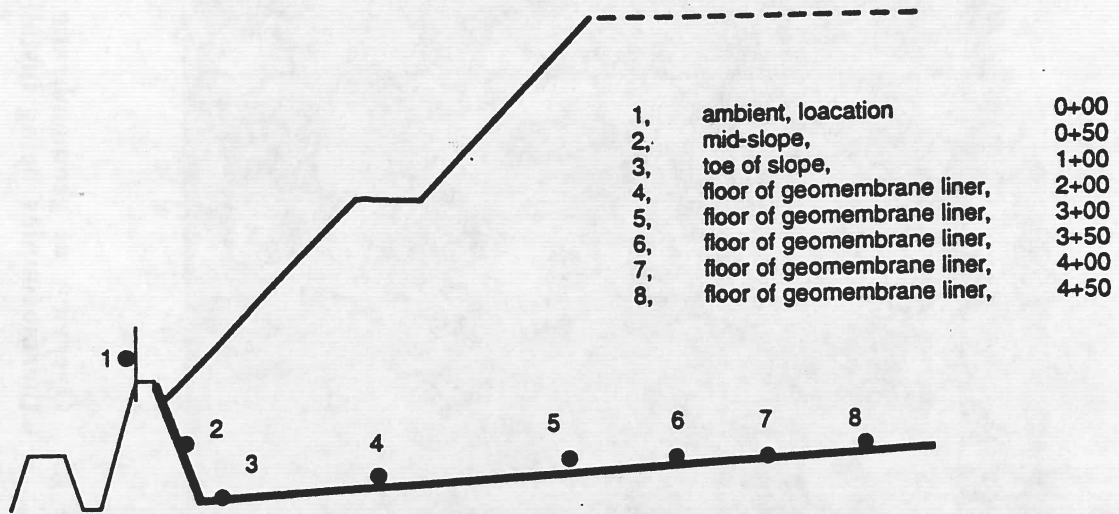
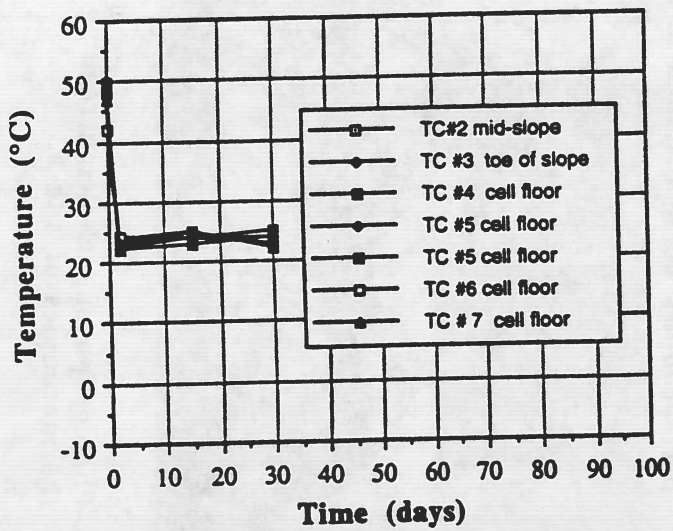
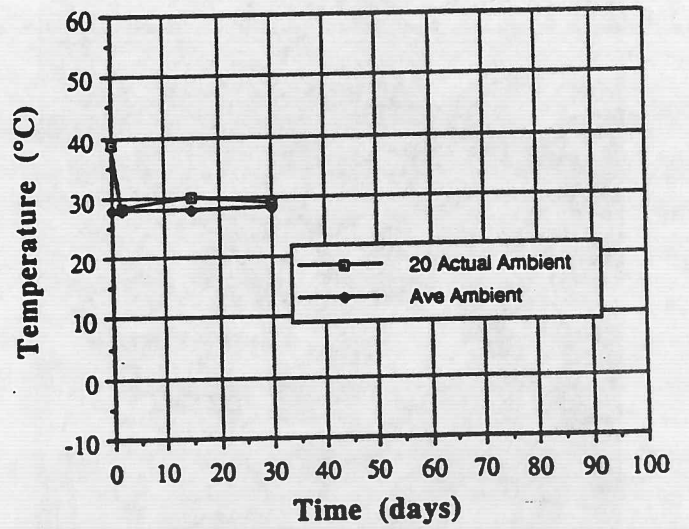


Figure 15, Schematic cross section diagram of site #3 showing the locations of the thermocouples



(a) Geomembrane liner results



(b) Ambient results

Figure 16, Temperature versus time thermocouple responses of #3

interesting to note that the geomembrane temperature response was not drastically different with respect to geographic/environmental locations. In addition to continued monitoring of the existing landfills, there are plans to instrument other landfills. Additional data will supplement information already collected.

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