Subsurface Heating Events at Solid Waste and Construction and Demolition Debris Landfills: Best Management Practices

Landfill subsurface heating events can cause risks to human health, safety, and the environment; increase costs to landfill operators and local governmental entities; and create nuisance conditions for the local community. Examples of impacts from a landfill subsurface heating event are:

- odors;
- smoke;
- toxic emissions;
- liner or cap damage;
- gas and leachate management structure damage;
- slope failure;
- ground water and/or surface water contamination; and
- disruption of landfill operations.

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Purpose and Use of this Document

This document summarizes information gathered by Ohio EPA and from other sources regarding the prevention, detection, investigation, and suppression of landfill subsurface heating events at solid waste and construction and demolition debris (C&DD) landfills. Each landfill is unique and can experience different manifestations of a subsurface heating event. The information contained in this document is presented as a survey of information and best management practices related to landfill subsurface heating events and are not intended to address any given set of site-specific conditions.

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Background

Subsurface heating events are described by many terms, such as subsurface fire, smoldering fire, slow pyrolysis, glowing combustion, subsurface oxidation, and reaction. For the purposes of this document, a subsurface heating event encompasses all of these types of events.

A subsurface heating event may occur at any given solid waste or C&DD landfill. Examples of some of the causes of subsurface heating events include:

- Aerobic microbiological decomposition of waste (cause is often associated with an operational failure such as poor cover or the over application of vacuum on a gas extraction well)
- Chemical reaction (e.g. oxidation) in the waste material. Examples are:
  - Spontaneous combustion, which can occur in such common household wastes as oily rags, paints, solvents, batteries, and pool chemicals.
  - Exothermic reaction when water is combined with certain wastes, such as aluminum production waste (see the aluminum production waste advisories at ***http://www.epa.ohio.gov/portals/34/document/newsPDFs/aluminum_advisory.pdf*** and ***http://www.epa.ohio.gov/portals/34/document/newsPDFs/aluminum_advisory_2.pdf***), municipal solid waste ash, lime, iron waste, steel mill waste, and other metal wastes. These reactions can result in the emission of toxic, flammable, or potentially explosive gases such as hydrogen, ammonia, carbon monoxide, and acetylene.
  - Oxidation of cellulose and plastics to form peroxides which have a low ignition temperature.
- "Hot loads," such as cooking charcoals, ashes, or smoking materials that are buried but not extinguished.

Subsurface Fire Indicators

The FEMA document *Landfill Fires Their Magnitude, Characteristics, and Mitigation* (May 2002) {***www.usfa.dhs.gov/downloads/pdf/publications/fa-225.pdf***} and the California Integrated Waste Management Board *Landfill Fires Guidance Document* (January 2007) {***www.calrecycle.ca.gov/SWFacilities/Fires/LFFiresGuide/default.htm***} identify six indicators that generally confirm a subsurface fire. These are:

- Substantial settlement over a short period of time.
- Smoke or smoldering odor emanating from the gas extraction system or landfill.
- Elevated levels of CO in excess of 1,000 parts per million (ppm).
- Combustion residue in extraction wells or headers.
- Increase in gas temperature in the extraction system (above 140°F).
- Temperatures in excess of 170°F.

Not all of these indicators need to be present to indicate a subsurface heating event.

Once waste temperatures begin to rise and are sustained, the heating "front" may move further into the landfill. Factors affecting propagation include oxygen (air) intrusion, moisture, waste type/size, and void space.

Preventing Subsurface Heating Events

Many landfill operational activities effective in preventing or reducing the risk of a subsurface heating event are already required by rule in Ohio (e.g. cover, good compaction, prohibition of cliffing, diversion of surface water, management of hot loads). Therefore, it is important that owners and operators properly operate and manage their landfills in accordance with applicable regulations and authorizing documents.

When designing the landfill, the engineer should consider how each individual element interacts with others in the landfill's systems from the perspective of preventing subsurface heating events in addition to other purposes. A design decision for one element can have an unintended impact on the effectiveness of another element in preventing or minimizing the propagation of a subsurface heating event or decreasing the protection of the integrity of an engineered component. For example, during a subsurface heating event, an FML cover may be employed to deal with odors from an exothermic reaction, which could result in condensate being generated and infiltrating back into the disposed material, potentially exacerbating the exothermic reaction.

Oxygen Management

Minimizing oxygen (air) intrusion into the landfill is effective in preventing the overheating of waste due to aerobic microbiological decomposition and in minimizing the propagation of the heating front through the disposed material. The owner or operator can minimize oxygen levels in the disposed material by employing some or all of the following:

- Identify where oxygen intrusion can occur and take steps to minimize or eliminate the intrusion. The location of air intrusion can be some distance from the area affected by the subsurface heating event. Means of intrusion can be through the following:
  - Landfill components, such as leachate collection system (LCS) sideslope risers, can introduce air into the disposed material.
  - Configuration of the landfill, such as steep side slopes, can be conducive to creating a chimney effect.
  - Environmental factors, such as weather (e.g. wind, temperature, and barometric pressure) can have an impact on air intrusion in the landfill.
  - Type and condition of daily, intermediate, and final cover. FML and low permeability cohesive soil is more effective as a barrier than a porous soil. Eliminate air intrusion pathways by repairing cracks in soil cover or holes and tears in FML components. Ensure the FML is anchored deep enough so air cannot infiltrate under the edges.
- Good compaction of waste to minimize and reduce void spaces in the disposed material.
- Actively manage and maintain the landfill gas collection and control system (GCCS) by doing the following:
  - Effective and proper tuning of the GCCS. Although the New Source Performance Standards (NSPS) limit for a normal operating landfill is 5.0% oxygen, a lower target, such as 1.5% oxygen level in interior gas extraction wells, can prompt a tuning of the gas well before levels exceed regulatory limits. Wells at the perimeter may tend to show more oxygen due to boundary conditions.
  - Do not over apply vacuum on a gas extraction well.
  - Maintain gas lines and well head seals and boots. Repair holes and tears.
  - Constantly assess GCCS effectiveness and add more extraction wells as necessary.
  - Inform all personnel (e.g. employees, contractors, and regulators) on gas system operational status. If higher operating values (HOVs) are encountered, make all efforts to adjust the system to lower the value. See also Ohio EPA's guidance on Higher

Operating Value (HOV) Demonstrations.
{***http://epa.ohio.gov/LinkClick.aspx?fileticket=kOn3aOhbQOo%3d&tabid=4489***}

- Utilize redundancy in landfill design features. Configure the GCCS header line to be a loop. A loop configuration allows vacuum to be applied to a well from another direction if a segment of the line needs to be isolated for maintenance or repair, thus removing the incentive to over apply vacuum to surrounding wells to compensate for the loss of the well.
- Install horizontal gas collectors in deep cells (>150 to 200 feet) to reduce the need to over apply vacuum to draw from deep vertical wells.
- Incorporate a soil or FML layer in the cap system or intermediate cover for the purpose of preventing or excluding oxygen from entering the disposed material.

Waste Acceptance

Waste acceptance protocols and screening can help reduce the risk of a subsurface heating event. The following criteria can be incorporated into a landfill's waste acceptance plan:

- Work with generators for a more complete characterization of the waste profile.
    - Identify if wastes are incompatible (e.g. extreme pH, oxidizers, water).
    - Include protocols for identifying wastes which may exhibit an exothermic reaction. See suggested tests in the box below.
- Place municipal solid waste ash, industrial sludges, dusts, FGD sludges, etc. on a "watch list."
- Log receipt and disposal location for "watch list" wastes in the landfill and keep records for future reference.
- Monitor for and manage hot loads in compliance with applicable operational rules, including OAC 3745-27-19(E)(7)(d) or 3745-400-11(F)(4).
- Monitor moisture content of incoming waste; meter and monitor solidification volumes. Divert disposal of wet wastes away from areas where "watch list" wastes were deposited.
- Avoid co-disposal of incompatible wastes.
- Restrict disposal of wastes exhibiting exothermic properties to a monocell or monofill.
- Limit the depth of the disposed material where waste exhibiting exothermic properties is disposed.
  Exothermic reactions have been observed to occur at depths of 150 feet. A theory is that the weight of the disposed material and resulting overburden pressure may be a contributing factor.

Suggested tests

- UN/DOT Test for Class 4.3 Waste Substances which in contact with water emit flammable gases (aka Dangerous When Wet Materials) {***www.unece.org/trans/danger/publi/manual/Rev4/ManRev4-files_e.html***}.
  Note: This is a general waste characterization test and is not applicable for RCRA reactive characterization testing.
- Tests found in U.S. EPA's Test Methods for Evaluating Solid Waste, Physical/ Chemical Methods (SW-846) {***www.epa.gov/osw/hazard/testmethods/sw846/online***}.
- Flashpoint.
- Ignitability of Solids.
- pH.

Liquid Management

Minimizing liquids in the landfill can help reduce the potential for subsurface heating events due to aerobic microbial decomposition or due to exothermic reactions in certain wastes that occur in the presence of water. Managing liquids in the landfill and limiting the infiltration or addition of other liquids into the disposed material can be achieved by performing some or all of the following activities:

- Minimize or avoid introducing additional liquids into the landfill, including solidification of liquids and leachate recirculation.
- Divert condensate and leachate recirculation away from areas where “watch list” wastes were deposited.
- Minimize perched zones.
- Maintain effective daily, intermediate, and final cover.
    - Eliminate ponding.
    - Eliminate infiltration pathways by repairing cracks in soil cover or holes and tears in FML components.
- Eliminate ground water infiltration.
- Employ best management practices for storm water. Avoid run-on of surface water onto or into the disposed material.
- Install final/transitional cover as soon as possible.
- Underneath temporary FML cover, install dual horizontal collectors. Placement of dual horizontal collectors, with a gas collector on top of a leachate collector and spaced periodically up the slope, helps control pillowing of leachate at the toe and at benches. Sub-cap liquid collectors can also be installed in shallow trenches to intercept and collect condensate which accumulates under the FML and divert it into the leachate collection system.
- Dewater gas extraction wells in such a way so as not to create aerobic conditions for biological decomposition.
- Use dual-extraction gas wells to enable dewatering of the gas well. Such wells can also be used to pump in gas or liquid to cool down the disposed material.

Limiting movement of the heating front and protecting engineered components

Should a subsurface heating event begin, the owner or operator can take steps to limit the movement of the heating front and to protect engineered components. Most of the suggestions below would need to be instituted at the landfill design stage, and not after the onset of a subsurface heating event.

Limiting movement of the heating front

- Fire breaks.
  Place soil (or other nonflammable material that provides a barrier to heat movement) between cells or phases. Such a barrier should be designed to not inhibit liquid movement, unless liquids are to be diverted from monocells where “watch list” wastes were disposed.
- Gas extraction barrier.
  Install gas extraction wells around the perimeter of an area affected by a subsurface heating event to relieve subsurface pressure, heat, gases, and/or liquids moving from the subsurface heating event. Such wells may also serve as a means to inject gases or liquids to cool or isolate the affected area and prevent the spread of the subsurface heating event.

Protecting engineered components

Employ buffer layers to protect engineered components and any temporary covers composed of geosynthetics (prone to damage from excess temperatures). The buffer layer can be used as a means to inject a cooling agent, or as a thermal barrier through which hot gas and liquid cannot travel.

- Design redundancy.
  Employ natural materials to be redundant with geosynthetics (prone to damage from excess temperatures). For example, using both geonet and aggregate as the leachate collection drainage layer.
- Use temperature and chemical resistant materials.
  - Use CPVC, stainless steel, or fiberglass instead of PVC in the GCCS.
  - Use more durable gaskets, valves (i.e. stainless steel), flexible tubing (metal vs. kanaflex), pumps, floats, and drains in the leachate management system.
- Rely on gravity conveyance rather than mechanical systems for diverting liquids.
- To monitor risk to the engineered components, place temperature monitoring devices into landfill systems as part of normal construction activities.

Investigating subsurface heating events

Visual confirmation or other analytical evidence can be used to determine if a subsurface heating event exists.

Landfill Inspection

One of the best investigative tools for subsurface heating events is visual inspection. Investigations could begin with a focus on what is normal for that particular landfill as a baseline, and then look for changes that are unusual or unexpected. The following are features or events that could indicate a subsurface heating event:

- Unusual or rapid settlement.
  - Incidents of equipment falling through voids.
  - Development of sink holes.
- Stressed vegetative cover (although there may be other causes of stressed vegetation).
- Smoke and steam (visible water vapor). Smoke and steam are not necessarily distinguishable in the field based solely on visual appearance.
  - Smoke and steam may be observed in the gas system or escaping from cracks in the cover.
  - The absence of smoke is not confirmation that a subsurface heating event is not occurring. The disposed material can filter the visible particulate matter from the smoke.
  - An exothermic reaction in waste may produce steam at the landfill surface or within the disposed material (e.g., rising from a boring). Be aware of ambient temperatures and steam – warm gas on a cold morning may ‘steam.’
- Combustion residue (char) in gas extraction wells and in flame arresters at flares. Some subsurface heating events do not exhibit char; however, if it is there, there are no known alternative sources other than a subsurface heating event. To distinguish from condensate residue, visual observation may not be conclusive so a lab analysis may need to be conducted.
- Patchy snow melt (heating event would be closer to surface to observe this effect, although can occur with very deep heating events if hot gas or the heating front is migrating to surface).

- Odors may be an indicator of a subsurface heating event.
    - New odors, particularly odors that smell “hot” or “burning” or of volatile fatty acids or sulfur compounds such as mercaptans.
    - Ammonia odor.
    - Chemical or metallic odor.
- Excessive liquid generation may be an early indicator of a subsurface heating event.
    - Gas extraction wells full of liquid. Liquid in a gas extraction well is normal, so look for excessive amounts; it is presumably from moisture being driven out by heat condensing in the well. It could also be due to leachate outbreaks.
    - Leachate rapidly recharging the sump after the liquid level is pumped down.
    - When excessive liquid cannot be attributed to seasonal variability or operation/construction staging, it could be from a chemical reaction or from moisture being driven out by the heat, condensing elsewhere, and migrating to the leachate collection system.

Landfill Gas Analysis

Gas quality could be an early indicator of a subsurface heating event. Certain chemical constituents are indicative of combusting waste, and if a subsurface heating event is suspected, analysis of the landfill gas from the gas extraction system (or other observation ports imbedded in the disposed material) is recommended. It is critical for the owner or operator to constantly review data from the GCCS to identify changes in the landfill’s normal gas composition, pressure, and temperature.

Gas extraction wells that exhibit characteristics indicative of poor methane generation, excessive oxygen or nitrogen levels, positive pressure, or erratic performance should be monitored more frequently for wellhead temperature, pressure, and the following gases: methane (CH_4), nitrogen (N_2), oxygen (O_2), hydrogen (H_2), carbon dioxide (CO_2), and carbon monoxide (CO). See also Ohio EPA’s guidance on Higher Operating Value (HOV) Demonstrations {***http://epa.ohio.gov/LinkClick.aspx?fileticket=kOn3aOhbQOo%3d&tabid=4489***}.

- Carbon monoxide (CO) and Carbon dioxide (CO_2)
    - Different types of combustion (gas-phase/flaming combustion, smoldering, and glowing combustion) produce CO and CO_2 in different amounts.
    - To confirm a subsurface heating event by using CO, the results should be acquired through quantitative laboratory analysis.
        - Most field equipment only has qualitative abilities and is susceptible to cross-sensitivity with high temperatures, humidity, and other constituents of landfill gas (e.g. volatile organic compounds, hydrogen sulfide). As a result, landfill gas readings may show artificially high carbon monoxide readings when using portable monitors.
    - CO levels in excess of 1,000 ppm are viewed as a positive indication of an active subsurface heating event.
    - CO levels between 100 and 1,000 ppm are viewed as suspicious and further air and temperature monitoring is needed for confirmation.
- Volatile organic compounds (VOCs).
- Semi-volatile organic compounds (SVOCs).
- Polycyclic aromatic hydrocarbons (PAHs).
- Polychlorinated dibenzodioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs).

- Methane (CH_4)
    - CH_4 production often decreases during a subsurface heating event as methane-producing microorganisms are inhibited by high temperatures. The level of CH_4 detected during a subsurface heating event is generally below 45%.
    - If there is more CO_2 than CH_4, biological activity is being inhibited for some reason, possibly due to a subsurface heating event.
- Air
    - Presence of O_2 greater than 5% or N_2 above 20% may indicate over application of vacuum on the GCCS.
    - Presence of balance gas greater than 8.5% may indicate over application of vacuum on the GCCS, or that a subsurface heating event is generating gases other than CH_4, CO_2, or O_2 (e.g. CO, H_2).
- Hydrogen (H_2)
    - H_2 Levels above 5%. H_2 is a result of many processes, so some presence does not necessarily mean a subsurface heating event is occurring.

Landfill Gas Pressure

Excessive landfill gas pressure is a lagging indicator of a subsurface heating event. Some positive pressure is normal; therefore the owner or operator should look for excessive pressures, such as:

- Observation of fumaroles, geysers, or staining of soil around a crack or hole in the cover. Bubbles on the surface of thick cover after a rain event are a common phenomenon; however, it could also be an indication of excessive pressure, especially at a landfill with a GCCS.
- Pump switch transducers giving false liquid level indication, which can also cause pump burn-out.
- Evidence of gas at the anchor trench (using the leachate drainage layer as a pathway).
- Gas extraction system requiring pressure adjustment beyond normal tuning.
- Excessive pressures measured at wellheads.

Temperature Survey

A heating event is characterized as an increase in temperature. The threshold temperature for pursuing further investigations and initiating suppression measures is dependent upon the medium being measured.

- Gas
    - Any time a wellhead temperature equals or exceeds the New Source Performance Standards (NSPS) operating temperature of 131° Fahrenheit, a subsurface heating event investigation should be considered. See also Ohio EPA's guidance on Higher Operating Value (HOV) Demonstrations {***http://epa.ohio.gov/LinkClick.aspx?fileticket=kOn3aOhbQOo%3d&tabid=4489***}.
    - Anaerobic methanogenesis ceases at temperatures above 140° Fahrenheit; therefore wellhead temperatures above 140° Fahrenheit can create additional concern related to the rate of decomposition of the waste or viability of recovering CH_4 as an energy source.
    - If a landfill is experiencing a rapid temperature change, even if the temperatures are below the levels of concern, further investigation is warranted.
    - Inter-well and intra-well gas temperature monitoring is useful for determining the vertical and horizontal extent of the heating front.

- Leachate
  - If above-typical leachate temperatures are observed, a subsurface heating event investigation may be warranted. Leachate temperatures above 100° Fahrenheit are cause for concern. Note: If the heated leachate is diluted by unaffected leachate, the temperature increase may not be detected.
  - Hot leachate and proximity of a subsurface heating event to the leachate collection system and liner raise concerns of potential impact on the integrity of engineered components.
    - A temperature monitoring program using temperature monitoring devices (thermocouples) within the leachate drainage system can be instituted to monitor risk of damage to the engineered components.
    - Inter-well leachate temperature monitoring can also be conducted for this purpose; however, it would not provide the same degree of confidence as using temperature monitoring devices in the leachate drainage system.
- Waste
  - Temperatures in the disposed material will likely be much higher than the gas temperatures measured at the well head. Waste temperatures above 170° Fahrenheit are positive indication of a subsurface heating event.

Waste Temperatures
Waste temperature can also be obtained with hand-held scanning devices when waste is brought to the surface during borehole drilling or sampling.

- Infrared photography provides an overview of near surface temperature conditions at the landfill.
  - While infrared photography alone is not conclusive to determine the presence of a subsurface heating event, when coupled with other investigative techniques it can prove useful.
  - Infrared photography, with the proper resolution and benchmark surface temperature points, can identify the warmest areas near the landfill surface. This can help direct a temperature survey, gas analysis, and other investigations to the area most likely experiencing a subsurface heating event.
  - In some subsurface heating events, hot gases may use “wormholes,” or small passages as pathways away from the heating event, that can lead to secondary heating events. These preferential pathways form a spider-web appearance in an infrared photo, which are otherwise difficult to detect.

Leachate Chemical Analysis

A change in leachate quality, or the presence of certain chemicals in the leachate, can be an early indicator of a subsurface heating event. However, leachate quality is normally assessed on an annual basis thus lessening its ability to be an early indicator. If a subsurface heating event is suspected, the owner or operator should monitor and evaluate leachate quality for changes.

Suppression of Subsurface Heating Events

If measures to prevent subsurface heating events were inadequate and an incident occurs, affected parties can institute measures to minimize its propagation. It is important to act quickly to prevent or limit such negative impacts as toxic air emissions, smoke, and damage to engineered components. The following is a list of common techniques used to suppress a subsurface heating event or propagation of the heating front. Selection of a technique should be based on the specific nature of the incident and the structure of the landfill. Measures taken to decrease temperatures may work more rapidly to suppress the subsurface heating event than measures taken to exclude oxygen.

- Apply cover.
    - Soil. A thick layer of low permeability soil is often successful.
    - Waste is not recommended because it may combust, resulting in a surface fire.
    - FML could be effective if it will not be subject to high temperatures (could melt the FML) or differential settlement (could tear the FML). If damaged, FML is not as easy to repair as soil cover. FML can also mask settlement, slope failure indicators, and leachate outbreaks.
    - Shotcrete can be used on vertical faces where soil cannot be applied.
- Inject cooling agents or suppressants.
    - Foam. It is important to make sure the appropriate type of foam is used, one that will suppress, and not accelerate, the subsurface heating event. Reaching the subsurface heating event is difficult, and even if reachable, complete suppression may be unlikely.
    - Liquid. Dousing the landfill surface or injecting liquid into the landfill can overwhelm the leachate collection system, run-off can contaminate surface water, increased pore water pressure in the disposed material or engineered components can lead to a slope failure, and an exothermic chemical reaction can be exacerbated or initiated. Reaching the subsurface heating event is often difficult. To protect engineered components, a cool liquid could be flushed into the leachate collection system of a hot zone to keep temperatures down; however, reaching the area at risk could be difficult, and excessive depth of leachate on the liner could develop.
    - Gas. An inert gas can be injected, or the GCCS can be manipulated to reverse the flow of oxygen or redistribute cool gas to hot spots. Injection of inert gas can be expensive and distribution to all the hot spots may be difficult.
- Excavation of the hot waste is also a potential suppression method. However, with excavation comes the threat of flare ups from the introduction of oxygen. Foam, water, or other suppression methods may need to be used in conjunction with excavation. Excavation may not be a viable option if the subsurface heating event is very deep, extensive, or propagating too rapidly.
- Fire break. Excavation of waste ahead of the heating front.
- Gas collection and control system (GCCS) management.
    - Shutting down the extraction well and instituting a staged return to active use. This might only be effective if the subsurface heating event is caused by increased aerobic microbial activity due to over application of vacuum on the well, and if the heating event is addressed before the heating front propagates away from the well.
    - Shutting down extraction wells surrounding the impacted area and instituting a staged return to active use.

Suggested Reading

Ohio EPA aluminum production waste advisories
www.epa.ohio.gov/portals/34/document/newsPDFs/aluminum_advisory.pdf and www.epa.ohio.gov/portals/34/document/newsPDFs/aluminum_advisory_2.pdf

Ohio EPA Higher Operating Value (HOV) Demonstrations guidance
http://epa.ohio.gov/LinkClick.aspx?fileticket=kOn3aOhbQOo%3d&tabid=4489

Landfill Fires Their Magnitude, Characteristics, and Mitigation —FEMA (May 2002)
www.usfa.dhs.gov/downloads/pdf/publications/fa-225.pdf

Guidelines for Public Health Actions in Response to Landfill Fires, Appendix B in Landfill Gas Primer — Agency for Toxic Substances and Disease Registry (ATSDR)
www.atsdr.cdc.gov/hac/landfill/html/appb.html

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Smouldering Combustion Phenomena in Science and Technology, by Guillermo Rein, published in Interational Review of Chemical Engineering, Vol 1, pp 3-18, January 2009
www.era.lib.ed.ac.uk/handle/1842/2678

Understanding landfill fires, by Patrick Foss-Smith, published in Waste Management World, Volume 11, Issue 4, August 2010

Ignition and Suppression of Smouldering Coal Fires in Small-Scale Experiments, by R. Hadden and G. Rein, 6th Mediterranean Combustion Symposium, Ajaccio, June 2009
www.see.ed.ac.uk/~grein/rein_papers/Hadden_SuppresingCoalfires_2009.pdf

Investigation on the spontaneous combustion of refuse-derived fuels during storage using a chemiluminescence technique, by Atsushi Matunaga et al., published in Waste Management & Research; 2008: 26: 539-545

Self-Heating in Yard Trimmings: Conditions Leading to Spontaneous Combustion, by Richard Buggeln and Robert Rynk, published in Compost Science and Utilization (2002), Vol. 10, No. 2, 162-182
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Gas generation in incinerator ash, by Maria Arm and Johanna Lindeberg
www.energiaskor.se/pdf-dokument/presentationer%202006/ arm_lindeberg_gas_generation_paper.pdf

Physical, biological and chemical processes during storage and spontaneous combustion of waste fuel, by William Hoagland and Marcia Marques, published in Resources Conservation & Recycling 40(2003) 53-69

Effect of an uncontrolled fire and the subsequent fire fight on the chemical composition of landfill leachate, by Joar Karstn Oygard et al., published in Waste Management, 25(2005) 712-178

Treating Subsurface Landfill Fires, by Robert C. Stearns and Gaalen S. Petoyan, published in Waste Age, March 1984

Fighting a Landfill Fire, by Tony Sperling. Waste Age, Jan 2001
http://wasteage.com/mag/waste_fighting_landfill_fire/