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FIELD SYSTEM FOR CONTINUOUS MEASUREMENT OF LANDFILL GAS PRESSURES AND TEMPERATURES

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The driving forces for gas movement in the subsurface include both concentration gradients (diffusion) and pressure gradients (convection). Near the top of the landfill, small soil gas pressure differences with respect to atmospheric pressure have been typically disregarded but may be important to considerations of gas flux into and out of landfill cover materials. The authors have developed a portable, inexpensive system using off-the-shelf components to sensitively monitor pressures, temperatures and meteorological variables on a continuous basis. Previous experience has indicated that continuous monitoring of pressure changes is necessary to understand the dynamics of convection in the shallow subsurface.

This application relies on a distributed network of commercially available Z-180 microprocessor-based integrated controllers to condition signals from electronic pressure transducers, meteorological sensors, and various temperature-sensing devices: thermocouples, thermistors and resistance temperature detectors (RTDs). Output is recorded continuously over an Appletalk™ network. The sensitivity of the authors' current system exceeds 4 Pa for pressure and 0.01°C for temperature (thermistor sensors).

This paper will describe the basic system components. The various choices for both temperature and pressure sensors will be discussed with respect to their sensitivity, adaptability and resolution. In addition, sample data output will be presented to illustrate the dynamics of shallow subsurface pressure and temperature changes.

Key Words—Landfill, data acquisition, pressure, temperature, monitoring system, network, continuous measurement, landfill gas.

1. Introduction

There are two main strategies for computerised data acquisition systems using personal computers: single or multiple collection nodes. In the single node systems, the primary hardware is a card interface or an analog-to-digital converter for a computer input port. These single node systems are relatively expensive (>U.S.$2000) but have been extensively documented for single location data collection (Hoftiezer & Balnar 1991; Imaino *et al.* 1991; Posada *et al.* 1991; Wirth & Moeglein 1991; Kim & Zabik 1992; Blaszczyk & Czajkowski 1993). However, for simultaneous data collection from several locations (as in a field setting), these systems become impractical for several reasons. First, for initial set-up, all sensors must be wired to one location in order to collect all of the signals at a single point; this is extremely expensive and cumbersome in field locations where long cable lengths may be necessary. More importantly, since signals are run over long lead lengths, extensive signal conditioning is usually necessary to avoid jeopardising data integrity (Horowitz & Hill 1980; Pasquarette 1992). Thus a

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distributed system is more practical for reliable environmental field monitoring. In this arrangement, data collection occurs at the point of the various sensor installations. This paper will discuss a multiple node system that has proven useful in a landfill setting for continuously monitoring pressures, temperatures and meteorological variables. This system is based on commercial Z-180 microprocessor controllers coupled to a field-based Appletalk™ network.

2. Description of data acquisition boards

The basis of the multiple node data acquisition system is a Z-180 miniature micro-controller (Little Giant™, Z-World Engineering, Davis, CA, U.S.A.). This controller has a number of built-in digital and analog interfaces for a wide range of sensors available for environmental monitoring, and it provides an easy and economical solution to real time data acquisition. It is totally programmable using Dynamic C™ (a version of the C programming language for controller development) and has on-board gain amplifiers which are completely user-selectable. This controller operates on 9 V DC power, which can be easily supplied to the unit in remote locations by a car or marine battery. Figure 1 provides an overview of the layout of the micro-controller board and associated features. In the current set-up at the Olinda Landfill in Brea, California, the research team utilised this system for pressure, temperature, wind speed and wind direction monitoring systems.

2.1 Temperature, wind speed and wind direction monitoring system

For temperature, there are several options for sensing devices; thermistors, thermocouples and RTDs (resistance temperature devices). The authors' system relies on the board to measure the resistance of thermistors. Thermistors are installed in small diameter boreholes in the cover material and refuse to record the vertical temperature gradient. The major advantage of thermistor and RTD sensors is that the resistance change is related to a corresponding temperature change. In a thermocouple, however, the temperature change is manifested in a minute voltage (or current) change in the millivolt range. For a field application where electronic interferences are often impossible to predict, the thermistor and RTD sensors offer higher sensitivity, longer term stability, and are affected least by external electrical interferences.

Currently, for landfill field uses, the thermistor has proven the more favorable option over RTD sensors due to the fact that the thermistors have the larger resistance change corresponding to a change in temperature and do not require additional signal conditioning. Thermistors are available commercially in a pre-constructed form, protected by a vinyl sheath over the sensing element and equipped with a phono-plug. This protective arrangement makes field interchangibility of sensors easier, plus the phono-plug facilitates periodic checks with a hand-held thermistor reader. The thermistor can be measured directly by the Z-180 controller whereas the RTD would require additional signal conditioning circuitry to compensate for the lead wire resistance changes. The lead wire resistance [typically less than 10 Ω (ohms)] needs to be accounted for when using RTD sensors due to the fact that the RTDs have a more limited resistance change over the typical range of field temperature measurements (0–50°C). Thermistors are referred to by their resistance at 25°C. The thermistors that are used currently are 2252 Ω. These thermistors have a resistance range from 7000 Ω at 0°C to 811 Ω at 50°C, whereas the RTD sensors (European Curve, $\alpha = 0.00385$) have a range

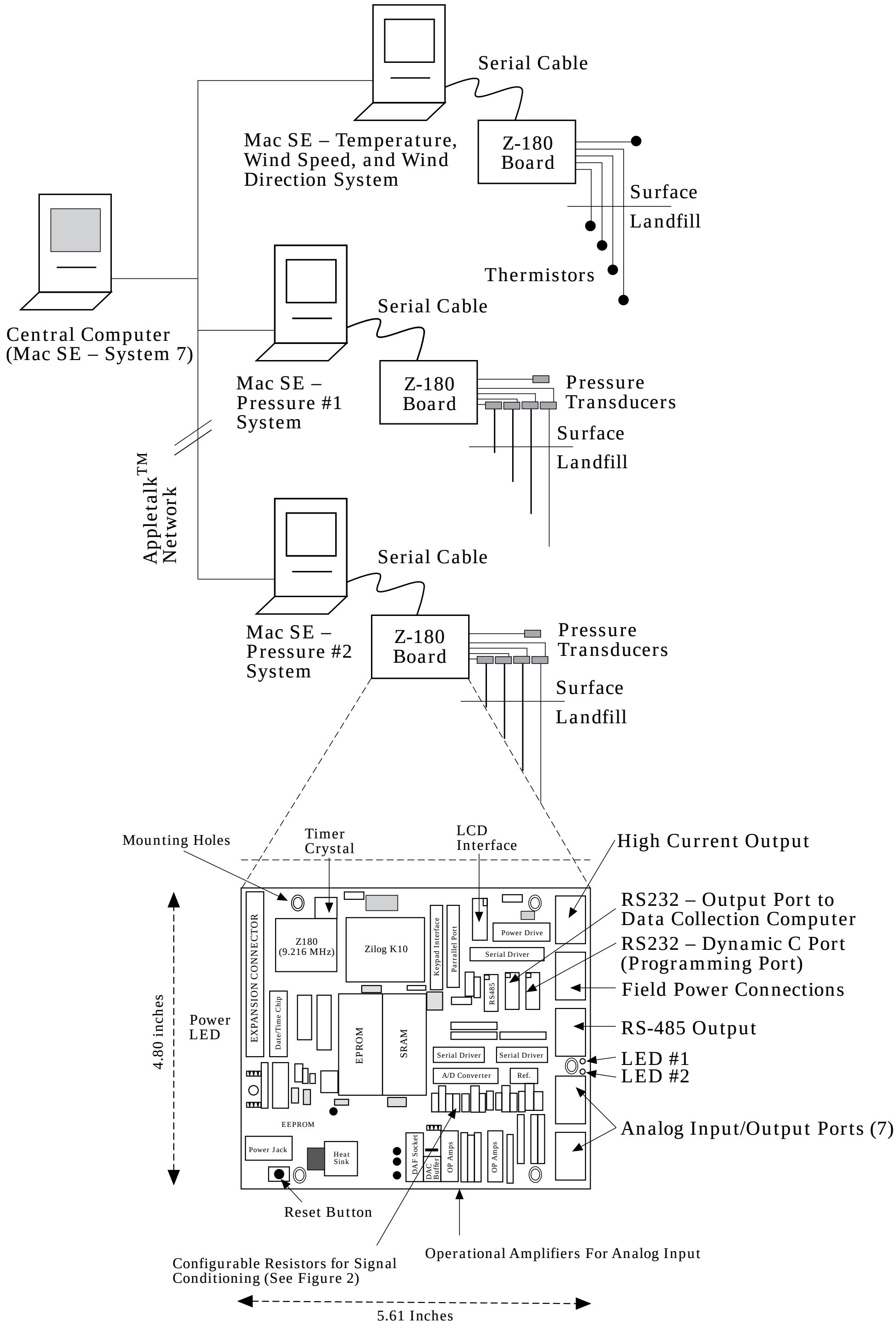


Fig. 1. Layout of data acquisition system and illustrations of features on Z-180 controller board.

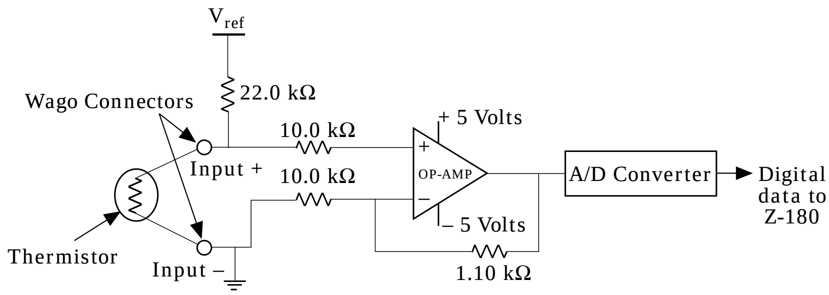
of 100 Ω at 0°C to 119.4 Ω at 50°C. From this perspective, the thermistor resistance change (approximately 6200 Ω for a 50°C range compared to 20 Ω for the RTD sensor) is more suitable for a field data acquisition application.

Calibration of the temperature system is achieved through a direct comparison of the thermistors with a National Institute of Standards and Technology (NIST)-traceable temperature probe or the calibration of the channels to a NIST-traceable voltage power supply. The calibration curves are constructed from the output of the A/D chip versus the reference temperature or voltage. By doing this, all non-linear effects can be accounted for in the calibration of the system. As needed, the custom program running on the controller is modified to accept new calibration equations, and the system is calibrated and ready for field use. Frequent field checks of the thermistors using the hand-held meter allow for a quick field check on the calibration. To date, the systems have a drift of less than 0.01°C over an extended period of time (1.5 years), and have retained their original calibration for the entire time of use.

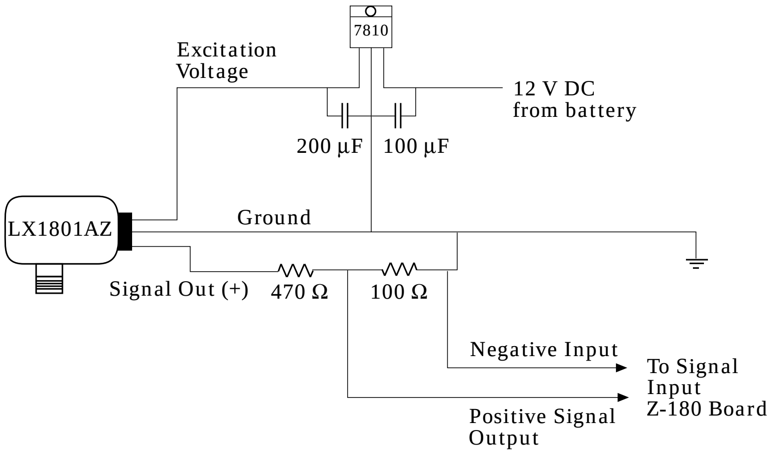
For wind speed and wind direction, this system reads an analog voltage output from the sensors and subsequently converts the voltages into appropriate units (ms^{-1} and direction from north in degrees). There are a variety of sensors available for wind speed and wind direction monitoring. The choice of sensors used in this system was based on accuracy, power requirements, type of output, and cost. The authors are currently using sensors from R.M. Young Company, Traverse City, Michigan, U.S.A. (Wind Monitor Model 05103). This wind speed and direction sensor was optimal for this application. The sensor is a high resolution ($\pm 0.3\ ms^{-1}$) rugged wind speed and direction sensor with an excitation power requirement of 8–24 V which was easily supplied from a marine or car battery. The output of the sensor is 0–1.0 V corresponding to 0–170 ms^{-1} wind speed and 0–1 V for 0–360° from north for wind direction. The sensor is competitively priced for these options.

2.2 Pressure monitoring systems

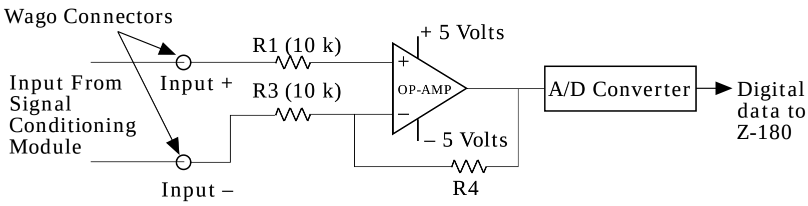
The pressure monitoring systems also utilise the Z-180 board. When using analog voltage output devices, it is necessary to optimise the output range of the sensor to the input range of the analog-to-digital converter (Austerlitz 1991). By doing this, the sensor is read to the highest sensitivity and accuracy available to the board. This is done by developing an operational amplifier to scale the sensor's signal to the correct voltage range of the A/D converter (Horowitz & Hill 1980). The advantage of the miniature controller used in the authors' system is that there are operational amplifiers already present for each channel, and these are user-configurable. For the initial transducers used (LX1801AZ, SenSym Sunnyvalle, CA, U.S.A.), the signal conditioning circuit is shown in Fig. 2. The output from the LX1801AZ transducers was 2.5–12.5 V corresponding to 68.9–137.9 kPa. The signal conditioning board utilised a 10:57 voltage divider and took the corresponding 18% of the signal to the Z-180 board. With this step, the output signal became 0.45–2.25 V over the entire input range. This voltage was then sent directly to the Z-180 board. This resulted in an instrument sensitivity of 0.6 mV over the entire voltage range, which corresponded to an overall sensitivity of measurement of 4.13 Pa. Pressure transducers are either left open to the atmosphere for barometric pressure or mounted on sealed probes to monitor subsurface pressures. The calibration plot was prepared by using a NIST-traceable voltage supply fed through the signal conditioning circuit, which calibrates the signal conditioning circuit as well as the A/D conversion for each channel.



All of the above circuitry is located on the Z-180 board itself for temperature measurement.



All of the above circuitry is located external to the Z-180 board for pressure signal conditioning.



All of the above circuitry is contained on the Z-180 board itself for pressure measurement.

Fig. 2. Configuration of operational amplifiers for temperature and signal conditioning for pressure transducers.

An excitation voltage is required for the pressure sensors. For this, external power conditioning circuitry must be constructed to provide an appropriate clean excitation signal from the 12 V DC power source. The output signal from the pressure transducer will only be as clean as the excitation voltage going to the sensor. Therefore, a perfect candidate for the voltage conditioning module is a voltage regulator (IC chip) that is connected with capacitors as filters to ground (Horowitz & Hill 1980).

TABLE 1
Pressure transducer comparisons

Transducer model	Manufacture	Range (kPa)	Sensitivity ($mV\ kPa^{-1}$)	Error margin ($\pm$kPa)
LX1801AZ	SenSym	68.9–137.9	145	0.7
163SC01D48	SenSym	−68.9–11.7	364	0.07
143SC01D	SenSym	−6.9–+6.9	363	0.07
ASCX01DN	SenSym	0–6.9	653	0.014
PX163-005BD5V	Omega Engineering	−1.38–1.38	1813	0.014
PX163-2.5BD5V	Omega Engineering	−0.62–0.62	4029	0.0062
210BWT2AA	GP:50 New York	0–1.24	4029	0.0062
PDA1DB15	DCT Instruments	0–3.4	1450	0.0055
SCXL004DN	SenSym	0–0.97	40	0.0048

The pressure system's accuracy is entirely dependent on the type of pressure transducer that is chosen for the application. Table 1 summarises the sensitivity and operational ranges of a number of candidate transducers. As seen in the table, the column entitled "Error margin" includes all errors associated with a pressure sensor's reading. These include offset shifts, linearity, hysteresis and repeatability.

For the current field study at the Olinda Landfill, a variety of sensors are being evaluated. An initial test occurred in December 1993. At that time, a SenSym LX1801AZ (68.9–137.9 kPa absolute) sensor was used in which the pressure reading was referenced to an internal standard vacuum (sealed within the sensor). The initial analysis of this data showed that the pressure differentials were approaching the sensitivity of the sensor, and any differences would be lost within the error margin of the sensor. In additional tests, a 0–6.9 kPa (0–70.3 cm H_2O) gauge and a −10 to +120 cm H_2O differential pressure sensor (both from SenSym) were both used instead of the 68.9–137.9 kPa absolute sensors for probe monitoring. In this fashion, the probe pressures are referenced directly to barometric pressure and small deviations from barometric can be recorded accurately. An absolute sensor (0–206.8 kPa absolute, SenSym) was used for the monitoring of barometric pressure at the field site during the time of data collection.

3. Sample data output

For both systems, data readings are taken at 200 Hz (samples per second) from each of the sensors connected to a controller. These data points are then averaged every 60 s (with each average representing 12,000 samples) and date/time stamped by the on-board Z-180 microprocessor. This average is sent over the serial link to the data collection computer. The data collection computer (Macintosh SE) runs with a customised program. This program has been designed to retrieve the transmitted data from the serial line, and transmit the data over an Appletalk™ network to the central collection computer (Macintosh SE—running System 7). The central collection computer can then be programmed to display the data that was retrieved from each collection station in real time. The arrangement of this network also allows the central collection computer to monitor the status of each collection node.

At the rate of sampling in the temperature monitoring system, small fluctuations in

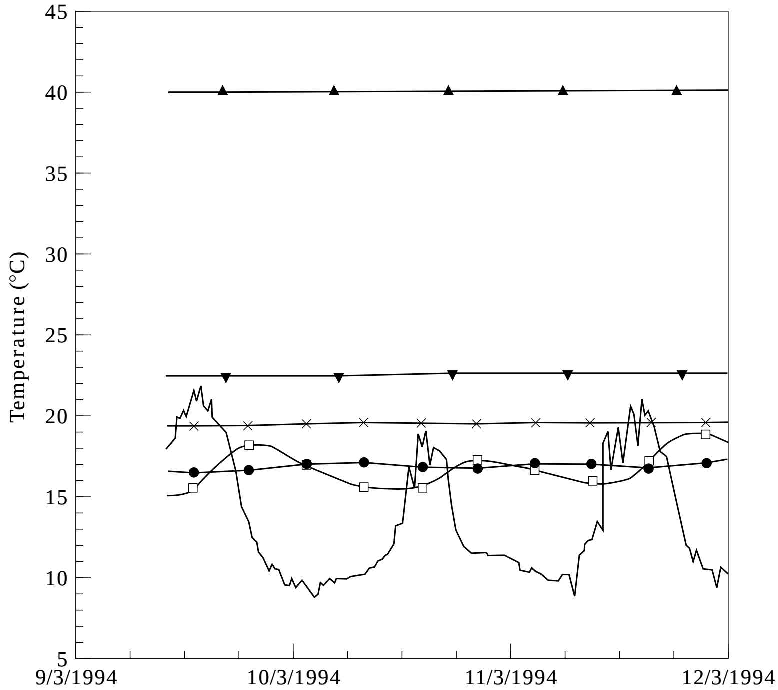


Fig. 3. Example plot of temperature system data on 9–12 March 1994 at Olinda Landfill, California, U.S.A. ——, air temperature; ●, 50 cm; ▼, 152 cm; □, 7 cm; ×, 80 cm; ▲, 610 cm.

temperature can be seen in Fig. 3, taken at Olinda Landfill in January 1994. From this plot, the daily fluctuations in temperature can be seen easily, with the greatest fluctuations at or near the ground surface. Temperatures increase to a maximum of 40°C at approximately 6 meters. The reliability of the temperature data is increased due to lead lengths being kept to a minimum. The power supply is virtually noise-free due to the clean DC signal from a deep-cycle lead acid battery and the short power connections [less than 30 cm after power conditioning circuitry]. The sample rate of 12,000 samples per 60-s interval provides a gain of 110 in the signal to noise ratio. (The gain is calculated by taking the square root of the number of samples comprising the average.)

Figure 4 is an example of the pressure data collected at Olinda in January 1994 with the LX1801AZ transducers. Figure 5 is an illustration of the SenSym 163SC01D48 higher sensitivity transducers (-10 to $+120$ cm H_2O) that were used after the LX1801AZ tests. As with the temperature data, the reliability of the pressure data is increased by the short lead lengths and clean DC power supply to the controller, as well as the clean source of excitation voltage for the pressure transducers. Small daily fluctuations in soil gas pressures can be seen and recorded on a continuous basis as seen in Figs 4 and 5. Due to the rapid changes over a period of a few hours, these small fluctuations in pressure are critical components in understanding the convective transport of gases through the cover materials at landfill sites.

4. Conclusions

The system discussed in this paper provides an accurate and affordable method for remote acquisition of pressure, temperature and weather data in remote landfill settings.

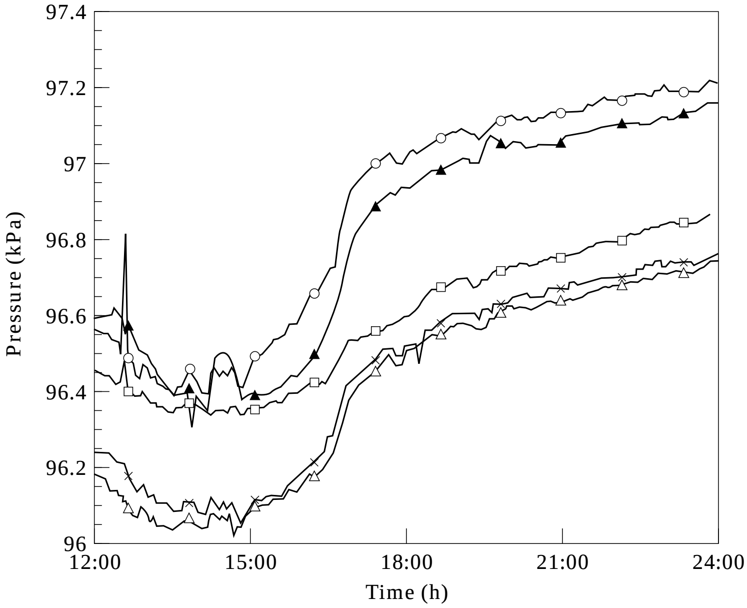


Fig. 4. Example plot of pressure system data using LX1801AZ transducers on 15 December 1993 at Olinda Landfill, California, U.S.A. ○, 25 cm; □, barometric pressure; ▲, 152 cm; ×, 610 cm; △, 40 cm.

It is flexible enough to provide an excellent platform for construction of a field monitoring system. The system is programmable to meet any requirement various applications may demand. Calibration routines and instructions for continuous data acquisition can be programmed into the Z-180 controller and the personal computers using various programming languages, resulting in a highly flexible modular system that can be easily adapted to specific site conditions.

While not sacrificing the sensitivity of larger data acquisition systems, this system can be configured at a fraction of the overall cost of the larger systems. For example, the current cost of the temperature monitoring system is approximately U.S.$1500.00 which includes: seven thermistors, a Z-World Little Giant Board, a Mac SE collection computer, battery, battery charger, AC/DC converter, field enclosure, Z-World enclosure, phone cable for network connection, and the network adapter for collection computer.

This system facilitates the collection of essential environmental data to support landfill monitoring and modeling. The types of data collected by this system serve two major purposes. First, meteorological data provide useful background on general weather conditions and their variability during specific monitoring periods. In particular, wind speed, wind direction relative to major surface features, air temperature and barometric pressure influence the movement of gases into and out of surface soil materials. Secondly, since gases are compressible fluids with their molecular activity subject to temperature influences, pressure and temperature data are needed to convert volumetric gas concentrations, as determined by gas chromatography, to a mass per unit volume basis. In most cases, an assumption of normal temperature and pressure is inappropriate for soil gases in landfill settings. To achieve uniformity in pressure and temperature measurements, the same transducers were used for barometric pressure/ subsurface pressure monitoring and the same thermistors for air temperature/subsurface

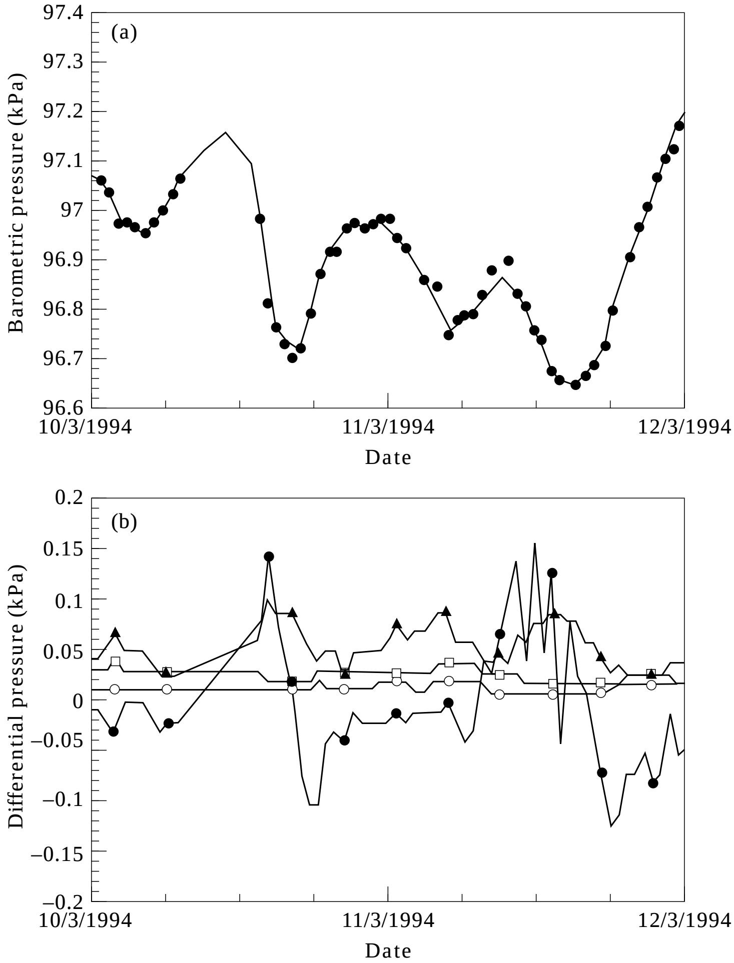


Fig. 5. Example plot of pressure system data using 163SC01D48 transducers on 10–12 March 1994 at Olinda Landfill, California, U.S.A. (a) ——, barometric pressure. (b) ○, 25 cm; □, 100 cm; ▲, 310 cm; ●, 620 cm.

temperature monitoring. The authors' experience suggests that continuous data collection is necessary to deduce trends seen in the data. With the exception of deeper subsurface temperatures, one daily reading is inadequate for landfill surface and shallow subsurface environments.

Acknowledgments

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