Mapping Elevated Temperatures in Municipal Solid Waste Landfills

[1]Jafari, Navid; [2]Stark, Timothy; [3]Thalhamer, Todd

[1]Louisiana State University, njafari@lsu.edu; (225) 578-8475; [2]University of Illinois at Urbana-Champaign, tstark@illinois.edu, (217) 333-7394; [3]California Environmental Protection Agency, todd.thalhamer@calrecycle.ca.gov, (916) 341-6356

Elevated temperatures in MSW landfills can produce obnoxious odors, toxic gases, and aggressive leachates, as well as damage gas extraction, leachate collection, interim cover, and composite liner systems. Several factors can lead to elevated landfill temperatures, including air ingress, partially extinguished surface fires, exothermic chemical reactions, and spontaneous oxidation. A case study is used herein to relate elevated gas and waste temperatures, changes in gas composition and production, leachate volume, slope movement, and settlement into a progression of landfill indicators.

The case study is a MSW landfill permitted for waste disposal in 435 ha and receives up to 9,000 metric tons of MSW per day. The elevated temperature area encompass 64.7 acres and 4 cells, which were constructed in phases from late 1997 to early 2001. After reaching the permitted elevations in 2005, the area was capped with intermediate 0.6 m of fine-grained soil and a gas control and collection system was installed. In August 2009, five gas wellheads 5 experienced temperatures above 68°C and as high as 95°C. Associated laboratory gas sampling from the wellheads reported CO concentrations >1,000 ppmv, with a maximum of 10,200 ppmv.

In response to the elevated temperatures, the facility initiated an expanded monitoring program to monitor and delineate the elevated temperatures. The program included:

- Weekly measurements of gas wellhead temperature, flow rate, and pressure.
- Weekly measurements of CH_4, N_2, O_2, H_2, CO_2, and CO with a portable field gas chromatographer.
- Monthly topographic survey.
- Monthly measurement of stability pins (slope movement and elevation).
- Weekly downhole temperature measurements.

Gas temperature, flow rate, and vacuum pressure were sampled at the wellhead and recorded using the GEM™ 2000 meter. Fixed gases (CO_2, CH_4, N_2, O_2, H_2, and CO) were measured by a portable field gas chromatographer. Settlement pins installed into the cover system were used to monitor changes in northing, easting, and elevation. Downhole temperatures were obtained from Type T thermocouples installed in sand backfilled boreholes. Leachate was collected and removed at sumps located in each cell. The facility reported the number of hours each sump was operated. Although the volume of leachate is unknown, a comparison between sump operations was used to infer the migration of leachate into each cell.

One of the most important parameters used to assess whether or not a MSW landfill is operating normally is temperature. Landfill temperatures can be measured: (1) at the gas wellhead, (2) from waste samples recovered during gas well drilling, and (3) with thermocouples installed at various depths in gas extraction well pipes, in boreholes, and in leachate collection pipes. Gas extraction wells collect gas from a slotted pipe, so temperatures represent an average over the slotted well pipe length and gas extraction well radius of influence. Temperatures of waste cuttings generated during drilling operations can be immediately measured by a thermal infrared camera. Downhole thermocouple arrays provide time-lapse temperatures with depth. An example of temperatures from each method is presented in Figure 1, which shows that gas wellhead temperatures should be correlated with downhole temperatures because they are more reliable, provide maximum temperatures, and show time-lapse changes. Wellhead temperatures under predict waste temperatures (e.g., by 20-40°F) in the reported case.

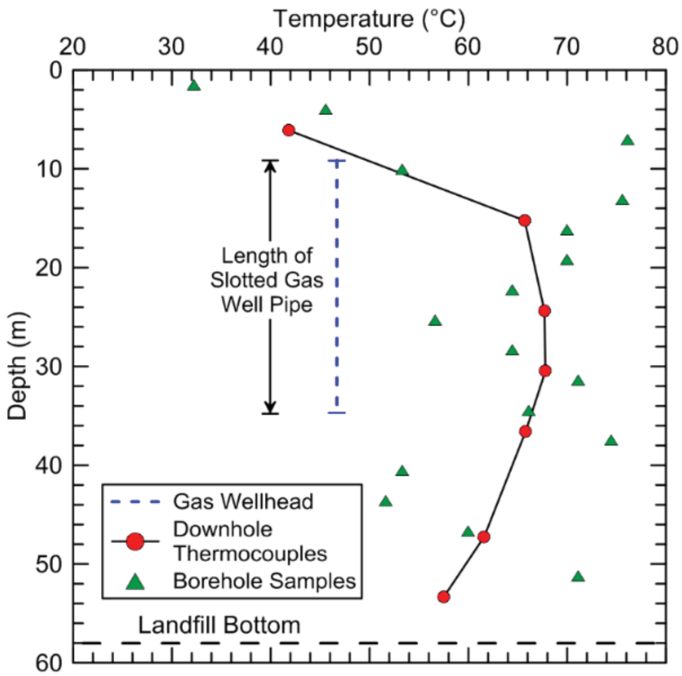

Figure 1. Comparison of subsurface temperatures in Cell 4 prior to elevated landfill temperatures

Figure 2 shows the relationship between increasing wellhead temperature and changes in the ratio of CH_4 to CO_2 gas flow rate, hydrogen levels, and carbon monoxide concentrations for a single gas extraction well in Cell 5. During anaerobic biodegradation, landfill gas is composed mostly of methane (45–60% v/v) and carbon dioxide (40–60% v/v), so a ratio of CH_4 and CO_2 close to unity provides a useful measure of microbial activity. The flow rates of CH_4 and CO_2 were calculated by multiplying the average percentage of CH_4 and CO_2 gas by the adjusted flow rate at the wellhead. Wellhead temperatures were used to standardize the flow rates to standard pressure and temperature of 20°C and 101 kPa. Temperature and flow rate were measured at the gas wellhead using the gas analyzer GEM™ 2000, while gas concentrations were measured by a portable field gas chromatograph.

In Figure 2(a), the gas extraction well in Cell 5 is operating under normal conditions because wellhead temperatures are below the NSPS limit of 55°C and the ratio of CH_4 to CO_2 is greater than unity (see Figure 2(b)). Conditions remain steady until an elapsed time of 550 days when the ratio of CH_4 to CO_2 precipitously decreases from 1.2 to 0.3 in only 50 days (time = 600 days). Wellhead temperatures exceeded the NSPS threshold of 55°C at a time of 580 days, i.e., about a month after methane levels began decreasing, and gradually increased to 75°C at t= 800 days. Decreasing ratio of CH_4 to CO_2 flow rate before wellhead temperatures increase is a trend among several gas extraction wells at this facility. The delay before wellhead temperature increase may be attributed to the difference in gas flow and heat conduction through the waste. For example, heat conduction is a slower process than gas flow to an extraction well, so elevated temperatures may arrive after gas has been removed. This observation suggests that changes in gas composition can occur in advance of the heating front, with increasing wellhead temperatures being an indication of the approaching smoldering front. Hydrogen levels were < 2% v/v and carbon monoxide (CO) was not measured when the ratios of CH_4 to CO_2 remained above unity. Figure 2(c) shows that hydrogen increased at t= 550 days to a maximum concentration of 20% v/v. Similar to hydrogen, CO increased to ~1,800 ppmv at an elapsed time of t= 550 days, and remained in the range of 2,000 to 2,500 ppmv for the duration of the monitoring period. Combining the timeline in Figure 2(b) to (d), it is evident that changes in the ratio of CH_4 to CO_2, hydrogen, and carbon monoxide occur at the same time. Moreover, the ratio of CH_4 to CO_2 and carbon monoxide are characterized by rapid changes while hydrogen increase occurs at a slower pace, similar to wellhead temperature changes. Therefore, the development of elevated temperatures causes methane concentrations to decrease concomitantly with increased hydrogen and carbon monoxide concentrations. Because the ratio of CH_4 to CO_2 above unity indicates anaerobic biodegradation, contour plots of the ratio of CH_4 to CO_2 flow rates provide a spatial estimate of where internal landfill processes are transitioning away from anaerobic biodegradation. In addition, increasing wellhead temperatures coupled with decreasing ratio of CH_4 to CO_2 can be used to delineate the front boundary of the elevated temperature region.

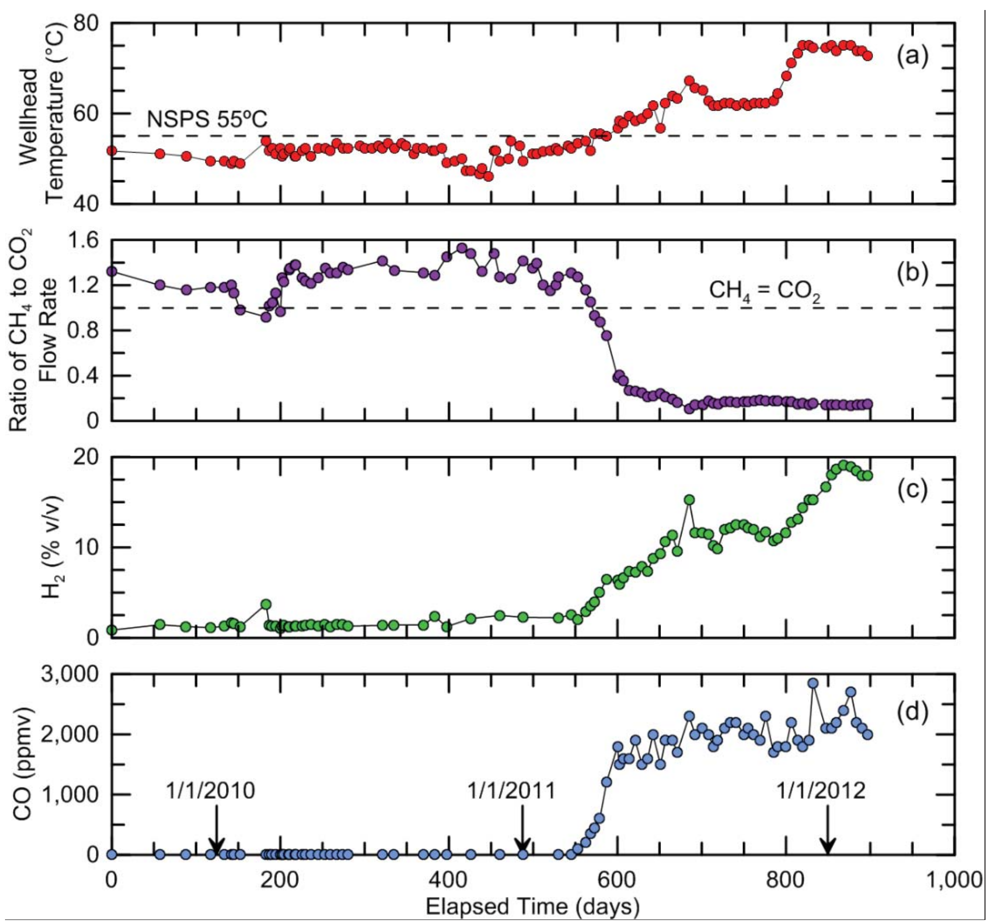

Figure 2. Gas extraction well trends: (a) temperature, (b) ratio of CH_4 to CO_2 flow rate, (c) hydrogen, and (d) carbon monoxide

The convection of moisture rich gas from dehydration of MSW can facilitate redistribution of leachate within the waste mass. When water vapor condenses, it can gravitate to the leachate collection system and contribute to increased leachate volume. When gas and leachate migrate to landfill side slopes and are impeded by the cover system (soil and/or flexible membrane liner (FML)), gas pressures and leachate can accumulate and cause leachate outbreaks. The elevated leachate and gas pressures occasionally manifest as “leachate geysers” that can eject 9 to 11 m into the air. These leachate geysers also can be encountered when borings are drilled in the waste for gas wells or exploratory purposes.

Elevated temperatures can induce excessive settlement, e.g., >60 ft. Over time, as the settlement expands to form a bowl-like shape, the gas and leachate pressure force the landfill slopes outward. A comparison of anaerobic biodegradation and elevated temperature shows that the rate of settlement is ~1.5 ft/yr and ~15.5 ft/yr. Strain rate contours provide a useful method to characterize the location where thermal degradation is the dominant process. In this case study, strain rates below 2%/yr indicate normal biodegradation settlement while strain rates greater than 3%/yr indicate elevated temperatures.

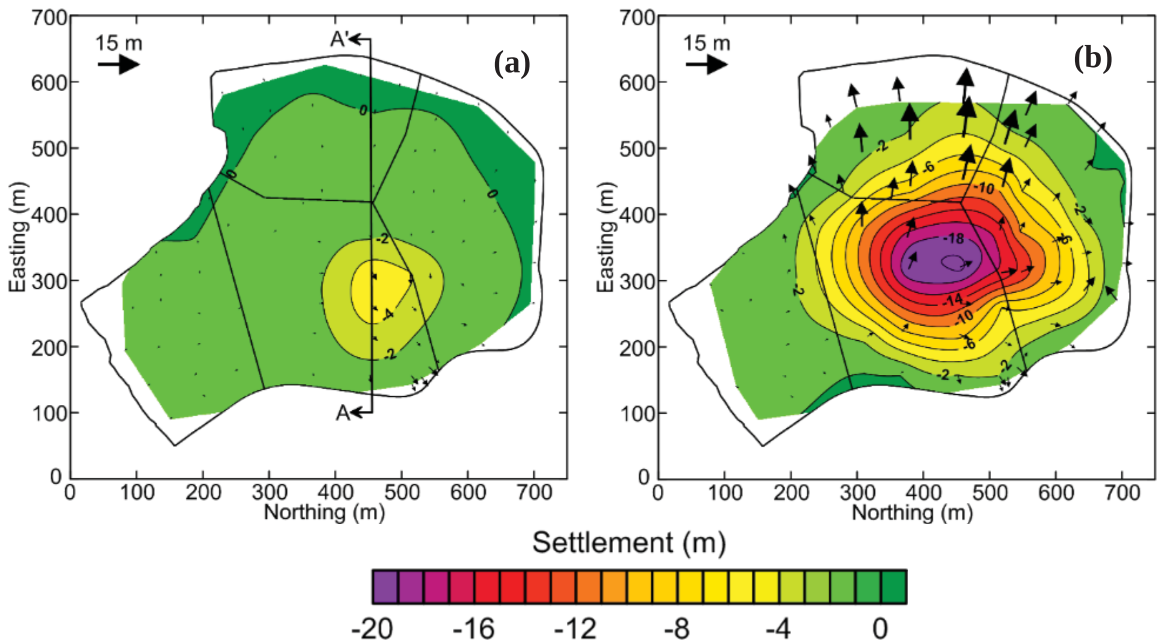

Figure 3. Spatial expansion of settlement (color contours) and slope movement (vectors) for: (a) September 2010 and (b) September 2012

In summary, the sequence of indicators that describe the transition of landfill behavior with advancing elevated temperatures was found to be: (1) Changes in landfill gas composition, which are characterized by decreasing ratio of CH_4 to CO_2 flow rate ratios and elevated carbon monoxide and hydrogen levels (gas composition is found to advance in front of the elevated temperature region); (2) Increased odors; (3) Elevated waste and gas temperatures, e.g., wellhead temperatures increased from below the NSPS threshold of 55°C to 90°C; (4) Elevated gas and leachate pressures that cause leachate outbreaks; (5) Increased leachate volume and migration; (6) Slope movement; and (7) Unusual and rapid settlement.