21st Annual Landfill Gas Symposium
Austin, Texas
March 23-26, 1998

REUSE OF SHREDDED WASTE TIRES FOR LANDFILL GAS COLLECTION AND LEACHATE INJECTION SYSTEMS IN YOLO COUNTY'S LANDFILL BIOREACTOR DEMONSTRATION PROJECT

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ABSTRACT: This paper provides data on the performance of shredded waste tires in a landfill gas collection system and leachate injection system. These systems were constructed as part of a landfill bioreactor demonstration project to enhance methane production. Horizontal and vertical gas collection systems using shredded tires were constructed and monitored over two years and have been evaluated against standard vertical gravel gas collection wells. The leachate injection system made from shredded waste tires was successfully constructed to distribute and recirculate leachate in the bioreactor. Gas composition, pressure and flow rates are reported for each type of gas collection system. Results from this project provide data documenting that shredded waste tires perform as well or better than gravel as a gas collection medium and at a lower cost. Observations on the economics of shredded tire utilization in this landfill application are also reported.

KEY WORDS: tires, tire reuse, shredded tires, gas collection, leachate recirculation, bioreactor

INTRODUCTION

Each year over 260 million scrap waste tires are generated in the USA. Due to limited markets it is estimated that over 70% of scrap tires generated end up being disposed of in landfills, stored in stockpiles, or illegally dumped (Duffy, 1995). California alone generates 29.5 million tires and has over 100 million waste tires stockpiled around the state (CIWMB, 1996). These stockpiles are potential fire hazards, as well as breeding grounds for disease. Landfilling old whole tires pose difficulties in operation and final closure in many landfills. Waste tire disposal represents a loss of a useful resource and landfill capacity, as well as adding addition costs for disposal and processing costs. Therefore, development of new tire markets is needed to reduce the waste of this useful resource. Waste tire diversion alternatives include reuse, retreading, recycling and combustion. An emerging market for waste tire use is in civil engineering applications. However, due to concerns of potential fires and lack of engineering data on the performance and design requirements, civil engineering markets are limited. To promote innovative waste tire markets by acquiring the necessary data, the California Integrated Waste Management Board (CIWMB) funded the research of shredded waste tires as a medium for gas collection and leachate injection at the Yolo County Bioreactor Project. The constructabilty and performance of vertical and horizontal shredded tire gas collection systems were investigated and documented. Based on the project results, it is hoped a new tire market in the landfill industry may be created. This beneficial use of waste tires can help to alleviate some of the disposal problems of used tires while providing a potentially cost-effective construction material in the landfill industry.

PROJECT SETUP

An objective of the Yolo County Bioreactor Demonstration Project is to investigate the constructability and performance of shredded waste tires as a medium for landfill gas collection and leachate distribution. This project was conducted in conjunction with research investigating "enhanced or controlled" landfilling techniques to maximize methane production through accelerated waste decomposition. The methane enhancement project located at the Yolo County Central Landfill (YCCL) near Davis, California entailed the construction and instrumentation of two demonstration test cells. Instrumentation of each cell includes measurement of waste temperature, moisture, pressure, and volumetric gas flow. One cell serves as a control cell while the other cell receives controlled liquid additions and is called the "enhanced cell". Each of the two cells has a base area of 100 by 100 feet and a depth of about 45 feet. Approximately 9,000 tons of municipal solid waste was placed in each cell. Cell filling occurred from April to

October 1995, and liquid addition to the enhanced cell began on October 23, 1996. The cells are covered with impermeable membranes and surrounded by compacted clay levees to ensure complete containment of all landfill gas and moisture. Each test cell has one experimental vertical shredded tire gas well and one standard vertical gravel gas well. A horizontal gas collection system that consists of a 'blanket' layer of shredded tires was also constructed over the surface of the waste in each test cell. See Figure 1 for cross section of demonstration cells. The design and construction of each gas collection system was documented and compared to determine the constructability of the shredded tire gas collection systems. A comprehensive monitoring plan was implemented to investigate the performance of each gas collection system. The monitoring plan includes gas composition measurements and gas collection tests performed on each well configuration. Results of the monitoring phase were compared between each well type to determine the relative performance of shredded tires as a gas collection medium. The horizontal shredded tire layer in the enhanced cell also served as a medium to distribute both water and leachate into the solid waste. Moisture sensors placed throughout the waste along with field observations and maintenance records will be used to determine the relative performance of the shredded tires in this application.

WASTE TIRES AS A GAS COLLECTION AND LIQUID DISTRIBUTION MEDIUM

The effectiveness of shredded tires in landfill gas collection and leachate distribution systems depends on four main technical issues: permeability, compressibility, chemical and biological interactions, and constructability. After examination shredded tire properties with respect to each technical issue were found to be comparable to gravel in these applications.

Permeability

The ability of shredded tires to transfer landfill gas and distribute liquid depends on the shredded tire's permeability. Laboratory permeability tests performed on 3 inch minus shredded tire pieces have been shown to be equivalent to gravel aggregate (Humphrey, 1993). Recent demonstration projects have also been successful in using shredded tires as drainage material in landfill cover designs. These projects commonly use 3 inch minus shredded tire pieces. However, at the time of the project construction 3 inch tire chips were not available, so 'one-pass' 12 inch shredded tires were used. Based on field observations made during construction, the larger tire chips created sufficient void spaces for gas transfer and liquid distribution.

Compressibility

Due to their elastic nature, shredded tires tend to compress more readily than gravel. The compressibility of shredded tires depends on the applied normal stress, and has been measured to compress along a range of 5 to 50 percent. Based on test data conducted on various tire chip sizes, a minimum permeability of 0.10 cm/sec is attainable regardless of the overburden pressure (Donovan, 1997). In the case of the horizontal tire layer of the project the 3 foot uncompressed tire layer was observed to compress to 2 feet under the applied normal load from the overlying soil cover.

Chemical and Biological Interactions

There has been concern that chemical or biological interactions between shredded tires and the landfill environment may cause the tires to leach materials. However, degradation or decomposition is not likely due to the inert nature of tires. In fact, laboratory tests conducted at the University of Wisconsin indicate tire chips actually absorb both vapor and liquid phase volatile organic compounds (Donovan, 1997). It is recommended in this study to excavate a portion of the shredded tires from the horizontal gas collection layer in both cells. Samples would then be analyzed to determine the effects of a corrosive landfill environment and leachate recirculation has on shredded tires over time.

Constructability

Constructability is a technical concern due to the lack of previous construction experience with shredded waste tires. Therefore, construction of a horizontal test pad was performed to determine the feasibility of the design. Construction of the vertical gas well and the horizontal layer using shredded tires was also documented to provide guidelines for future projects.

A brief description of the well configuration, and design and construction considerations is presented in the following section

Vertical Gas Collection Wells

Each cell was constructed with one 'conventional' vertical gravel well and one experimental shredded tire well. The wells consist of a circular wire mesh cylinder embedded in the buried waste and filled with either 'one-pass' 12 inch shredded waste tires or gravel. Gas is collected through a 4 inch slotted PVC pipe placed in the center of each well. A cut-off collar consisting of compacted clay and geomembrane was constructed near the top and bottom to isolate each well from the leachate collection system and horizontal tire layer, thereby eliminating any direct hydraulic connections between the wells. The vertical well assemblies were raised after each 5 foot lift of waste was placed, for a total depth of approximately 45 feet of solid waste in each cell.

Design and construction considerations: 1. The method of well construction used in this project is not standard industry practice. Typically, a 2 foot diameter gas well is drilled and installed into the refuse after completion of waste placement. In this project, the wells were not drilled after filling but were constructed as the waste was placed, increasing the height of the wells after each lift of waste was placed. This method of construction was chosen due to the nature of the project design and also allows the wells to be used as a conduit for the sensor instrumentation wires.

2. Both the gravel and shredded tire wells used the same construction procedure. Each well was filled by shoveling the gravel or shredded tires from a back hoe into a confining wire cage that contained the gravel or shredded tires while waste was placed around the wells.

3. Each well has a slotted gas collection pipe in the center of the well. Placing the large 'one pass' tire chips inside a 2 foot diameter well with the gas collection pipe in the center would have been difficult to fill. Therefore, for ease of construction, the shredded tire well diameter was increased to 4 feet. However, based on project results, it was found that the shredded tires may be able to conduct landfill gas to a collection point without a slotted gas collection pipe in the well. This would allow a smaller diameter well to be used for the shredded tires. Alternately, smaller tire chips such as 3 inch size would also allow for a smaller well diameter.

4. The large 4 foot diameter wire cage used to contain the shredded tires tended to bend and deform while extending the well vertically and placing the surrounding waste. The smaller wire cage used in the gravel wells was sturdier, which made the well construction easier. If the tire particle size was reduced or the slotted pipe was not used, the well size could be reduced thereby easing the tire well constructability.

Horizontal Landfill Gas Collection System

The horizontal gas collection system consists of a 'blanket' layer of shredded tires placed over the entire waste surface of each demonstration cell. The system profile starting at the waste and moving upward includes a 2 foot layer (compacted thickness) of 'one-pass' shredded tires, a non-woven geotextile layer, a 1.5 foot protective layer of soil, and a 40-mil linear low density polyethylene (LLDPE) geomembrane surface cover. This shredded tire layer serves to collect and conduct landfill gas to a perforated 4 inch diameter PVC pipe placed in the shredded tire layer and connected to the landfill gas extraction system. Application of this system design of surface collection with an overlying geomembrane surface cover, increases the landfill gas capture efficiency to nearly 100% and prevents fugitive emissions of greenhouse gases.

Design and construction considerations: 1. Before constructing the horizontal shredded tire gas collection system, it was necessary to construct a test pad to assess if the system profile would provide a smooth enough surface for placement of the 40-mil surface geomembrane. Construction of the 290 square foot test pad went smoothly. Following fine grading of the soil subgrade, the surface grade was found to be suitable for liner placement.

2. It was noted during the construction of the test pad that a front-end loader with a large bucket was the preferred equipment for the shredded tire placement. This was due to the bulky nature of the larger shredded tire pieces. If smaller particle sizes were used (3 inches minus) then a smaller bucket size would be suitable for tire placement.

3. The method of tire placement and grading was similar to aggregate material, in which a Caterpillar D6 dozer and backhoe were used. Difficulty in accurately reaching final grade was encountered due to the compressibility of the tire layer under the weight of the equipment. For this reason it is recommended that low-ground pressure equipment be used for tire placement. The shredded tire layer was 3 feet in thickness uncompressed, and 2 feet under the normal load from the overlying soil subgrade. The average uncompacted density of the shredded tires is approximately 17 pounds per cubic feet and compacted density is about 25 pounds per cubic feet. This was calculated based on the tonnage of shredded tires used in the horizontal layers, the surface area covered, and the observed thickness of the shredded tire layers.

4. During soil placement, the weight of the soil layer caused differential settlement in the shredded tire layer, resulting in the placement of an uneven thickness of soil to obtain a final smooth grade.

5. To protect the surface liner from punctures caused by metal protrusions from the shredded radial tires, a 1.5 foot layer of soil was placed above the shredded tire layer. A non-woven geotextile layer between the shredded tire layer and soil was placed to prevent clogging of the shredded tire layer by soil intrusion.

6. The surface liner must be adequately weighted after final placement to eliminate damage that may occur by wind uplift. It was also observed that to low of an applied

vacuum to the horizontal gas collection system would cause excessive surface liner ballooning due to accumulation of landfill gas in the tire layer.

7. The project's horizontal shredded tire gas collection system covers the full surface area of each demonstration cell and is part of the cover system. Typical horizontal gas systems consist of trenches similar to vertical gas wells in that they are placed in the waste with a set spacing. The constructability of a horizontal tire layer was proven by this project but the optimal design and application for this type of collection system still needs to be determined for full scale projects.

PROJECT RESULTS

One objective of this project is to demonstrate that shredded waste tires will perform as well as gravel material in landfill gas collection systems. This was achieved by monitoring and comparing the gas composition and flow rates of the two types of shredded tire gas collection systems to conventional gravel wells. Gas composition from each well configuration has been monitored throughout the monitoring phase of the project. Gas collection performance tests were conducted on each gas collection system to measure flow rates. Project results related to the performance of the shredded tire gas collection systems are discussed below.

Gas composition comparison

To determine the effect of shredded waste tires on gas composition, the methane percentage from each well was measured weekly beginning in November 1996. The landfill gas composition was measured using a portable gas chromatograph, which is able to detect methane, carbon dioxide, nitrogen and oxygen. The gas measurements were then corrected for air intrusion through surface liner leaks. The methane percentage from the horizontal tire layer, vertical tire well and vertical gravel well for the enhanced and control cell is plotted versus time in Figures 2 and 3. Throughout the gas composition monitoring, the percent methane did not vary significantly between the different well types. The methane percentage in the vertical tire well averaged only 1% higher than the gravel well in the enhanced cell and 2% higher in the control cell. The methane percent from the horizontal layers are consistent with the vertical well percentages. Based on these measurements, gas composition in this project is independent of the type of collection medium. The methane percentages from each well type ranged from 30% to 59% in the enhanced cell and from 37% to 60% in the control cell.

Gas flow rate comparisons

To determine if the permeability of compacted shredded tires is comparable to gravel as a gas collection medium, gas collection tests were performed. During each test, a vacuum was applied to one gas well and the volumetric flow was measured. Gas flow rates were then calculated and compared between each well type. Pressure measurements were also taken within the waste mass to determine if any correlation could be made with well type.

Horizontal gas collection tests

During the horizontal gas collection tests a vacuum was applied only to the horizontal layer while both vertical gas wells were closed. Table 1. lists the gas flow rates for the horizontal gas collection tests. Gas collection tests were performed in October 1996, February 1997 and January 1998. Gas flow rates from the October 1996 tests were about 55 standard cubic feet per minute (scfm) and at least five times larger than the average monthly flow for the cells. These elevated flow rates were attributed to air leaks in the gas recovery pipeline and do not represent actual gas generation and therefore are not reported in Table 1. The air leaks in the gas recovery pipeline were sealed in November 1996. Flow rates in the February 1997 test were within 6 scfm of the average flow rate of the month. The enhanced cell flow rate was 40 scfm and 20 scfm in the control cell. Results from the January 1998 flow rates test were similar to the February 1997 in that the control cell horizontal tire layer was able to transfer all the gas generated in the cell. However, during the test the applied vacuum stabilized to a lower pressure than was necessary to draw all the gas generated in the enhanced cell. The low vacuum is sufficient to extract all the gas generated in the control cell but was less than what was required in the enhanced cell. This was also confirmed by the enhanced cell's surface liner ballooning during the test due to the accumulation of landfill gas in the tire layer. Therefore, the flow rate measured in the test was less than the average monthly flow rate.

TABLE 1. HORIZONTAL TIRE LAYER GAS COLLECTION TEST RESULTS

Date and Duration of Test (minutes)	Applied Vacuum (inches of water) *(Applied Vacuum During Normal Operation)*	Control Cell Flow Rate (scfm) *(Average Monthly Flow Rate)*	Enhanced Cell Flow Rate (scfm) *(Average Monthly Flow Rate)*
2/27/97 120 minutes	-1.00 *(-0.7 to -1.2)*	20.3 *(25.8)*	40.4 *(38.7)*
1/29/98 305 minutes	start -0.80, end -0.42 (-0.80)	13 (11)	21 (30)

TABLE 2. ENHANCED CELL VERTICAL TIRE AND GRAVEL WELL GAS COLLECTION TEST RESULTS

Date and Duration of Test (minutes)	Applied Vacuum (inches of water) *(Applied Vacuum During Normal Operation)*	Tire Well Gas Flow Rate (scfm) *(Average Monthly Flow Rate)*	Gravel Well Gas Flow Rate (scfm) *(Average Monthly Flow Rate)*
2/28/97 156 minutes	-2.12 *(-0.0 to -0.1)*	45.9 *(38.7)*	—
3/6/97 294 minutes	-.81 *(-0.7 to -1.2)*	—	33.2 *(38.7)*
5/6/97 28 minutes	-1.25 *(-1.25)*	37 *(40)*	37 *(40)*
1/30/98 78 minutes	-0.45 to -1.60 (-0.80)	24 (30)	11 (30)

Pressure sensors are located throughout the horizontal tire layer and were measured during the gas collection tests. Pressure within the horizontal layer stabilized within ten minutes to an equalized pressure gradient. This quick stabilization of pressure indicates there are low friction losses within the shredded tires and minimum clogging of void spaces.

Based on the flow rates and pressure measurements, the horizontal tire layer was able to transfer all of the gas generated without extraction from the vertical wells. Placement of a horizontal shredded tire gas collection system in a landfill would be able to capture the gas while eliminating the need for vertical gas wells. Significant cost savings could be realized while developing a new market for shredded waste tires.

Vertical gas collection tests

A vertical gas collection test was performed on both the vertical tire and gravel wells. In each test the vacuum was applied to only one vertical well while the other vertical well and horizontal tire layer were closed. Gas volumes and pressure within the waste mass were measured during each test. Gas collection tests were performed in October 1996, February 1997, May 1997, and January 1998. Results of the vertical tire and gravel well tests for the enhanced and control cell are listed in Table 2 and 3. As previously discussed, results from the October 1996 test are not reflective of system performance due to air leaks in the gas recovery pipeline and therefore is not presented. Flow rates measured during the February and March 1997 tests are not directly comparable between the tire and the gravel wells due to the applied vacuum differences. However, results from the May 1997 test show the gas flow rates were the same between the tire and gravel well in the enhanced cell and differed only by 2 scfm in the control cell. The January 1998 results for the control cell are comparable between the well types with a difference of 4 scfm. However, the enhanced cell results were not comparable with the tire well having a flow rate 13 scfm higher than the gravel well. This difference in flow rate may be due to the variation of applied vacuum in combination with the higher landfill gas generation rate in the enhanced cell. The pressure measurements within the waste was measured during each test. These measurements varied significantly. At such a low applied vacuum, no sphere of influence was created by either gas collection well. The pressure measurements within the waste were reflective of the conditions within the waste and not on the well type.

TABLE 3. CONTROL CELL VERTICAL TIRE AND GRAVEL WELL GAS COLLECTION TEST RESULTS

Date and Duration of Test (minutes)	Applied Vacuum (inches of water) *(Applied Vacuum During Normal Operation)*	Tire Well Gas Flow Rate (scfm) *(Average Monthly Flow Rate)*	Gravel Well Gas Flow Rate (scfm) *(Average Monthly Flow Rate)*
2/28/97 156 minutes	-2.12 *(-0.0 to -0.1)*	39.0 *(25.8)*	———
3/6/97 294 minutes	-0.81 *(-0.7 to -1.2)*	———	13.1 *(25.8)*
5/6/97 28 minutes	-1.25 *(-1.25)*	29 *(26)*	31 *(26)*
1/30/98 78 minutes	-0.45 to -1.60 (-0.80)	11 (11)	15 (11)

Fire hazard potential

One of the greatest concerns in using shredded waste tires is the potential for them to catch on fire. Fire hazard from tires is increased when there are elevated temperatures and a supply of fuel and oxygen. To assess the fire potential of the shredded tires placed in the vertical wells, temperature measurements of the shredded tires and oxygen content were investigated.

To determine if any elevated temperatures are occurring within the shredded tires, temperatures inside each vertical well were measured and compared to the corresponding waste temperatures. Temperatures within each well and the surrounding waste temperatures are plotted versus depth in Figures 4, 5, and 6. The surrounding waste temperatures were measured by thermistors placed in the refuse during cell filling. The temperature in the wells was measured using a K-type thermocouple that was lowered into the well casing from the top of well. Due to difficulties in lowering the thermocouple into the enhanced cell gravel well, temperature measurements are limited to 25 feet below the top of the well on February 6 and March 4, 1997. A depth of 20 feet from the top of the well corresponds to Level 3 in the waste mass and a depth of 40 feet corresponds to Level 2 as depicted in Figure 1. In all figures the temperature in the tire wells followed the same general trend as the gravel wells. Temperatures increased slightly until reaching a steady state condition at a depth of about 20 feet (Level 3). The initial temperature increase is associated with moving the thermocouple past the exposed well section located above the surface liner to the well section embedded in the waste. In all figures the majority of the tire well temperatures were slightly lower than or equal to the gravel well temperatures. The lower temperature in the tire wells is attributed to heat losses while passing through the larger well diameter in the tire wells.

Both the tire and gravel well temperatures were representative of the surrounding waste temperature. The tire wells averaged 7 degrees Fahrenheit lower than the surrounding waste temperature while the gravel well averaged 1 degree Fahrenheit lower. The lower temperatures in the enhanced cell are due to the addition of cool liquid into the cell as part of the enhancement technique that cooled the waste.

The gas composition for each cell has been monitored since July 1996. The percent oxygen measured in the gas samples collected from the vertical wells and horizontal wells have averaged less than 1%. This is close to background levels of 0.7% oxygen associated with sample collection methodologies. The data collected in this project indicates shredded tires are a minimum fire hazard in this landfill application.

SHREDDED WASTE TIRES AS A LEACHATE INJECTION

The use of shredded tires as a leachate drainage and collection material is being investigated more recently due to waste tire availability and potential cost savings. In this project shredded waste tires were used to distribute liquid (water and leachate) to the waste in the enhanced cell. This is accomplished by evenly distributing liquid to fourteen infiltration trenches. The infiltration trenches were dug in the final lift of waste, backfilled with shredded tires, and are part of the horizontal shredded tire layer. Placed on 20 foot centers, each trench is roughly 10 feet long, 5 feet deep, and 3 feet wide. Moisture distribution within the waste is tracked through an array of moisture sensors placed during cell filling. Based on the moisture sensor readings, liquid was fairly uniformly distributed throughout the waste mass. As would be expected, the waste closer to the infiltration trenches achieved higher moisture content than the lower levels. Within each instrumentation level, moisture appears to be well distributed horizontally. However, moisture sensors located at the south side of the cell were the first to detect increases in moisture at all levels, significantly sooner than the corresponding sensors on the north side. The two vertical gas recovery wells are located near the south side of the cell. Since the vertical wells were constructed during waste filling, it is thought that the waste compaction was less in this area which may attribute to the rapid increase in moisture content. Significantly more settlement has also been observed around the vertical wells than the rest of the surface of the enhanced cell.

Based on field notes and maintenance records, no clogging of the infiltration trenches has occurred. Liquid infiltration rates have been shown to be dependent on the waste permeability and not on the shredded tire's properties. The rapid stabilization and uniform pressure gradients measured throughout the horizontal shredded tire layer is also in agreement with no clogging of the shredded tires.

ECONOMICS OF SHREDDED TIRE UTILIZATION

Based on the project results, shredded tires performed comparable to gravel as a gas collection medium. Therefore, the economic benefits and costs associated with their use in this application needs to be investigated. The following section provides a summary of some of the factors, which may effect the use of shredded tires.

The cost savings associated with using shredded tires as a substitute for gravel is dependent on the availability of waste tires, tire processing costs, transportation costs and the net landfill space acquired or lost. Due to limited markets for waste tires, there is a large available supply of waste tires throughout the United States. Transportation costs are based on nearest waste tire supplier or processor and can vary greatly between site locations. Tire processing costs depends on the desired chip size. In general, the processing costs increase as the chip size decreases. Average costs for processing large 12 inch tire chips such as the ones used in this project is about \$5.00/ton. Smaller chip sizes, 2-3 inches in wide and length, is about four times higher at \$20.00/ton. In this project the cost of shredded tires was less than gravel as a landfill gas collection material. This is largely due to the available supply of shredded waste tires in the area.

Placement of the shredded tire pieces in this project was the same as gravel since standard equipment was able to be used.

Yolo County currently does not landfill shredded tires because the tipping fee at YCCL is higher than at other waste disposal facilities located closer to waste tire processors. However, if full scale application of shredded tires use was implemented, Yolo County could attract shredded tires to YCCL by lowering the tipping fee for tire disposal. The revenue derived from the tipping fee would easily cover costs of shredded tire placement.

Landfill space is lost by the larger vertical tire well diameter and should be included as an additional cost. However, this may be neglected if the size of the tire chips were reduced so that the tire well is the same size as the gravel well. However, smaller chip size would increase the tire processing cost. An alternative to smaller chip size would be to install a 2 foot diameter shredded tire well with the same 12 inch minus pieces, but without the slotted gas collection pipe in the center. Based on gas flow rates and uniform pressure measurements within the horizontal shredded tire layer, a shredded tire well can collect and transfer the gas without the aid of the slotted gas collection pipe.

Well construction time was about the same for the vertical gravel and shredded tire wells. If the wells were drilled, equipment costs and time would not vary between the gravel and the tire wells, assuming equal well diameters.

The most significant cost of shredded tire layers or horizontal trenches is the loss of landfill volume that would be occupied by the shredded tires. Of course, vertical wells occupy landfill space also, but typically much less than horizontal systems. However, this loss of landfill volume could be mitigated by modifying the design cover system to use the shredded tire layer as a substitute for another component, such as the foundation layer; or using shredded tires as an intermediate cover within the waste fill. In other words, the shredded tire layer could be placed in such a way that the landfill volume occupied by the shredded tires is to some degree offset by substituting for the required intermediate cover soil layer.

Installation of horizontal shredded tire layers without a piping network would eliminate the cost of gas collection pipes. It would also lessen expenses related to the damage of gas collection pipelines from differential settlement.

An environmental benefit of shredded tire use is the reduction of gravel mining that has significant impacts on wetland habitats. Tire use would increase the waste tire diversion rate by creating new tire markets. The 2 foot thick horizontal tire layer used roughly 200 tons of shredded tires in the control cell, and 295 tons in the enhanced cell. The enhanced cell used more shredded tires to fill the 14 leachate infiltration pits used for liquid addition and leachate recirculation. Roughly 50,000 tires were used to construct the two horizontal layers. Placement costs for full scale projects using large quantities of shredded tires could be covered by the shredded tire disposal fees.

Additional benefits of shredded tires as a dual system (gas collection and leachate distribution) could improve the economics of gas to energy projects, extend landfill life and potentially reduce closure costs. In particular, the combination of early landfill gas recovery with accelerated landfill decomposition will greatly improve the economics for landfill gas energy projects. Even more significant is the potential for closure cost savings. Using horizontal shredded tire layers as a dual system to collect landfill gas early in the decomposition process and distribute liquid for accelerated landfill decomposition, the need for long-term waste containment with low permeability layers (geosynthetics or low permeability clay) could be precluded. If the landfill could be managed to rapidly decompose, thereby achieving total landfill gas yield within a relatively short time period, while controlling emissions, it might be possible to close the landfill with a soil layer for vegetative growth without the cost of a composite liner system (geosynthetics and soil) as current regulations require. Such an approach would result in a significant cost savings.

CONCLUSIONS

The objective of this project is to promote a potential market for waste tires in the landfill industry, in particular, the use of shredded tires as a component in landfill gas collection and leachate injection systems. It is hoped that results from this demonstration project will provide the necessary data for further investigations in full scale projects. Excavation and testing of shredded tires used in both the control and enhanced cell would also provide information on the long term effects of the corrosive landfill environment on shredded waste tires.

Shredded tires as a landfill gas collection medium shows great potential based on the results of this project. The low cost of shredded tires removes economic constraints and creates opportunities for innovative designs using shredded tires for gas collection. The use of shredded tires for intermediate cover or as a component of final cover system, could provide early and effective landfill gas collection at a low cost.

The constructability of vertical gas collection wells using shredded waste tires was successfully demonstrated. The same equipment and methodology was used to construct both the vertical tire well and the conventional vertical gravel well. However, due to the well configuration (i.e. placement of the gas collection pipe and size of tire chips), it was necessary to construct the shredded tire wells with a 4 foot diameter as opposed to a 2 foot diameter in the gravel wells. If the size of shredded tires were reduced, then the well size could also be reduced. Another alternative would be to use the 'one-pass' 12 inch minus shredded tires in a 2 foot diameter well without the installation of a slotted gas collection pipe. Based on project results, the shredded tires would be able to capture the gas without the aid of this slotted gas collection pipe.

Based on gas flow rates measured from the vertical shredded tire wells and the conventional gravel wells, the shredded tires performed comparably to gravel as a medium to collect landfill gas from solid waste landfills. The horizontal tire layer was able to transfer all of the gas generated in the each cell without extraction from the vertical wells. Pressure within the tire layer indicates that friction losses are low within shredded tires at the velocities associated with landfill gas collection. Low friction losses within the shredded tires indicate a gas collection pipe is not necessary for gas capture. Full scale horizontal shredded tire gas collection system in a landfill would then be able to capture the gas while eliminating the need for vertical gas wells. Significant cost savings could then be realized while developing a new market for shredded waste tires.

The constructability of a horizontal gas collection system that consists of a 'blanket' layer of shredded tires has also been successfully demonstrated in this project. Roughly 500 tons of shredded waste tires were used to construct two horizontal systems. The contractor was able to use standard construction equipment to place and grade the shredded tires. The tendency of the shredded tire layer to compress caused only minor difficulties in accurately reaching final grade.

Gas analyses performed on each gas collection system indicate that the gas composition is independent of the type of collection media. Well temperatures in the vertical gravel and shredded tire wells did not vary significantly and were representative of the surrounding waste temperature. The temperature measurements within the wells and oxygen concentrations in the landfill gas do not support the notion that shredded tires in the landfill are a fire hazard.

The horizontal shredded tire layer in this project is an innovative design. It served not only to collect landfill gas, but also in liquid addition and leachate recirculation. This combination of landfill gas recovery with accelerated landfill decomposition could greatly improve the economics for landfill gas to energy projects. By managing the landfill to rapidly decompose, the total landfill gas yield can be collected within a short time rather than over an extended period. Positive results from this project show promise that this design is feasible for full scale operation. However, since this is an innovative design, the optimal design still needs to be determined and should be investigated. By constructing and monitoring a full scale demonstration project, critical design issues can be assessed and further performance data collection. This would facilitate the promotion of a new market for shredded waste tires in landfill operations.

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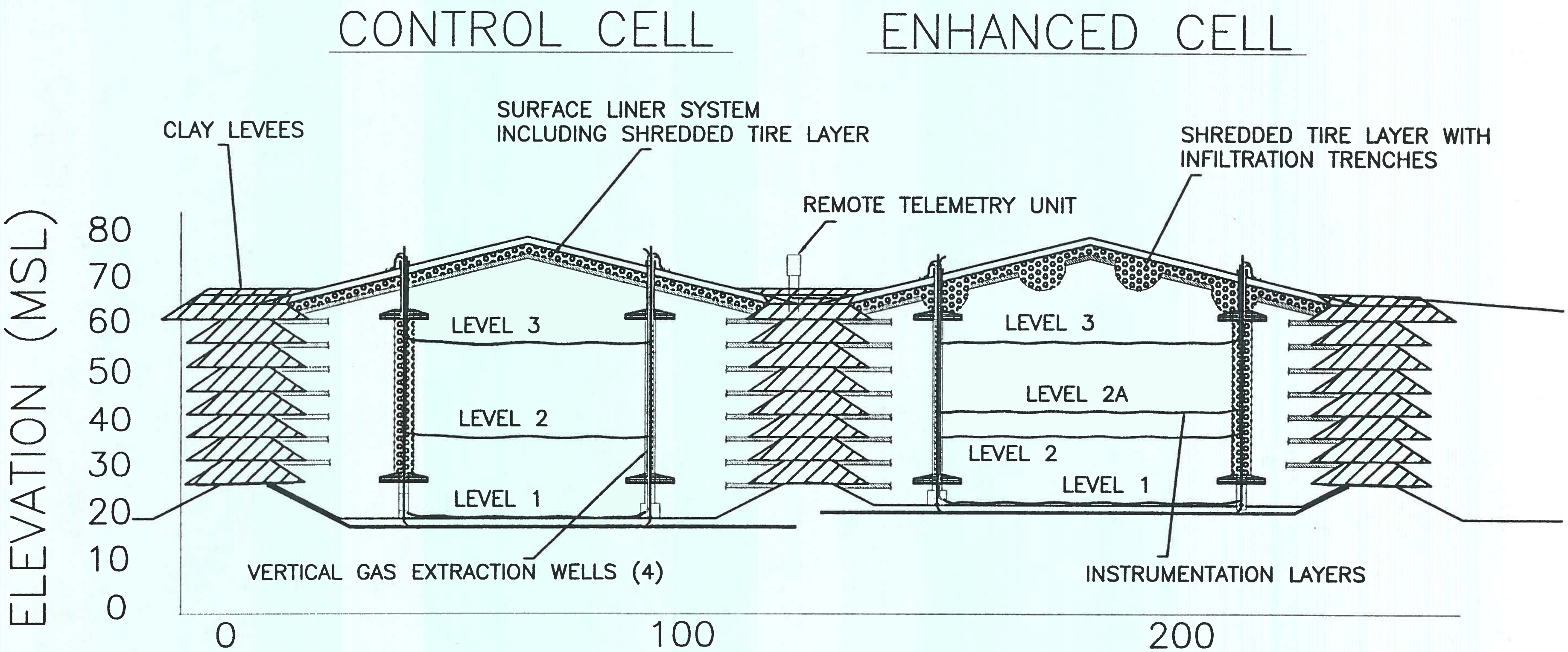

LANDFILL BIOREACTOR DEMONSTRATION CELLS
CROSS SECTION

FIGURE 1

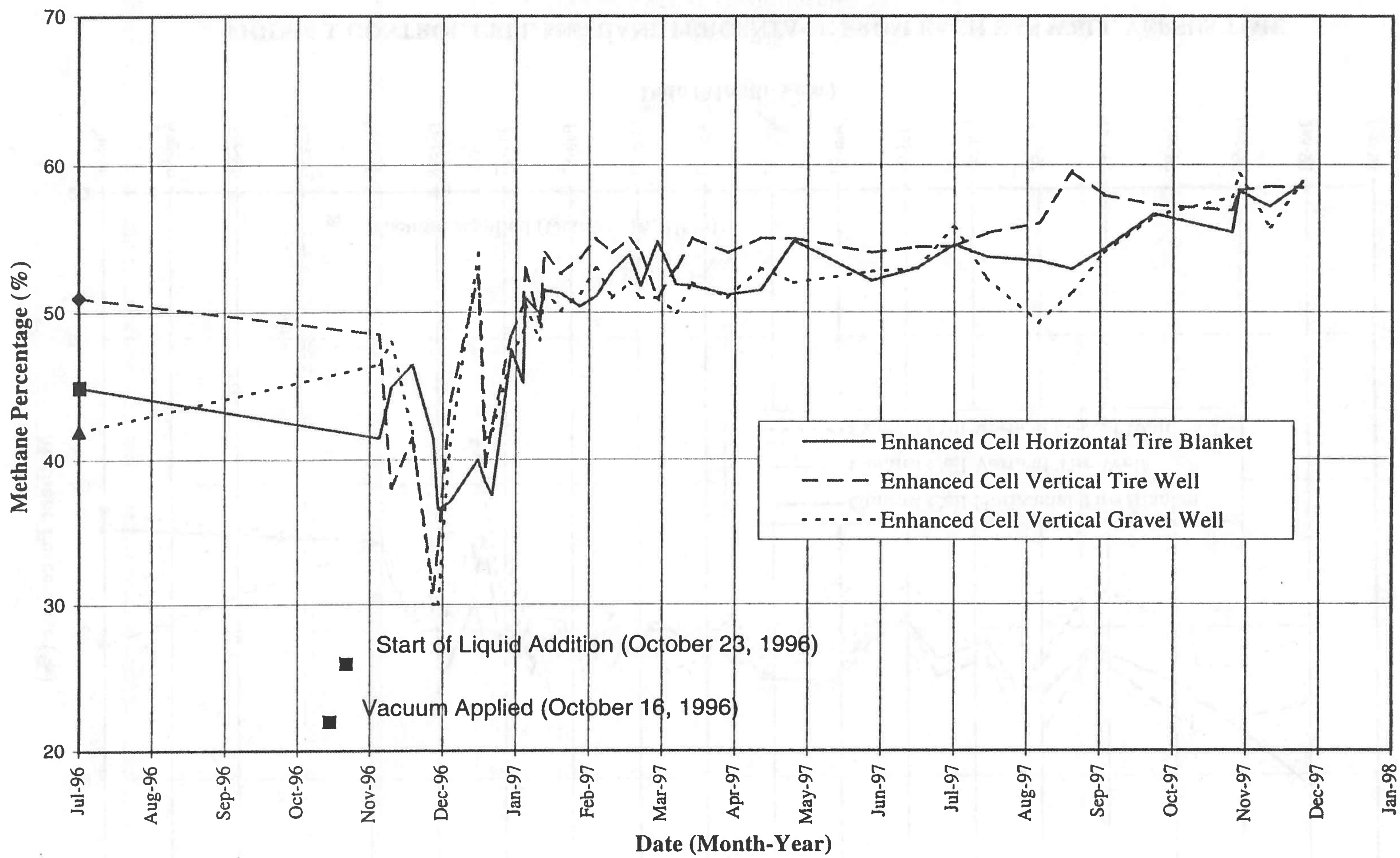

FIGURE 2. ENHANCED CELL METHANE PERCENTAGE FROM EACH GAS WELL VERSUS TIME

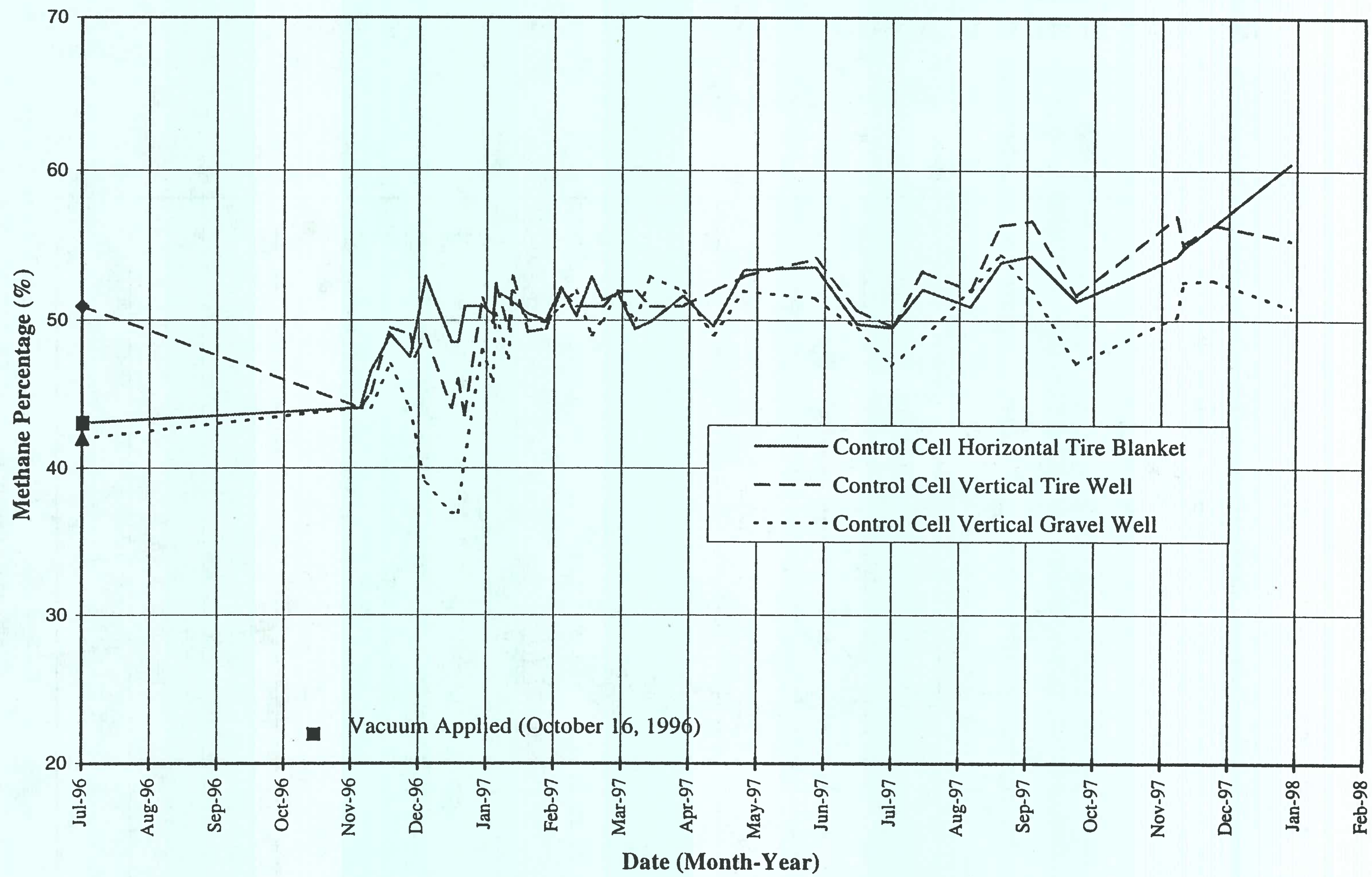

FIGURE 3. CONTROL CELL METHANE PERCENTAGE FROM EACH GAS WELL VERSUS TIME

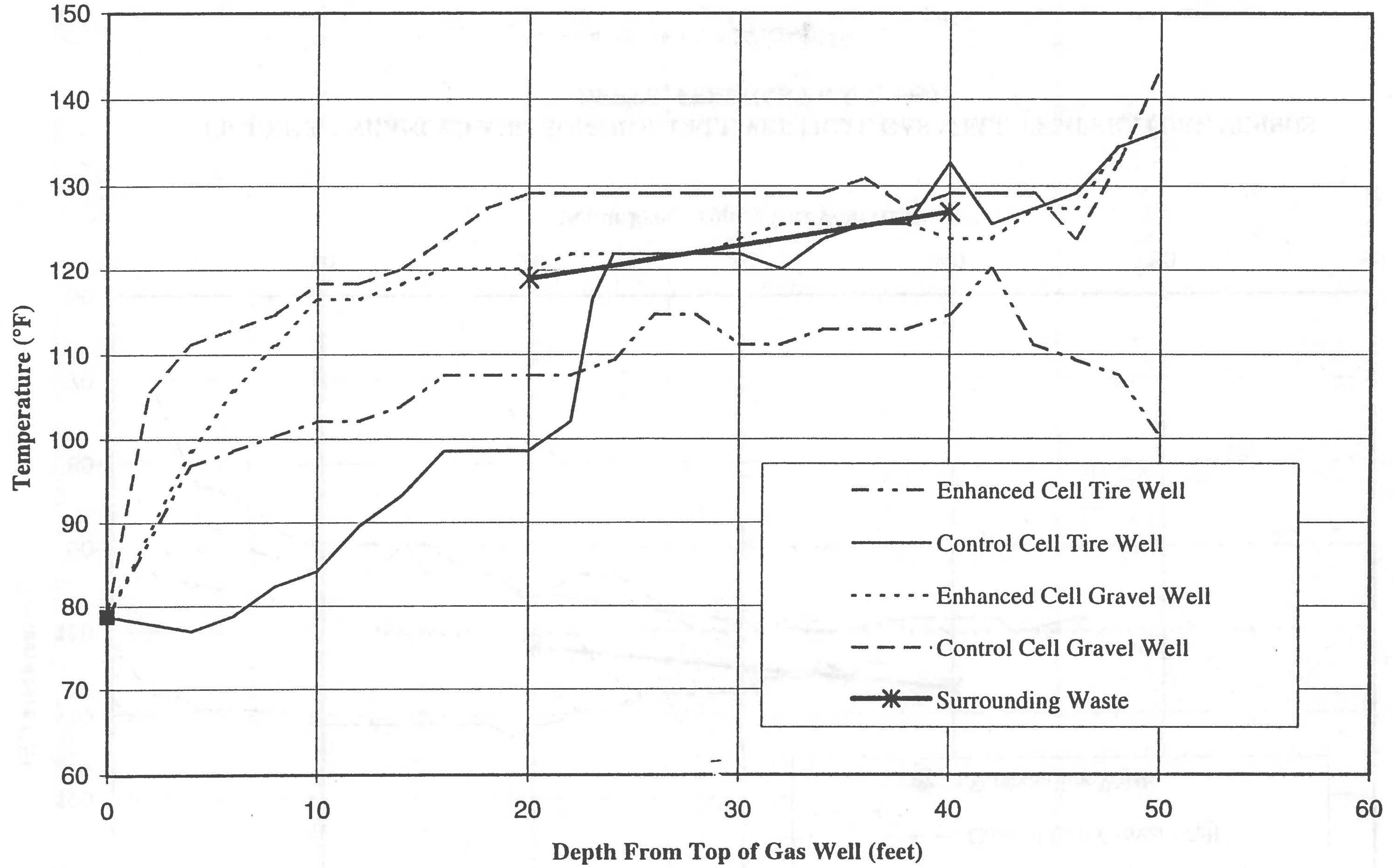

FIGURE 4. ENHANCED AND CONTROL CELL VERTICAL GAS WELL TEMPERATURE VERSUS DEPTH, NOVEMBER 5, 1995

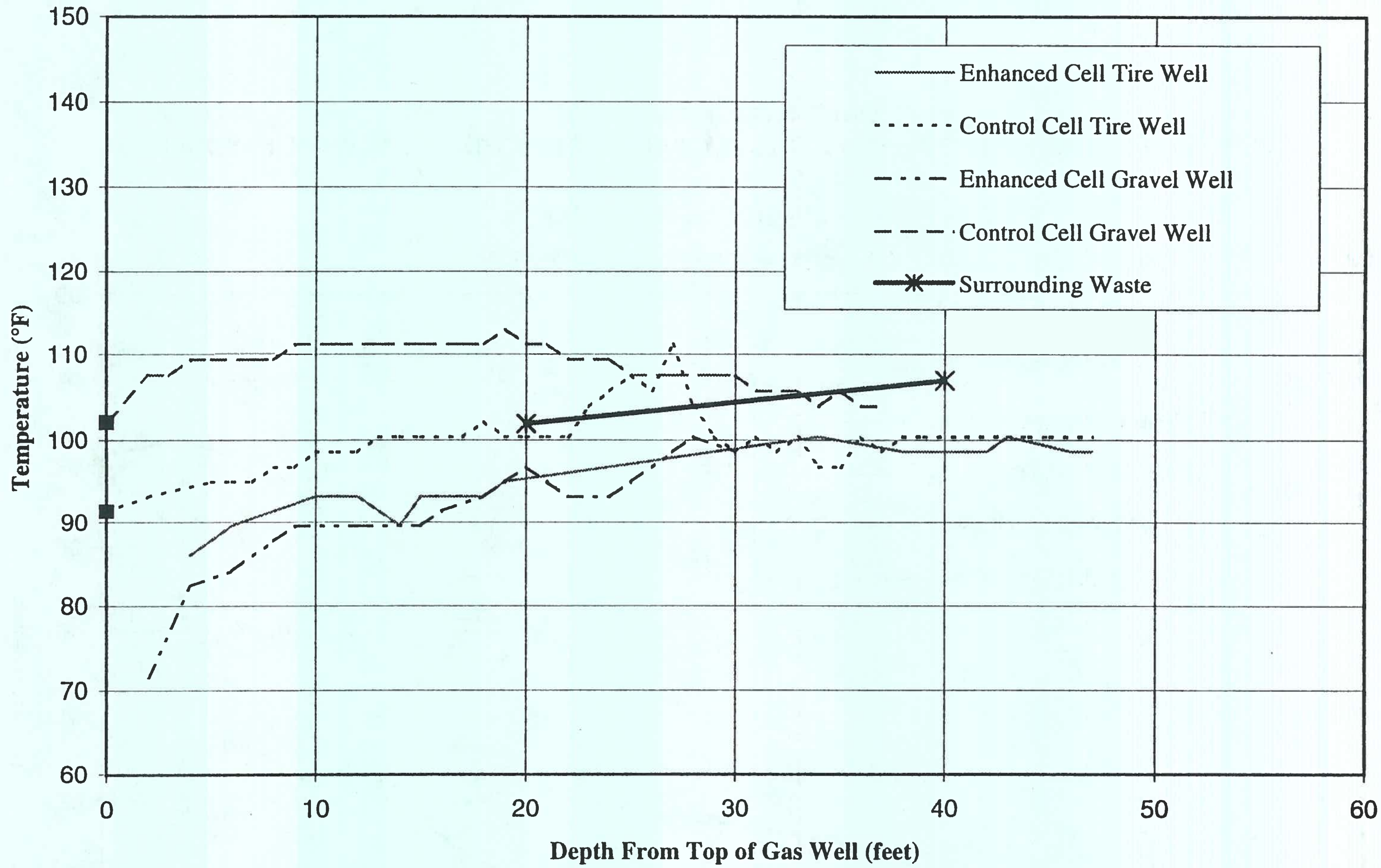

FIGURE 5. ENHANCED AND CONTROL CELL VERTICAL GAS WELL TEMPERATURE VERSUS DEPTH, FEBRUARY 6 & 7, 1997

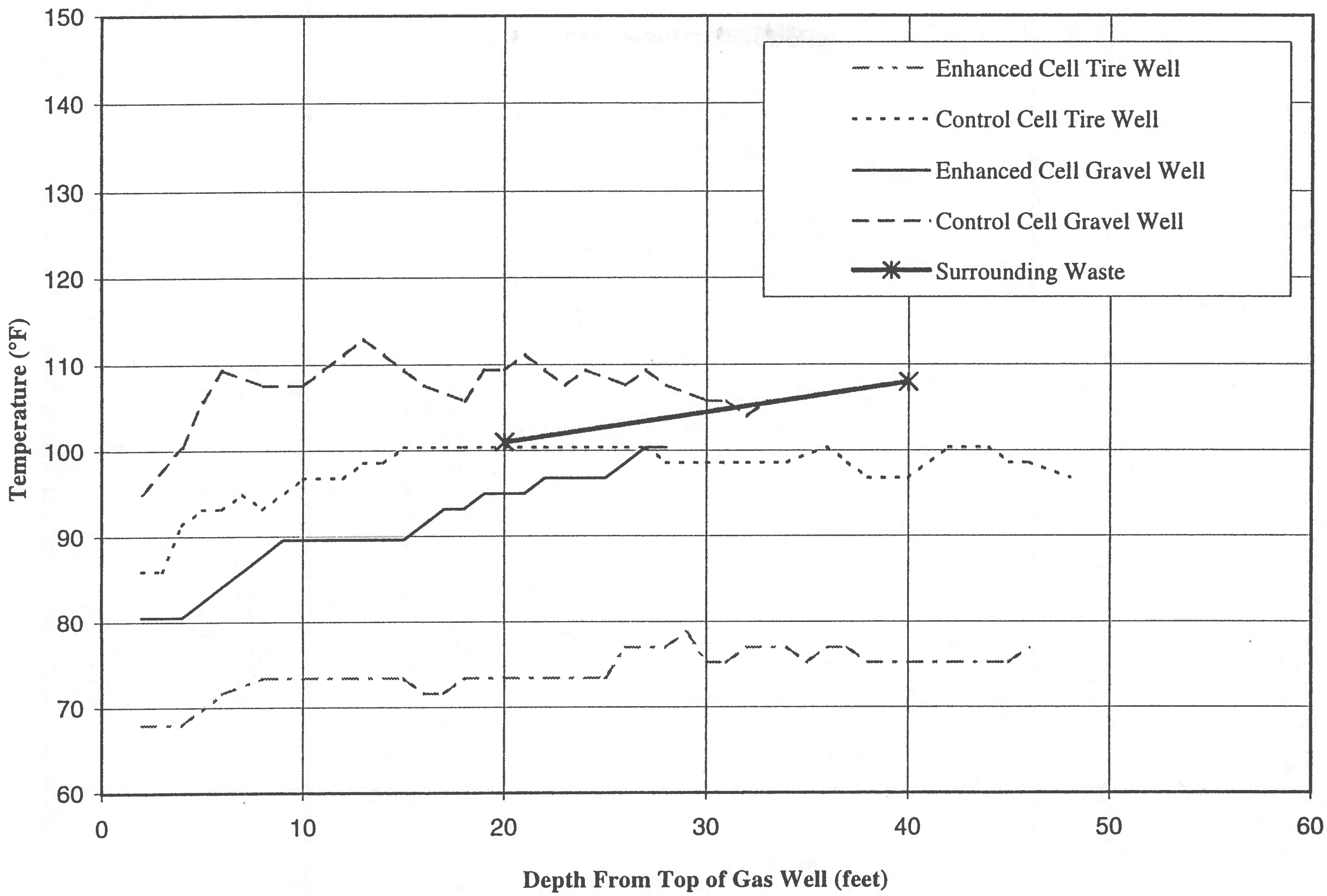

FIGURE 6. ENHANCED AND CONTROL CELL VERTICAL GAS WELL TEMPERATURE VERSUS DEPTH, MARCH 4, 1997