VOLUME 5

Deliverables to meet work plan objective 4: Instrument the landfill bioreactor to permit in-situ monitoring of bioreactor activity and to measure previously unmeasured information

5.1 Work Plan Objective and Deliverables

Objective 4 of the project work plan was:

> *Instrument the landfill bioreactor to permit in-situ monitoring of bioreactor activity and to measure previously unmeasured information (e.g. leachate head on the liner)*

The work plan identified the following methodology to meet objective 4:

> *Instrumentation will be installed for in-situ monitoring of landfill parameters. This instrumentation includes transducers for measuring head on the liner, and monitoring probes for measuring waste temperature and moisture content. Additional information on instrumentation is presented in Table 4.3 and respective tables (see Volume 1 Bioreactor work plan for tables) for sites other than the New River Regional Landfill site.*

The deliverables identified in the work plan included:

- *Statement of successful placement and operation of instrumentation and equipment.*
- *Presentation of data in periodic reports.*

5.2 Innovative use of Instrumentation for the Project

In the Florida bioreactor demonstration project, in-situ sensor technologies were used to monitor bioreactor status at several sites. Innovative uses of in-situ instrumentation included pressure transducers for head on liner, total earth pressure cells for overburden pressures, electrical resistance-based and time domain reflectometry (TDR) sensors for moisture measurement, thermocouple wires for temperature control, and piezometers for pore water pressure. The results of monitoring with the in-site instruments are presented the following lists of publication.

Appendix C. Theses and Dissertations

- Saraf, S. (2000). “Use of pressure transducers to measure landfill head on liner.” Masters Thesis, University of Central Florida, Orlando, FL.
- Thomas, P.A. (2001). “The testing and evaluation of a prototype sensor for the measurement of moisture content in bioreactor landfills.” Masters Thesis, University of Central Florida, Orlando, FL.
- Spafford, M. (2002). “Performance evaluation of landfill liner systems using pressure transducers.” Masters Thesis, University of Central Florida, Orlando, FL.
- Timmons, J. (2004). “Total earth pressure cells for measuring loads in a municipal solid waste landfill.” Masters Project, University of Florida, Gainesville, FL.

- Jonnalagadda, S. (2004). “Resistivity and time domain reflectrometry sensors for assessing in-situ moisture content in a bioreactor landfill.” Master's Thesis, University of Florida, Gainesville, FL.
- Jain, P. (2005). “Moisture addition at bioreactor landfills using vertical wells: mathematical modeling and field application.” Ph.D. Dissertation. University of Florida, Gainesville, FL.
- Powell, J. (2005). “Trace gas quality, temperature control and extent of influence from air addition at a bioreactor landfill.” Masters Thesis, University of Florida, Gainesville, FL.
- Larson, J.A. (2007). “Investigations at a bioreactor landfill to aid in the operation and design of horizontal injection liquids addition systems” Master's Thesis, University of Florida, Gainesville, FL.

Appendix D. Peer-reviewed Journal Articles and Conference Proceedings

- Reinhart, D. McCreanor, P, Townsend, T. (2002). “The bioreactor landfill: Its status and future.” *Waste Management and Research*, 20, 172-186.
- Reinhart, D., Townsend, T. and Bower, J. (2000). “Florida landfill bioreactor project.” Proceedings of the Waste Tech 2000, Landfill Technology Conference. Orlando, Florida, March 7.
- Reinhart, D., Townsend, T. and Bower, J. (2000). “The Florida landfill bioreactor project.” Proceedings of the 4th Annual Landfill Symposium, Solid Waste Association of North America. Austin, TX, June 24, 2000.
- Gawande, N., Reinhart, D., Thomas, P., McCreanor. P., Townsend, T. (2003). “Municipal solid waste in situ moisture content measurement using an electrical resistance sensor.” Waste Management, 23, 667-674.
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- Jain, P., Townsend, T., and Reinhart, R. (2005). “Experiences from the operation of a full-scale bioreactor landfill in Florida.” Solid Waste Association of North America’s Wastecon 2005, Austin, TX, September 27-29, 2005.
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- Kumar D., Jonnalagadda, S,. Jain, P., Gawande, N., Townsend, T., Reinhart,D. (2008). “Field Evaluation of Resistivity Sensors for In-situ Moisture Measurement in a Bioreactor Landfill” submitted to Waste Management

Performance and results of the instruments installed inside of the bioreactors are presented in Volume 5. Tasks conducted by research teams using in-situ instrumentation technologies are highlighted. Section 5.2 presents head on liner measured by pressure transducers, section 5.3 includes the change of overburden pressure at NRRL Cell 3 monitored by using total earth pressure cells, section 5.4 describe moisture distribution in the bioreactor which measured with the moisture sensors, section 5.5 describes the result of temperature change by operating the bioreactor, and section 5.6 presents pore water pressure that monitored by piezometers. Finally, section 5.7 summarizes all instrument technologies used for the Florida bioreactor demonstration project.

5.2 Head on Liner

The application of pressure transducers is a relatively new means of measuring liquid head on liner in a municipal solid waste landfill. Saraf (2000) and Spafford (2002) compared a performance evaluation of three different liner systems with respect to leachate removal and the accumulation of head on the liner and also evaluated the use of pressure transducers as a method to measure head on liner.

The particular transducer shown in this plot appears to be in proper working condition and in addition it has not recorded head above 12 inches at any given time as shown in Figure 5.1 and Figure 5.2. Examples of three dimensional profiles of head on liner measured using KPSI transducers and Druck transducers on October 1 1999 and April 1 2000 are shown from Figure 5.3through Figure 5.6.

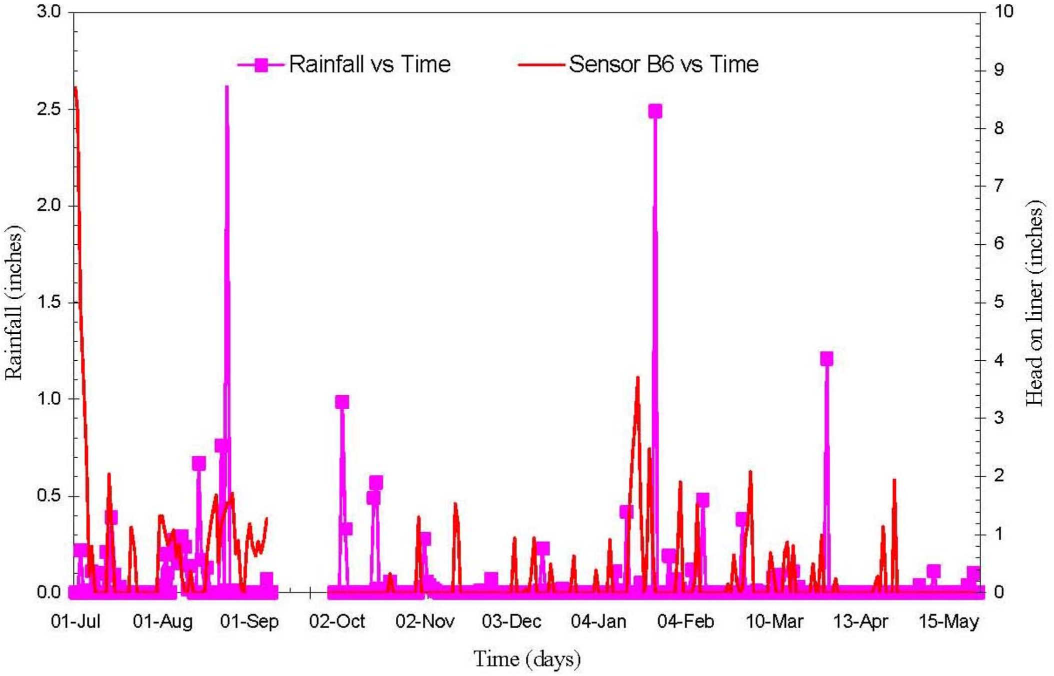


Figure 5.1 Head on liner (inch) and rainfall (inch) vs. time (day) for a KPSI transducer installed at NRRL Cell 2.

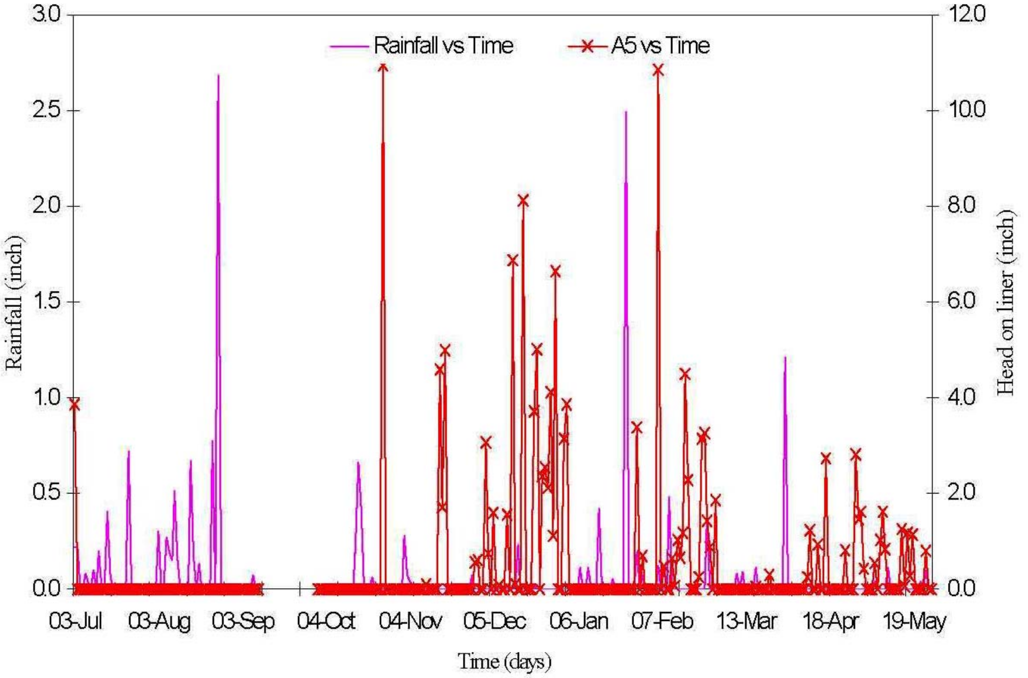


Figure 5.1 Head on liner (inch) and rainfall (inch) vs. time (day) for a Druck transducer installed at NRRL Cell 2.

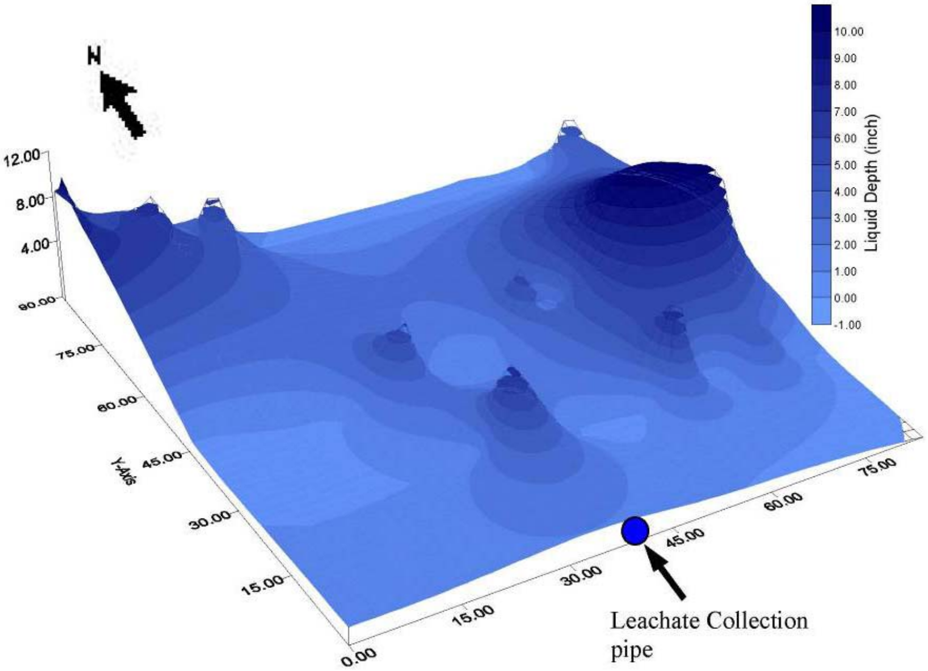


Figure 5.3. 3-D profile of head on liner on Oct. 1 1999 calculated by KPSI transducers

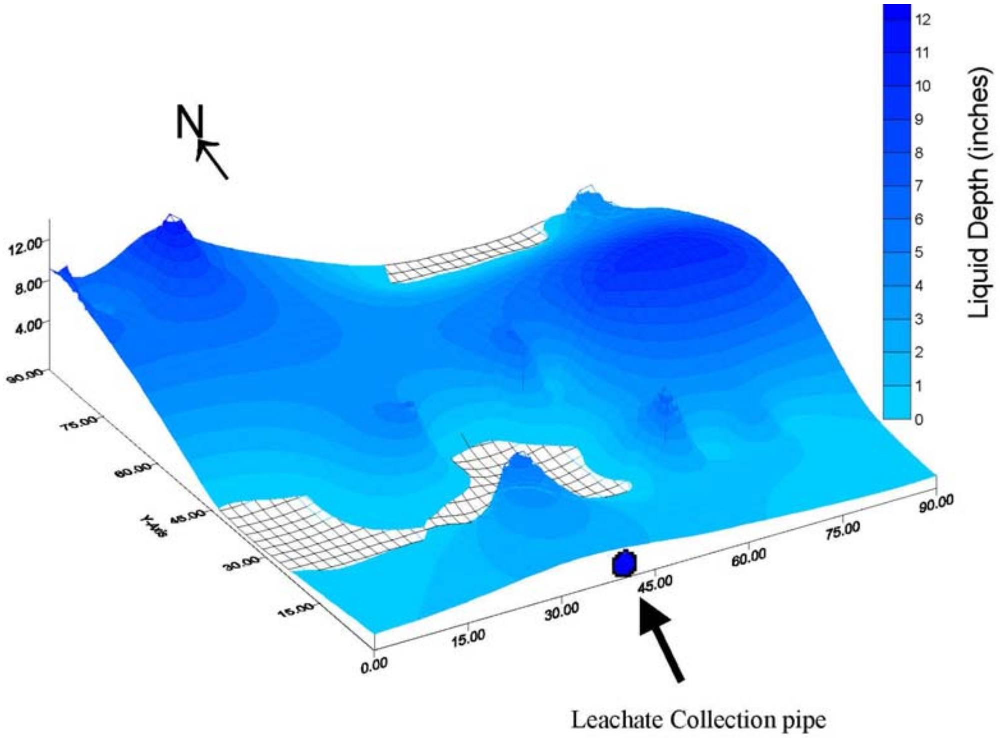


Figure 5.4. 3-D profile of head on liner on April 1 2000 calculated by KPSI transducers.

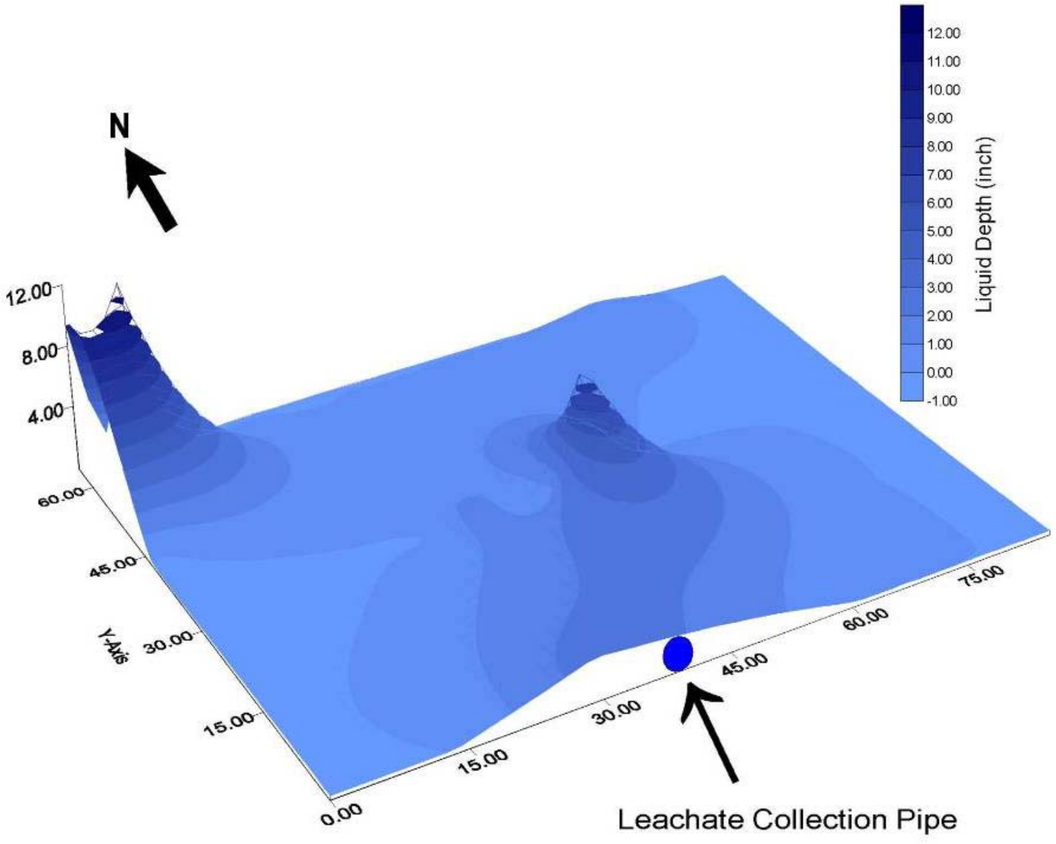


Figure 5.5. 3-D profile of head on liner on Oct. 1 1999 calculated by Druck transducers

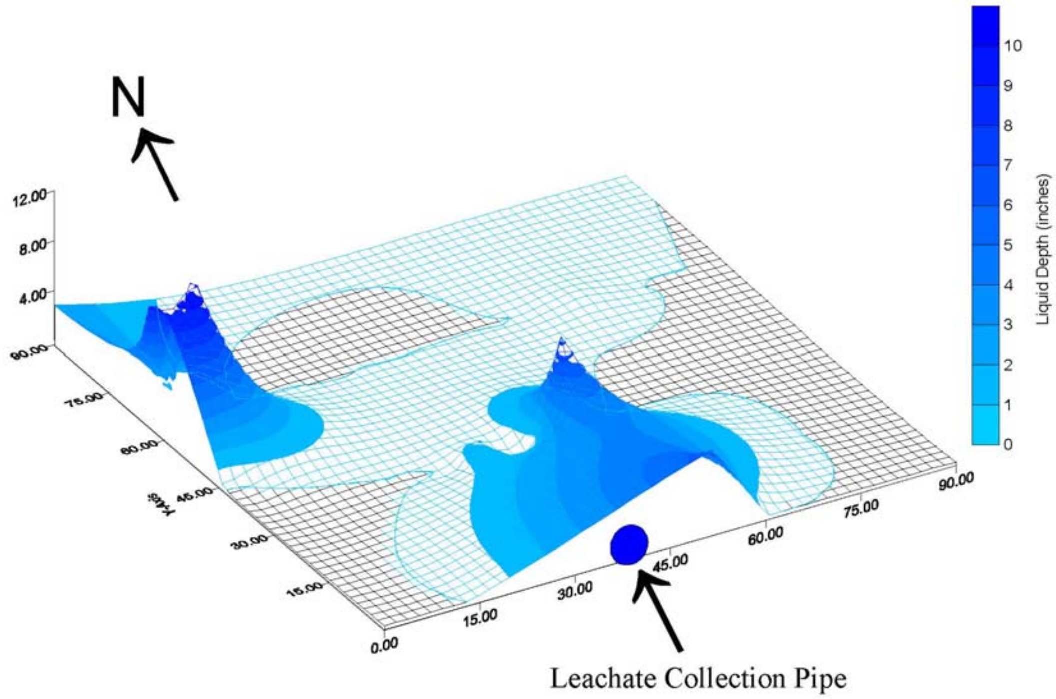


Figure 5.6. 3-D profile of head on liner on April 1 2000 calculated by Druck transducers

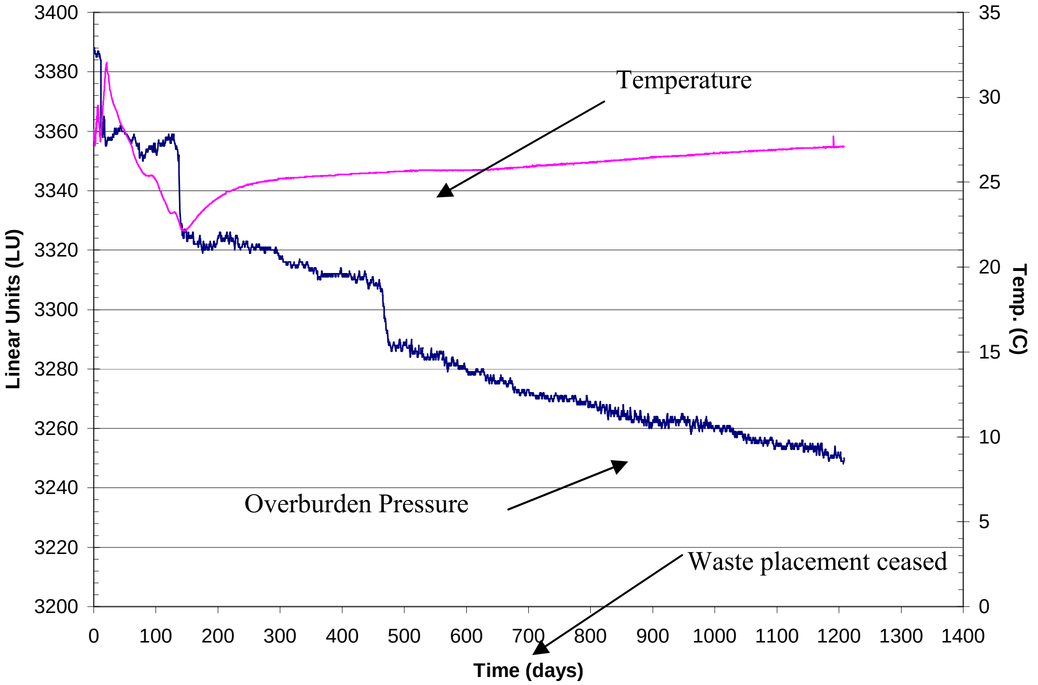
However, over the course of the experimental work however, it was evident that the use of pressure transducers was problematic and mostly inaccurate for measuring head on liner. Majority of transducers installed on Cell 2 (79%) and Cell 3 (77%) of NRRL and Tomoka Farms Load landfill (62%) failed because of lightning strikes at the data station, overburden pressure due to waste place above the sensors, marine grease applied to sensors to prohibit biological growth and improper orientation of sensors as they were installed. This information was used in later specification of instrumentation.

Appendix C Theses and Dissertations

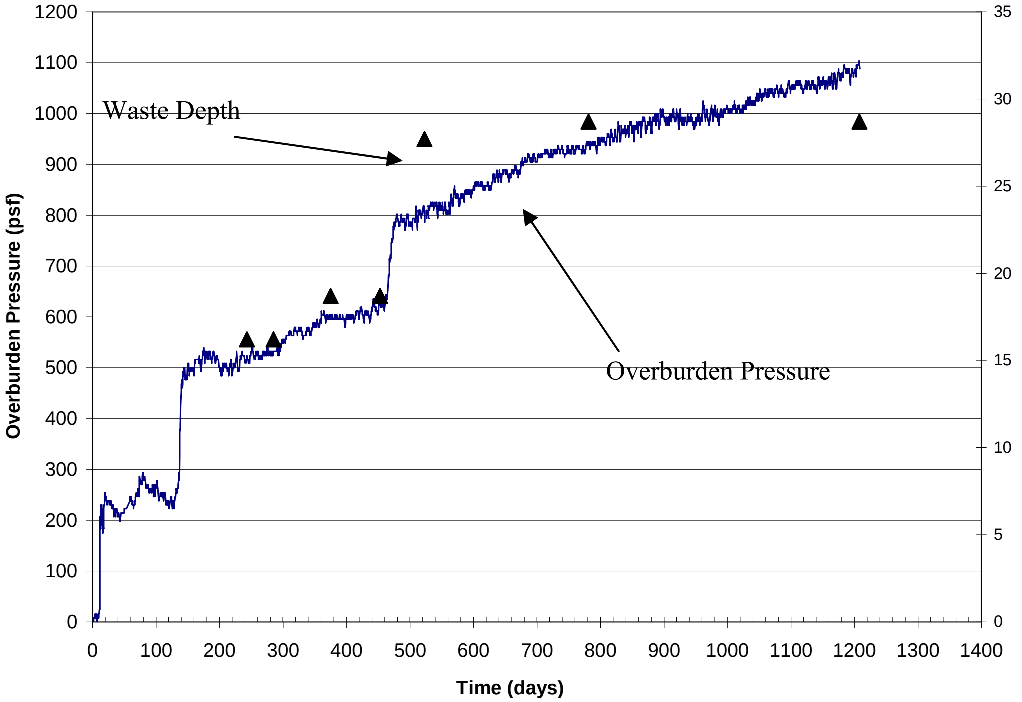
- Saraf, S. (2000). “Use of pressure transducers to measure landfill head on liner.” Masters Thesis, University of Central Florida, Orlando, FL. (Appendix C).
- Spafford, M. (2002). “Performance evaluation of landfill liner systems using pressure transducers.” Masters Thesis, University of Central Florida, Orlando, FL. (Appendix C).

5.3 Earth Pressure Cell

Overburden pressure is the force exerted on the landfill foundation of a system from the overlying waste and soil, and it is a necessary parameter for many aspects of landfill design. Timmons (2000) provided in-situ measurement of overburden pressure using total earth pressure cells (TPC) installed at Cell 3 of NRRL. Along with topographic survey data collected using a Z-model dual-frequency real-time kinematic (RTK) global position system (GPS) (Ashtech/Magellan Inc. Santa Clara, Califorina), depth and landfill volume were calculated using AutoCAD. Typical results from the TPC are presented in Figure 5.7 and Figure 5.8. The data clearly demonstrate the incremental pressure step increases that result from lift placement.



(a)



(b)

Figure5.7. Pressure Measurements Obtained Using the Total Pressue Cell. (a) Linear Units (LU) and Temperature (Celsius) and (b) Overburden Pressure (psf) and Waste Depth (ft)

When coupled with landfill surface measurements obtained using a Global Positioning System unit to evaluate settlement, a highly accurate waste specific weight can be determined. By comparing the calculated and measured overburden pressure, Timmons (2000) concluded that the measured over burden pressure was found to be on average 50% less than the expected overburden pressure based on calculations using waste height and density. This was attributed to factors such as arching, susceptibility to point loads, and possible pressure cell malfunction. The results are summarized on the Table 5.1.

Table 5.1 Overburden pressure in pounds per square foot (psf)

TPC ID	Type	Day 243	Day 285	Day 375	Day 583	Day 781	Day 1208
A	Measured[1]	521.4	532.0	603.5	802.0	939.6	1093.1
	Calculated[2]	1036.1	1020.2	1273.0	1772.8	2129.7	2129.7
B	Measured	262.6	268.3	371.0	505.2	605.1	705.0
	Calculated	543.6	566.8	1157.2	1408.0	1484.1	1484.1
C	Measured	681.9	787.9	839.5	990.3	1075.9	1162.8
	Calculated	1042.5	1240.6	1341.0	1580.8	1832.8	1832.8
D	Measured	274.1	92.3	290.4	331.1	385.4	464.1
	Calculated	652.4	705.3	762.4	1036.8	1127.9	1127.9
F	Measured	719.4	946.0	1048.8	1325.5	1441.5	1604.8
	Calculated	1228.0	1807.4	2055.8	2508.8	2908.8	2908.8
H	Measured	257.6	242.2	675.0	770.3	1107.7	1244.3
	Calculated	1151.3	1133.5	2042.2	2240.0	2448.7	2448.7
J	Measured	506.9	531.5	558.9	676.7	789.1	863.0
	Calculated	505.3	529.0	605.8	761.6	957.2	883.0
K	Measured	276.8	279.4	321.6	432.3	493.0	590.5
	Calculated	1004.1	988.7	1136.8	1708.8	2055.5	2055.5
N	Measured	249.4	265.4	418.3	630.1	809.7	962.6
	Calculated	1292.0	1272.1	2532.3	2828.8	4986.5	4838.1
O	Measured	795.7	989.9	1016.5	1112.3	1184.2	1250.7
	Calculated	1208.8	1253.2	1422.7	1337.6	1699.3	1699.3
P	Measured	682.4	909.0	988.2	1168.3	1637.9	1798.9
	Calculated	1381.5	2021.5	2253.2	2790.4	4793.6	4645.2
Q	Measured	714.5	916.0	969.7	1176.5	1670.7	1767.4
	Calculated	1068.1	1240.6	1341.0	1516.8	1832.8	1832.8
R	Measured	765.9	827.8	905.7	1109.9	1238.9	1322.3
	Calculated	1362.3	1801.1	2287.3	2918.4	5424.3	5350.1
S	Measured	874.3	907.3	940.3	2202.3	1286.7	1284.0
	Calculated	390.1	447.1	483.3	646.4	749.5	749.5
V	Measured	287.9	290.8	316.2	381.1	477.1	590.0
	Calculated	1471.0	1448.4	1565.7	2944.0	3561.8	3487.6
W	Measured	272.6	342.8	365.3	427.1	564.8	635.0
	Calculated	1279.2	1385.4	1769.9	1856.0	2411.6	2374.5
Average	**Measured**	**509.0**	**570.5**	**664.3**	**877.6**	**981.7**	**1019.9**
	Calculated	**1038.5**	**1178.8**	**1501.9**	**1866.0**	**2525.3**	**2344.0**

Note 1: Measured is the value of overburden pressure from the pressure cells.
Note 2: Calculated is the value of total landfill density multiplied by the waste depth

Appendix C Theses and Dissertations

- Timmons, J. (2004). “Total earth pressure cells for measuring loads in a municipal solid waste landfill.” Masters Project, University of Florida, Gainesville, FL. (Appendix C).

5.4 In-situ Moisture Measurements

The evaluation of moisture sensors was conducted at the field as well as in the laboratory. In the laboratory, moisture sensors were evaluated with different sizes of media and were tested with varying electrolytic conductivities. Calibration of the sensors was conducted in simulated waste. In field tests, data from the sensors collected and analyzed corresponding to liquid addition activity and air addition activity. Also, performance of MTG and TDR sensors was compared each other.

5.4.1 Laboratory study and calibration of MTC sensors

5.4.1.1 Testing sensitivity with varying packing media size and liquid electrical conductivity

In the laboratory study, the optimum particle size of sensor granular media was determined by evaluating sensor sensitivity and responsiveness. Sensitivity was evaluated by measuring resistance over time as water drained from a saturated sensor. Sands with uniform particle sizes having 0.5, 0.7, 1.0, 1.2, and 2.4-mm median diameters were tested using tap water (specific conductivity of 0.3 mS/cm). The sensor was inserted into a bucket of water and shaken gently to remove any air bubbles trapped in the matrix. The sensor was then allowed to remain submerged in the water for approximately six hours. The resistance of the sensor while fully submerged was recorded. The sensor was then removed from the water and transferred to an electronic scale (Sartorius BL 6100). The sensor was supported on a metal frame with a water reservoir below it, shown in figure 5.9. The sensor was suspended so that the weight of the sensor and the entrained moisture was automatically recorded as the water drained. Resistance measurements were recorded and logged using a Campbell Scientific CR 10X datalogger (recording measurements every five seconds). Resistance and weight measurements were simultaneously recorded.

In addition, experiments were performed to determine the response of the sensor to increases in specific conductivity of the test liquid. Three solutions were prepared with specific conductivities of 6.6, 13.9, and 22.7 mS/cm. Increments of KCl were added to deionized water and the conductivities measured until reaching the desired ionic strength. These values were chosen to approximate the specific conductivity strengths of the New River Regional Landfill leachate. Leachate obtained from this facility had an average specific conductivity value of 13.2 mS/cm.

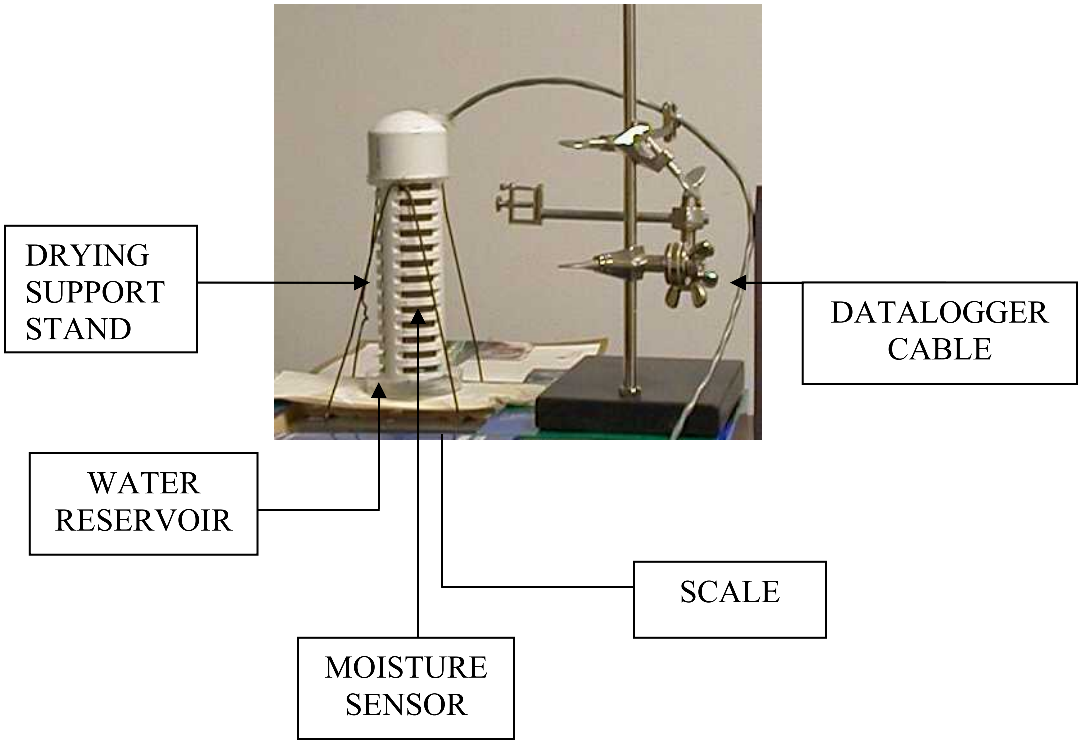


Figure 5.9 Sensor calibration testing apparatus.

The results of the laboratory tests showed that the sensitivity of the sensor was determined by its particle size with larger particles having greater sensitivity as shown in Figure 5.10. A decline in sensitivity was noticed when the specific conductivity of the liquid was increased as shown Figure 5.11. The sensor should not be used for media below its field capacity but should give a good indication of landfill leachate flow patterns (when above field capacity). The sensor has limitations, however due to its low cost, non-hazardous operation and its ability to detect moisture in media above field capacity makes it a viable choice in moisture sensing equipment for bioreactor landfills.

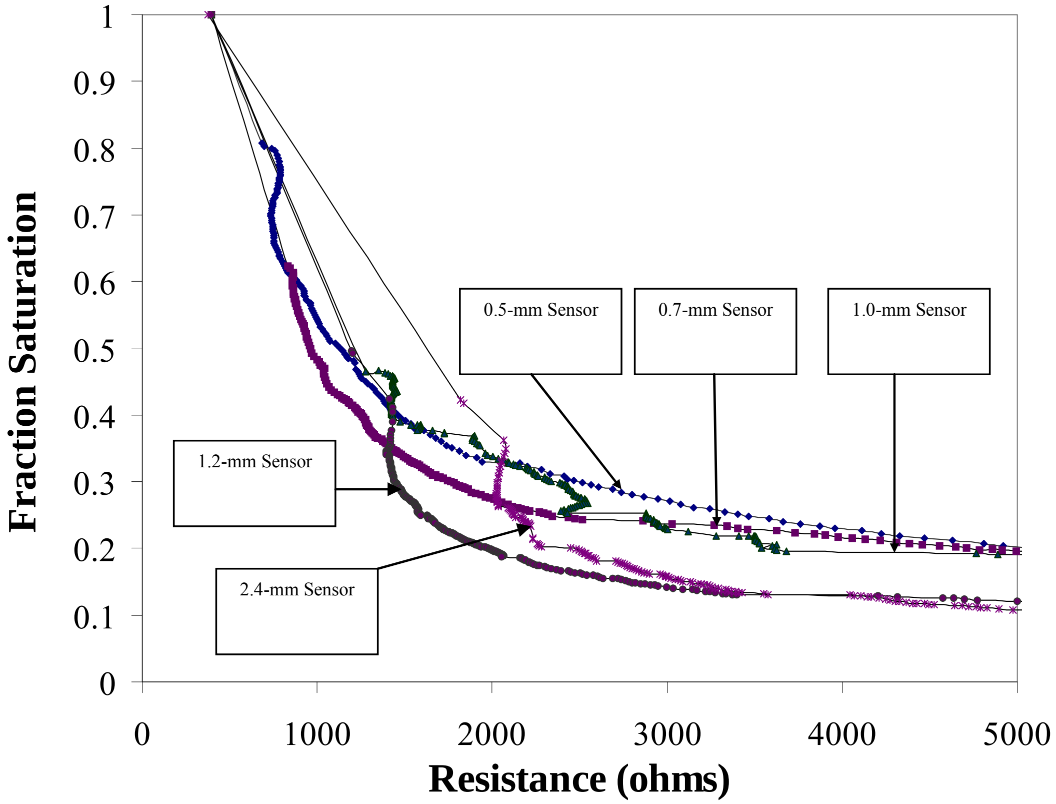


Figure 5.10. Standard calibration curves for all sensor sizes in tap water (0.3 mS/cm)

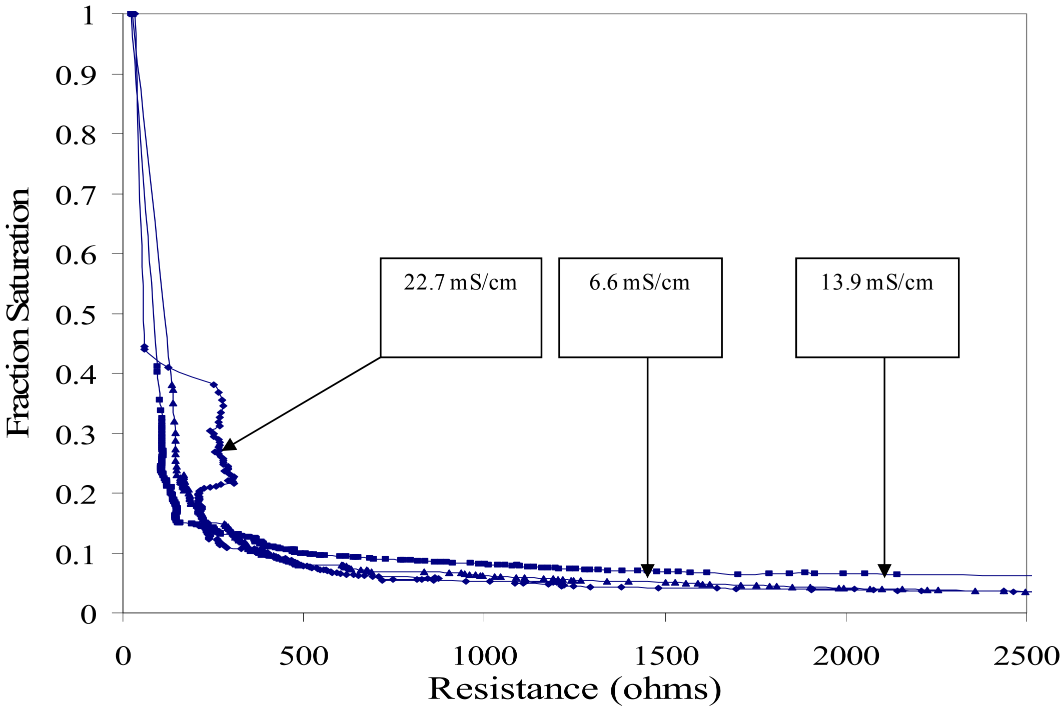


Figure 5.11. Calibration curves of 2.4-mm sensor with different electrolytic conductivities.

5.4.1.2 Sensor calibration

Calibration experiments were conducted with sensors containing 1.0-mm particle size medium. A 50-kg sample of dry synthetic solid waste was made in the laboratory as per the composition given in Table 5.2 (Tchobanoglous et.al. 1993). Twenty- liter plastic buckets with a diameter of 27 cm were used as test cells. Because of the limited size of the container, synthetic waste components size was reduced to 5 cm or less. It was felt that this size reduction would have minimal impact on moisture retention characteristics of the waste. The bulk density of waste was maintained at values similar to those found in operating landfills (500 to 950 kg/m^3). Calibration experiments were carried out for various waste moisture contents. True moisture content of the tested samples was determined gravimetrically by oven drying 150-g sub-samples (dry minimum) at 75 ± 2^oC for 48 hours to minimize losses due to combustion. All of the calibration experiments were conducted at 22 ± 1 ºC.

Table 5.2. Composition of solid waste used in laboratory experiments (after Tchobanoglous et al., 1993)

Component	**Percent weight**
Food wastes	3.43
Paper	40.61
Cardboard	7.23
Plastics	8.76
Textiles	2.28
Rubber	0.63
Leather	0.51
Yard wastes	9.39
Wood	2.03
Glass	9.90
Tin cans	7.36
Aluminum	0.63
Other metals	3.68
Dirt & ash	3.55
Total	100.00

Based on the experimental data empirical relationships were developed to describe MC as a function of measured resistance [Eq. 5.1 for 4 mS/cm and Eq. 5.2 for 8 mS/cm] by Gawande et al. (2003). When field measurements of leachate samples collected at the site were made for electrical conductivity, the value was often greater than the previously used to develop the calibration curves. Thus, an additional calibration curve was developed for a solution of 16 mS/cm electrical conductivity [Eq. 5.3] (Reinhart et al., 2004). Figure 5.12 shows calibration curve for MTG sensors with different moisture conductivities

At 4.0 mS/cm:

$$MC = \frac{21.56}{1 - 0.682\ \exp\left(-0.0252\ R\right)} \tag{5.1}$$

At 8.0 mS/cm: $$MC = \frac{30.068}{1 - 0.568 \exp(-0.167\, R)} \tag{5.2}$$

At 16.0 mS/cm: $$MC = \frac{34.037}{1 - 0.488 \exp(-0.4036\, R)} \tag{5.3}$$

where MC = moisture content of solid waste (% wet weight) and R = resistance value measured from the sensor (kΩ).

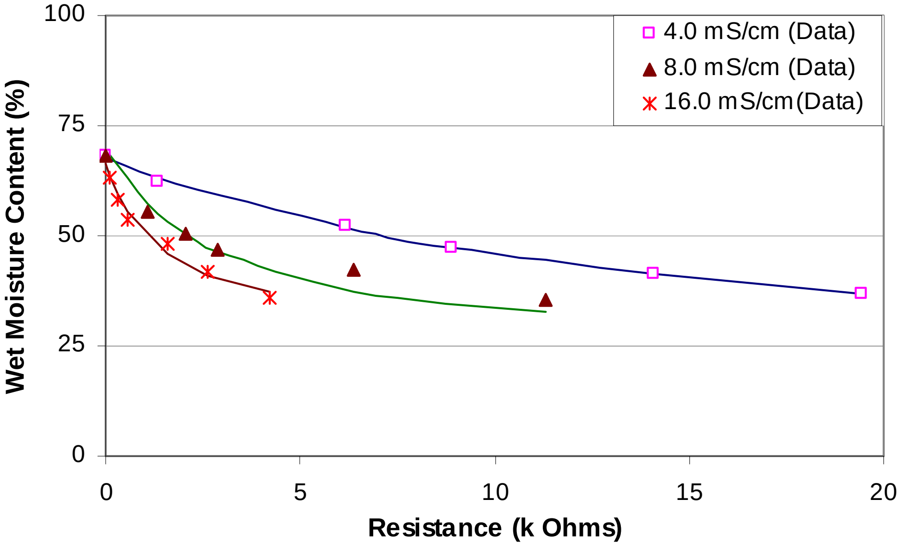


Figure 5.12. Calibration curve for MTG sensors for varying moisture conductivities.

5.4.2 Field Application

A total of 135 electrical resistance-based and 12 time domain reflectometry (TDR) sensors were installed in a NRRL bioreactor landfill in north central Florida. In situ moisture contents of the waste were measured using these two different technologies with laboratory-derived calibration equations.

5.4.2.1 Electrical resistance-based sensors

The effectiveness of the resistance-based sensors for in-situ moisture content determination in a bioreactor landfill was evaluated at the NRRL bioreactor. It was observed that 78% of sensors operated successfully in the field during the 1700-day experimental period. The MTG sensors response to liquid addition was as expected. Figure 5.13-14 shows the responses of the MTG sensors to moisture addition. Figure 5.15 shows calculated moisture content using laboratory-driven calibration. Drying behavior was observed in the sensors located in top 5 m layer but the sensors located in the middle and deep landfill zones did not responded to drying even with the drying expected due to discontinuation of liquid addition and addition of air. However, it is evident that moisture content calculated using laboratory-driven calibration for the MTG sensors may overestimate the absolute moisture content.

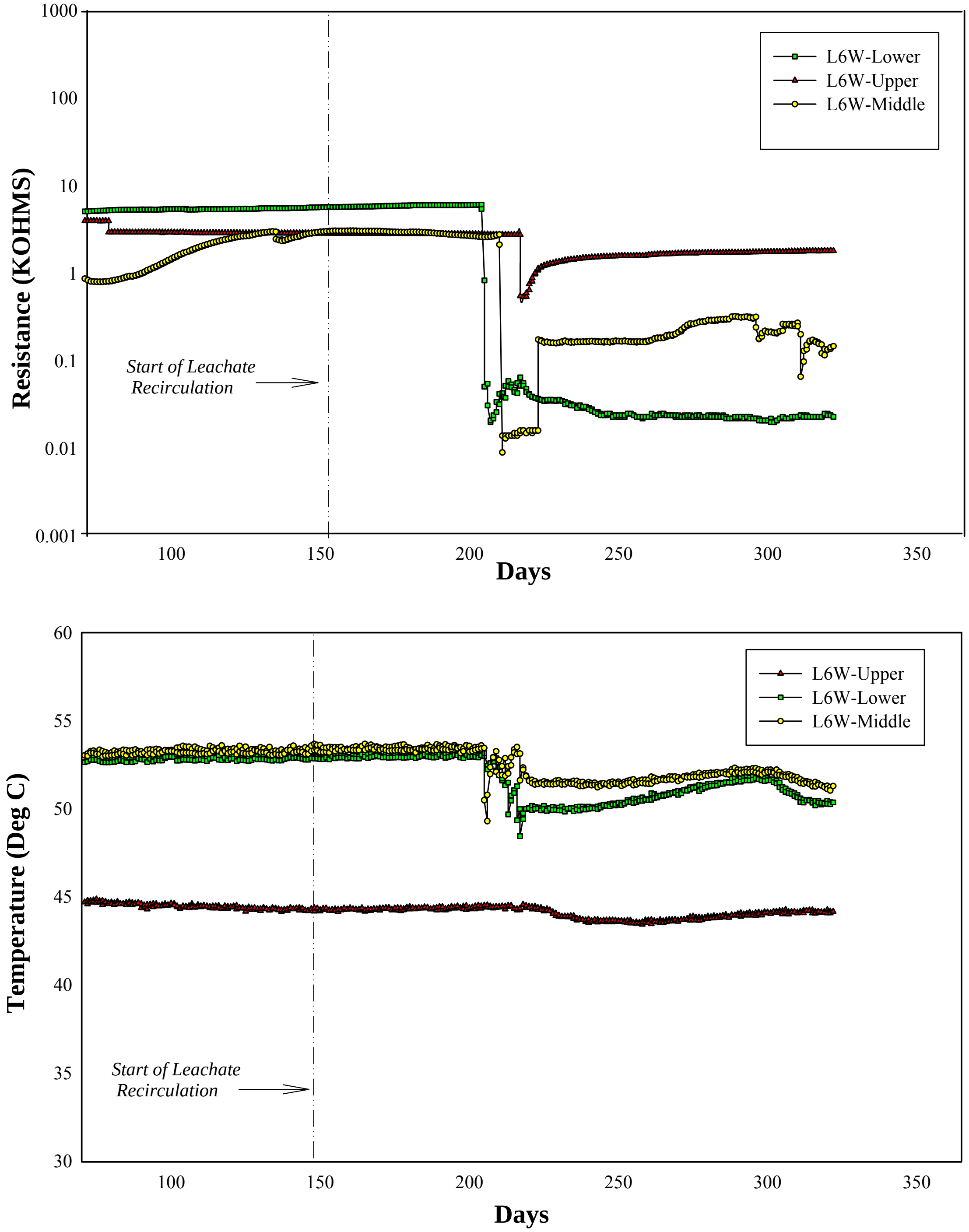


Figure 5.13. Response of resistivity sensors at cluster L6W to leachate recirculation (Day 1 = 01/01/2003)

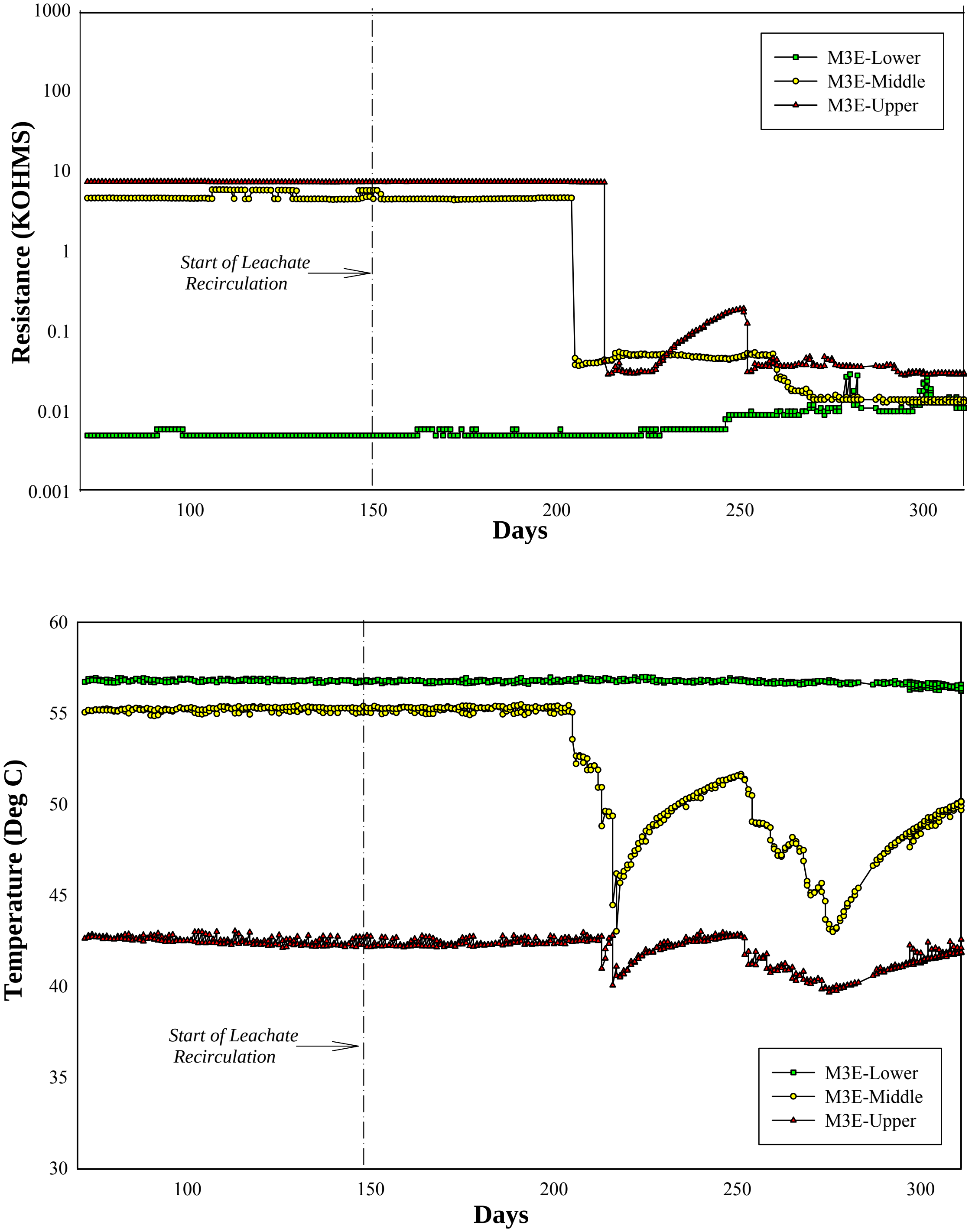


Figure 5.14. Response of resistivity sensors at cluster MM3E to leachate recirculation (Day 1 = 01/01/2003)

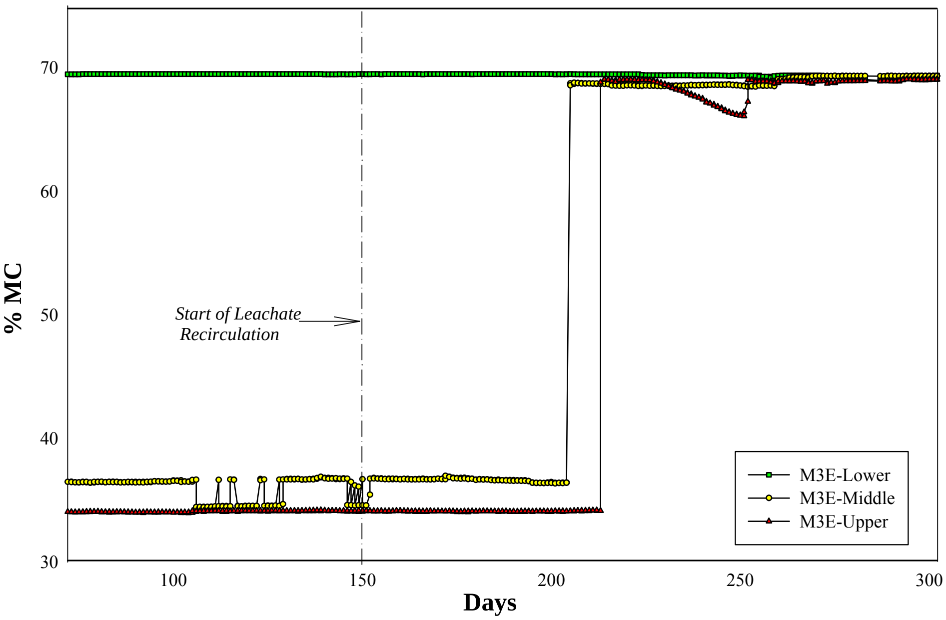


Figure 5.15. Calculated moisture content from cluster MM3E using a laboratory-driven calibration curve.

Kumar et al. (2008) introduced field-driven calibration methodology using field data collected at NRRL bioreactor as shown in Figure 5.16. Comparison of temporal variations of moisture content estimated using sensors and mass balance approach is shown in Figure 5.17.

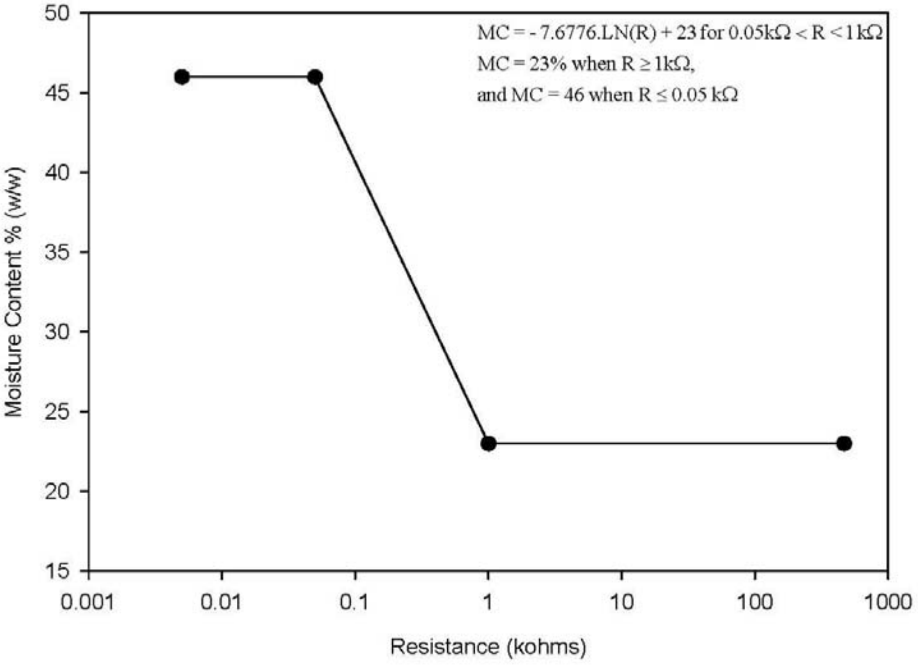


Figure 5.16. Field-driven Calibration Curve.

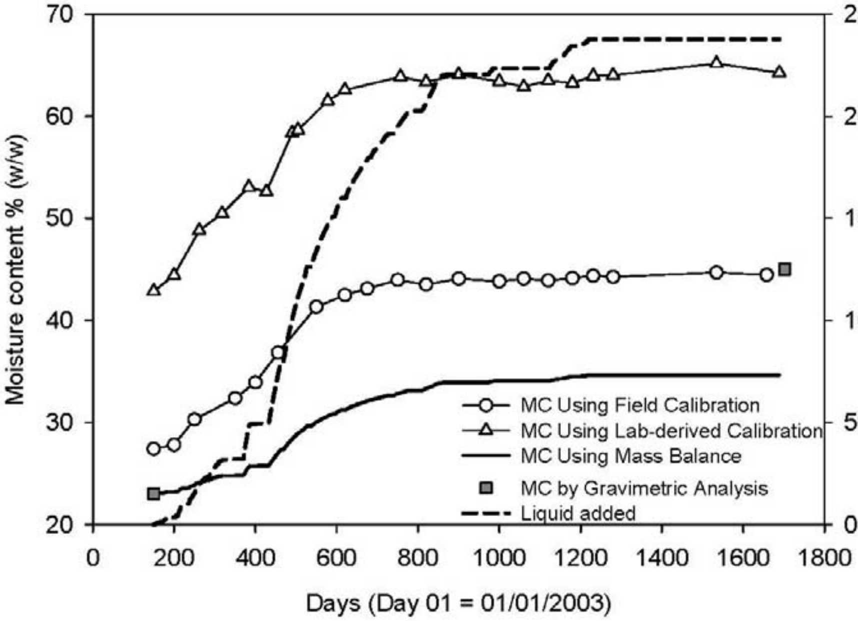


Figure 5.17. Comparison of temporal variations of moisture content estimated using sensors and mass balance approach.

The initial moisture content of the landfill estimated from the sensors were 42.8% and 27.4% for the laboratory-derived and field-derived calibration methodologies, respectively, which was higher than the gravimetric moisture content value 23% calculated after laboratory analysis of the samples collected from the landfill and the values reported in the literature. The final spatial average moisture content values calculated after 23,700 m^3 of liquid addition were 64.2% and 44.4% based on laboratory-derived and field-derived calibration methodologies, respectively, compared to 45% measured gravimetrically from excavated waste samples. All these estimates of moisture content were higher than the expected average moisture content 34.6% calculated based on mass balance.

The resistance-based MTG sensors show the potential for assessing moisture levels in bioreactor landfills. The sensors were able to track the changes in the moisture contents and detect the wetting and drying cycles in the field. The ability of MTG sensors to measure various in-situ parameters, and the convenience in automating the data collection process make it an attractive prospect for its potential use in the bioreactor landfills. These instruments may be limited for assessing the moisture content magnitude. They also suffer from inherent moisture pathways created by the installation process. Further information on the MTG sensors can be found in Appendixes.

Appendix C. Thesis and PhD dissertation

- Thomas, P.A. (2001). “The testing and evaluation of a prototype sensor for the measurement of moisture content in bioreactor landfills.” Masters Thesis, University of Central Florida, Orlando, FL.

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- Kumar D., Jonnalagadda, S,. Jain, P., Gawande, N., Townsend, T., Reinhart,D. (2008). “Field Evaluation of Resistivity Sensors for In-situ Moisture Measurement in a Bioreactor Landfill” submitted to Waste Management

5.4.2.2 TDR sensors

Out of the nine locations where the TDR and resistance-based sensors both functioned, four TDR sensors and five resistance based sensors responded to the leachate recirculation through day 322. Figure 5.18 shows the typical response of the TDR probe before and after recirculation. An increase in apparent length of the waveform (as indicated by L_a in the figure) means an increase in the relative dielectric constant of the medium, which indicates the increase in the moisture content of the medium. Figure 5.18 clearly shows the increase in the apparent length of the waveform with recirculation.

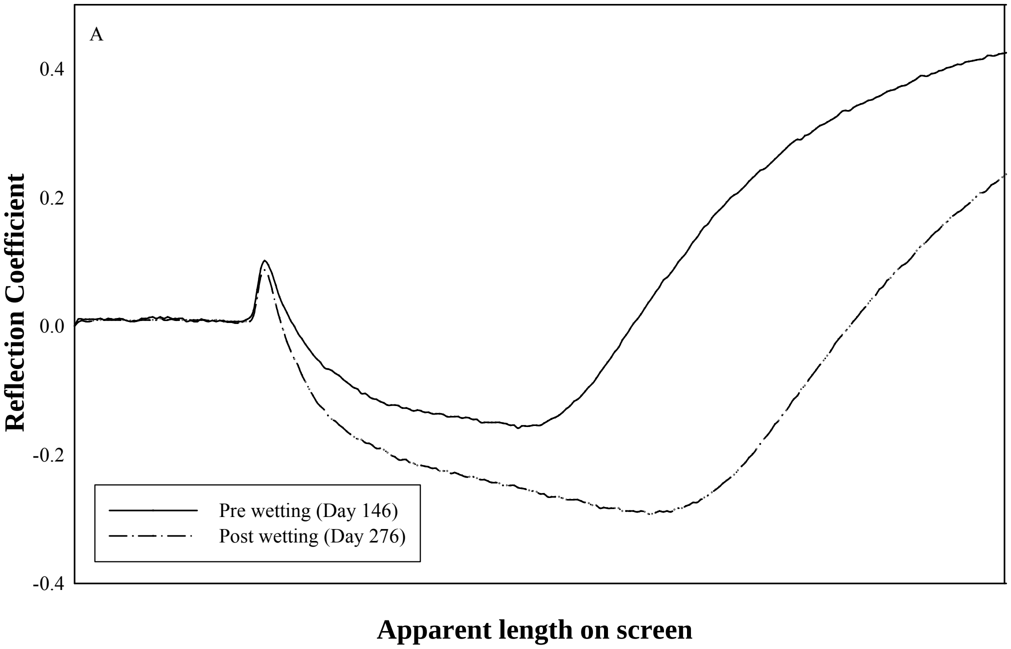

Figure 5.18. Response of sensors to leachate recirculation measured with TDR.

Figure 5.19 shows the changes in the moisture contents with time as for both the TDR and MTG sensors that are adjacent to each other and placed in a same hole. As shown by this figure, before recirculation the moisture contents of the sensor were observed to be 35-45 % (w/w). However, after the start of recirculation, the moisture content from the sensors went up to 68 % (w/w). It can be seen that there was a simultaneous increase in the obtained moisture contents from both the sensors.

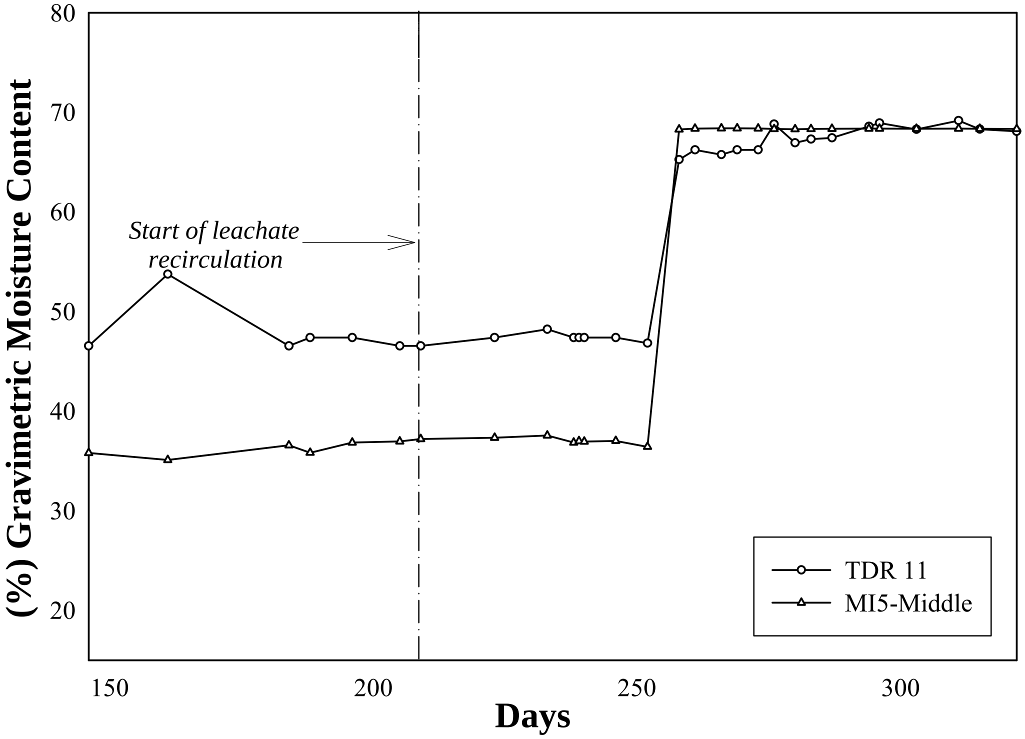

Figure 5.19. Change in moisture content of TDR and MTG sensor

5.4.2.3 TDR vs. MTG

Figure 5.20 showed the relation between results of TDR and MTG sensors showing that both MTG and TDR sensors were able to predict the increase in the moisture content of the medium. However it is difficult to measure exact moisture contents due to the heterogeneity of the waste. However, the absolute moisture content could not be determined for both measurement techniques. Due to the high manufacturing cost of the TDR sensors (approximately $25 per MTG and $500 per TDR sensor) this technology could be limited in its application to bioreactor landfills where there is a need to measure moisture contents at multiple locations. In this study, the operational performance of TDR sensors was observed to be less robust than resistance-based sensors.

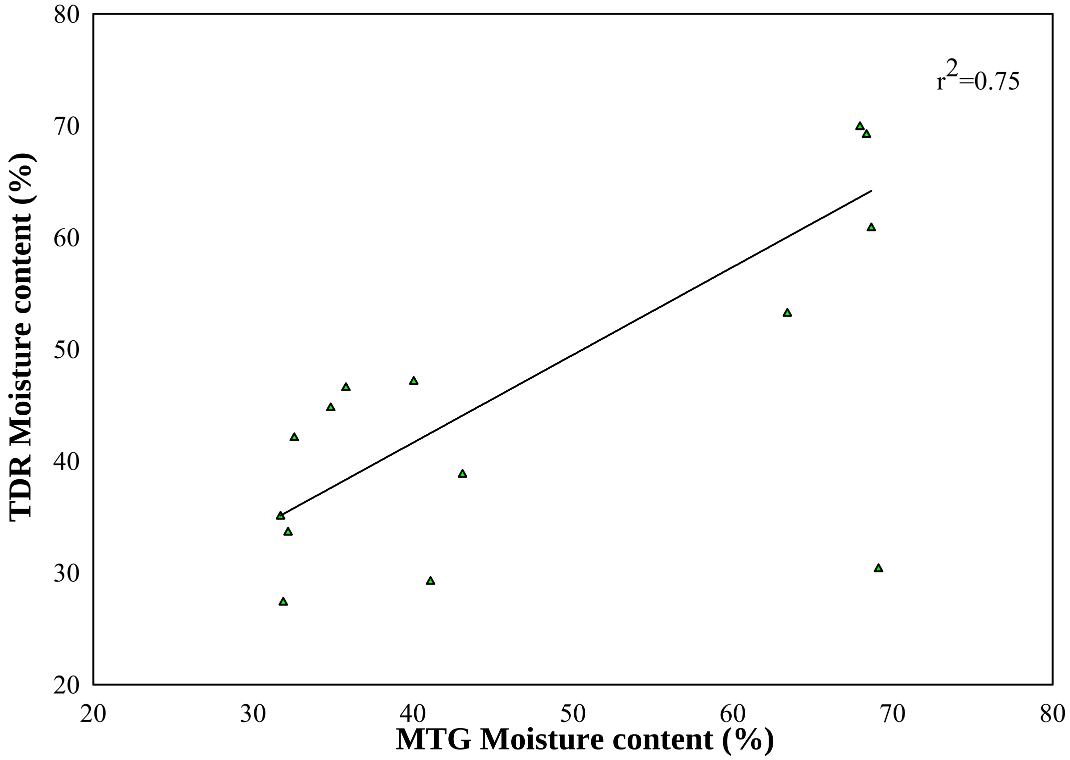

Figure 5.19. Comparison of moisture contents from TDR and MTG sensors

Appendix C. Theses and Dissertations

- Jonnalagadda, S. (2004). “Resistivity and time domain reflectrometry sensors for assessing in-situ moisture content in a bioreactor landfill.” Master's Thesis, University of Florida, Gainesville, FL.

Appendix D Peer-reviewed Journal Articles and Conference Proceedings

- Imhoff, P., Reinhart, D., Englund, M., Guerin, R., Gawande, N., Han, B., Jonnalagadda, S., Townsend, T., Yazdani, R. (2007) “Review of state of the art methods for measuring water in landfills.” Waste Management, 27(6), 729-745.
- Jonnalagadda, S., Kumar, D., Jain, P., Gawande, N., Townsend, T., Reinhart,D. (2008). “Comparison of Resistivity and Time Domain Reflectometry Sensors for Assessing Moisture Content in Bioreactor Landfills” Draft prepared for submission.

5.5 Temperature Measurements

Temperature is one of the impotent factors influencing activity of microorganisms responsible for waste decomposition. Figure 5.20 shows the temperature of the bioreactor with different depths before operating moisture addition. Kumar (2007) studied temperature change by liquid addition at the NRRL bioreactor. He observed that the ambient temperature has no effect on the global temperature inside a bioreactor landfill even at a shallow depth of 4.6 m. While analyzing the trend of waste temperature inside the landfill, liquid injection was found to lead to an increase in temperature.

In case of aerobic bioreactor that conducting air injection, temperature control is critical for fire prevention. Aeration the landfilled waste increased overall temperature of the area where air added. Figure 5.21 presents changes of temperature measured at a monitoring cluster with different depths. Considerable temperature rise by air addition was observed from thermocouples installed at 4.6m deep. The temperature changes in the shallow layer (4.6m) likely depended on flow rates of adjacent injection wells. However, temperature change at 9.2 m and 15.2 m deep did not show a large variation of temperature during the aeration. As a result of rapid increase in shallow monitoring points as show in Figure 5.22, air addition was limited by temperature rises of landfilled waste being aerated. Temperature changes were not only affected by the air flow rate of the nearest air injection well cluster but also probably by ther adjacent air injection wells, heterogeneousity of the waste, moisture level of the waste. Locations of gas extraction wells may also be important in terms of controlling the air flow direction and the flow rates.

Appendix C. Theses and Dissertations

- Kumar, A. (2003). “Temperature inside the landfill: effects of liquid injection and ambient temperature.” Masters Thesis, University of Central Florida, Orlando, FL.
- Jonnalagadda, S. (2004). “Resistivity and time domain reflectrometry sensors for assessing in-situ moisture content in a bioreactor landfill.” Master's Thesis, University of Florida, Gainesville, FL.
- Powell, J. (2005). “Trace gas quality, temperature control and extent of influence from air addition at a bioreactor landfill.” Masters Thesis, University of Florida, Gainesville, FL.

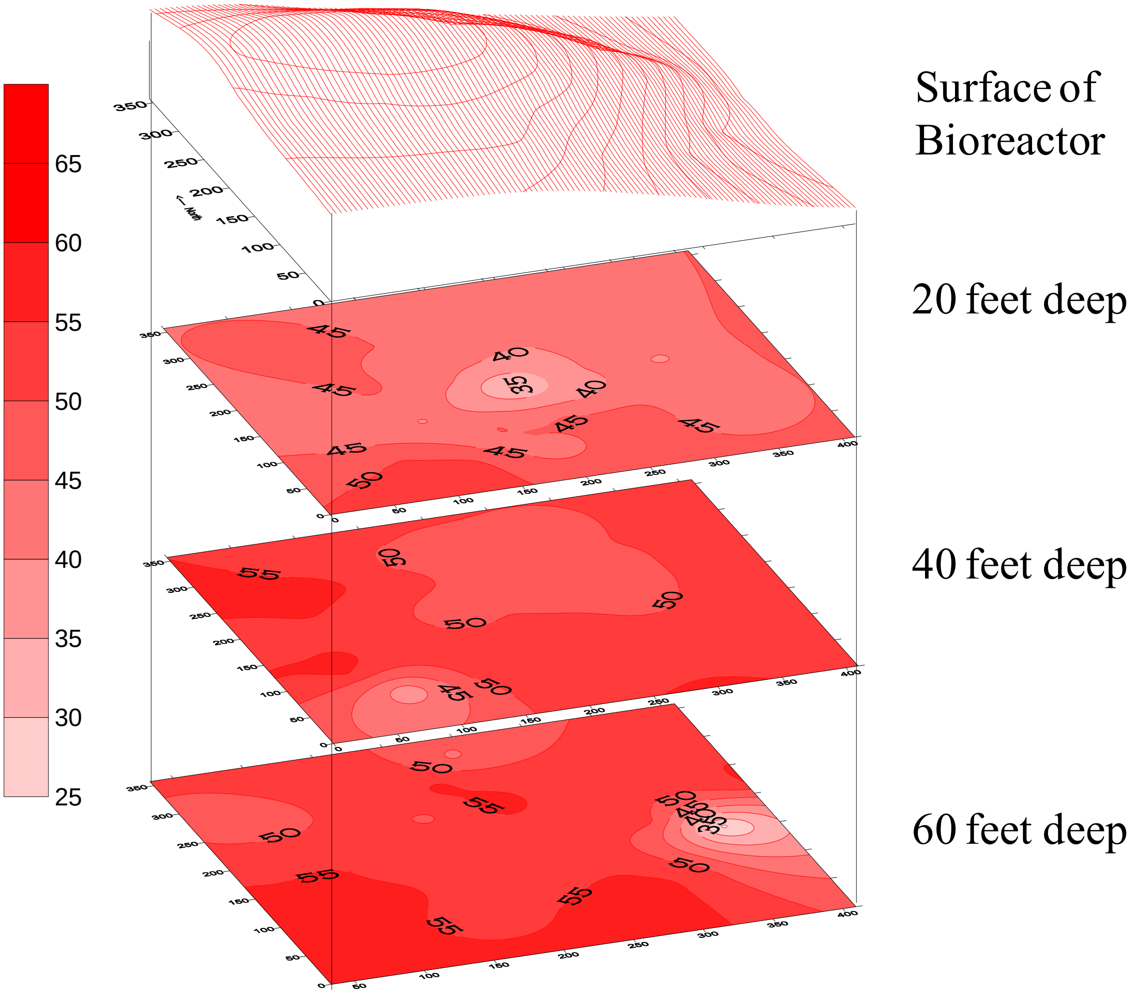

Figure. 5.20. Temperature profile of NRRL bioreactor measured on December 2002.

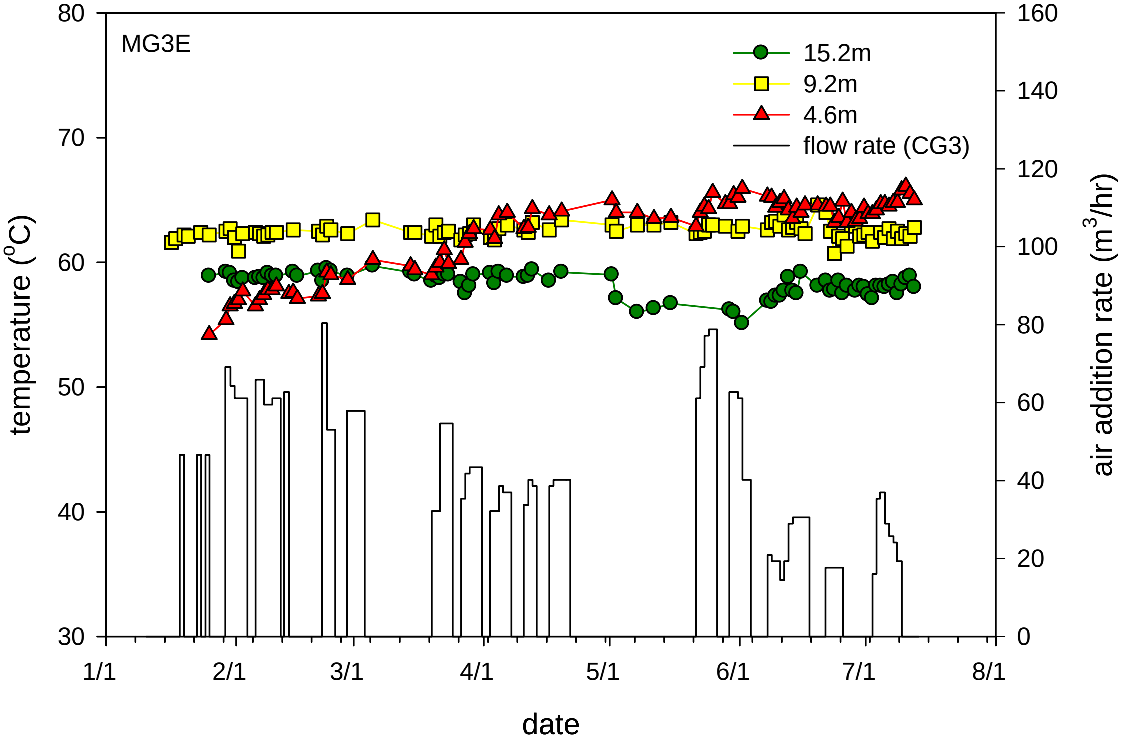

Figure 2.21. Temperatures measured at temperature monitoring clusters with 4.6m, 9.2m, and 15.2m in depth with various air addition rates.

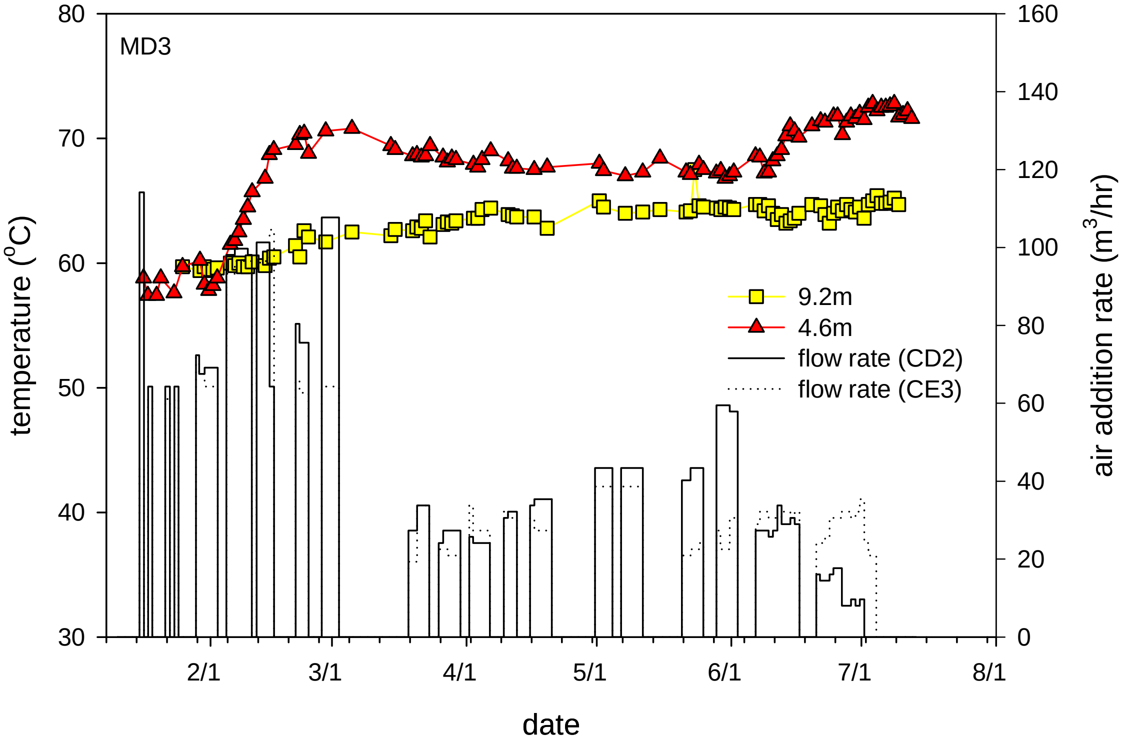

Figure 2.22. Temperatures measured at temperature monitoring clusters with 4.6m, and 9.2m in depth with various air addition rates.

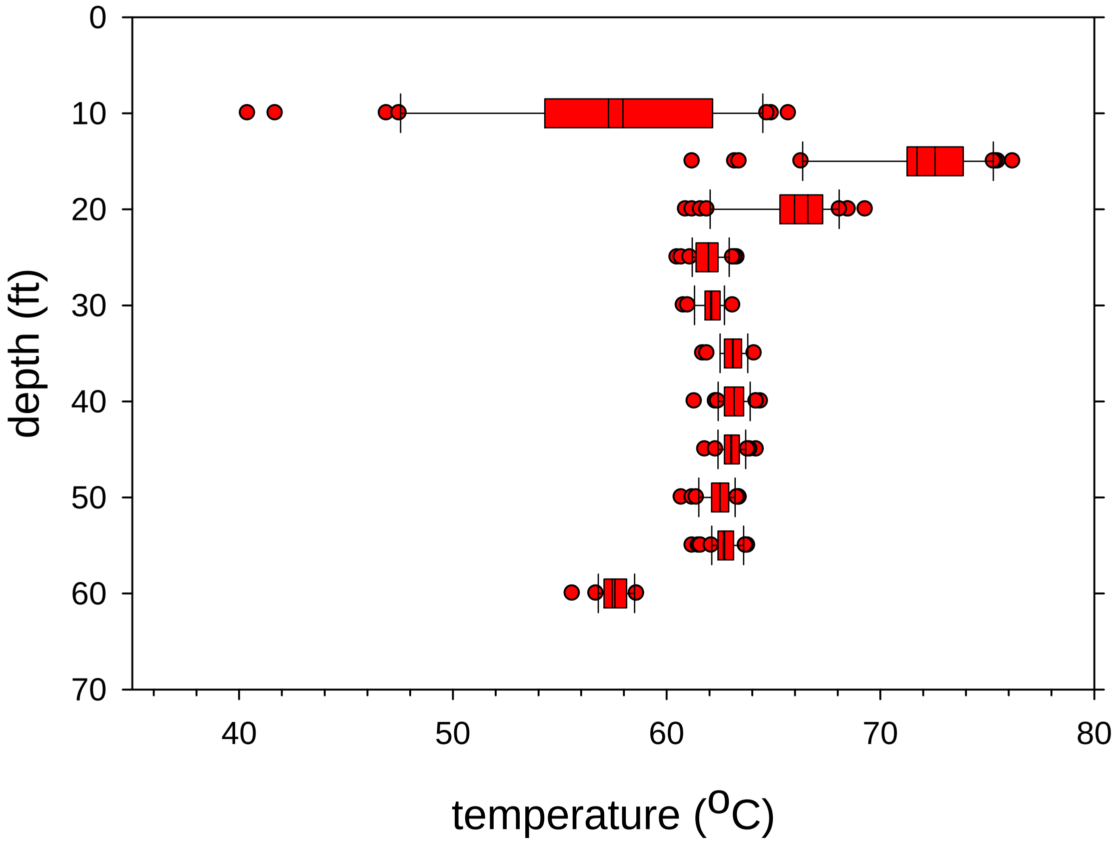

Figure 5.23. Temperature change with different depths by on/off aeration. It was measured in a temperature profile well.

5.6 Summary and Conclusions

The research conducted has shown some limitations of different sensors and has produced recommendations for the modification of sensor to make them more adaptable for use in bioreactor landfills.

Head on liner using pressure transducers

- Pressure transducers appeared to initially be in proper working condition and. However, over the course of the experimental work however, it was evident that the use of pressure transducers was problematic and mostly inaccurate for measuring head on liner.
- The majority of transducers installed in Cell 2 (79%) and Cell 3 (77%) of NRRL and Tomoka Farms Load landfill (62%) failed because of lightning strike at the data station, overburden pressure due to waste placement above the sensors, marine grease applied to the sensors to prohibit biological growth, and improper orientation of the sensors as they were installed.

Overburden pressure using total earth pressure cells

- Total earth pressure cells demonstrated that the incremental pressure step increases that result from lift placement.
- Over burden pressure measured by TPCs was found to be on average 50% less than the expected overburden pressure based on calculations using waste height and density. This was attributed to factors such as arching, susceptibility to point loads, and possible pressure cell malfunction. This observation is now being examined further at the Polk County bioreactor.

In-situ Moisture Measurements

- It was shown that the sensitivity of the MTG sensor (ratio of change of moisture content with change in resistance) was determined by the particle size employed with the smaller sizes (0.5-1.0 mm) having a lower sensitivity than the larger sized particles (1.2 and 2.4 mm).
- The sensor was affected by changes in specific conductivity of the liquid noted by a decline in sensitivity.
- The simultaneous increase in the moisture content of the TDR and MTG sensors that installed at the NRRL bioreactor gave an indication that both technologies were capable of estimating the transient moisture changes in the landfill. However, the values of the obtained moisture content indicated that there is some degree of error between the two measurement technologies while predicting the absolute moisture content.
- Due to the high manufacturing cost of TDR sensors, this technology could be limited in its application to bioreactor landfills where there is a need to measure moisture contents at multiple locations.

Temperature Measurements

- The ambient temperature has no effect on the global temperature inside a bioreactor landfill even at a shallow depth of 4.6 m.
- While analyzing the trend of waste temperature inside the landfill, liquid injection was found to lead to an increase in temperature.
- Aeration the landfilled waste increased overall temperature of the area where air added.
- Temperature in the shallow layer (4.6m) easily was affected by air injection rate of adjacent injection wells. Rapid temperature raises limited air addition to prevent from fire.

Additional Measurements

- Work is ongoing at both the NRRL and the Polk bioreactor evaluating in-situ pressure measurement instrument.