IN SITU VITRIFICATION OF BURIED WASTE: CONTAINMENT ISSUES AND SUPPRESSION SYSTEMS

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ABSTRACT

Pacific Northwest Laboratory (PNL) and Idaho National Engineering Laboratory (INEL) are developing a remedial action technology for buried waste through the adaptation of the in situ vitrification (ISV) process. The ISV process is a thermal treatment process originally developed for the U.S. Department of Energy (DOE) to stabilize soils contaminated with transuranic waste. ISV tests with buried waste forms have demonstrated that the processing of buried waste is more dynamic than the processing of soils. This paper will focus on the issue of containment of the gases released during the processing of buried waste and on engineered suppression systems to alleviate transient events associated with dynamic off-gassing from the ISV melt.

INTRODUCTION

Pacific Northwest Laboratory (PNL) and Idaho National Engineering Laboratory (INEL) are jointly pursuing adaptation of the in situ vitrification (ISV) process for remediation of buried waste. During June and July 1990, two ISV field tests were conducted at INEL in a cooperative effort between INEL and PNL using the PNL intermediate-scale ISV processing equipment. Transient events during the 1990 field-scale tests demonstrated that processing of buried waste forms leads to dynamic events in the off-gas hood not previously seen for tests with contaminated soils.(1) Such transient events include pressure and/or temperature spikes in the off-gas hood caused by the dynamic release of gases from the melt. Transient pressure events are of particular concern since such events have the potential for the release of untreated material to the environment.

As a result of the transient events observed during the processing of buried waste, containment of the dynamic gas releases from ISV processing of buried waste is a major issue. Efforts to address this issue are focused on understanding the mechanism(s) that lead to transient events and engineering systems to suppress and/or eliminate the effects in the off-gas hood from these transient events. To facilitate the study of ISV processing of buried waste, PNL upgraded its engineering-scale unit to be compatible with transient events similar in nature to those observed during field-scale testing.

An operational acceptance test (OAT) for the upgraded engineering-scale ISV unit was conducted at PNL in September 1991. During the OAT, proof-of-principle testing was conducted for a water spray suppression system designed to combat transient events in the off-gas hood. Results show that the water suppression system has great potential for combating both pressure and temperature transients in the off-gas hood that may occur from the processing of buried waste forms. Results from the OAT also provided insight into the parameters that need to be measured to understand the mechanisms leading to transient events in the off-gas hood.

IN SITU VITRIFICATION PROCESS

ISV is a thermal treatment process that melts contaminated soils and wastes to form a chemically inert glass and crystalline substance. The ISV process was developed by PNL during the 1980s, and the successful results of 59 tests conducted under a variety of site conditions and a variety of waste types have proven the general feasibility and widespread application of the process.(2) The process is initiated by a square array of four graphite electrodes inserted a few inches into the ground. Because soil is not electrically conductive, a mixture of graphite and glass frit is placed among the electrodes to serve as a starter path. Once an electrical potential is applied to the electrodes, an electrical current is started in the starter path which heats up and begins to melt the soil. The graphite starter path is eventually consumed by oxidation and the current is transferred to the molten soil, which is processed at temperatures between 1450 and 2000°C. As the molten or vitrified zone grows, it incorporates or encapsulates any radionuclides and nonvolatile hazardous elements into the glass structure. The high temperature of the process destroys many organic components by pyrolysis. The pyrolyzed by products migrate to the surface of the vitrified zone and combust in the presence of air. After processing the molten material is allowed to cool, and dissolved waste is incorporated into the vitrified product.

The ISV power system typically uses a Scott-Tee connection to transform a 3-phase input to a 2-phase secondary load on diagonally opposed electrodes in a square pattern. PNL is currently exploring the use of alternative power systems compatible with electrodes in patterns other than a square (e.g., triangle, hexagon). Electrodes are fed into the melt via a pneumatically controlled feed system. The electrode feed assembly consists of four independently controlled, air-actuated systems with a feed system for each electrode. This feed system was developed by PNL to provide an additional degree of operational control. Previous ISV tests utilized electrodes that were placed into holes predrilled into the ground. The use of electrode feeding allows the electrodes to be inserted into shallow holes at the surface and then fed as the melt progresses. This technique is believed to be most beneficial for application to sites containing large amounts of metal. Electrode feeding allows the electrodes to be held above any metal pools that may form at the bottom of the melt and avoids potential shorting conditions that might otherwise hamper operation.

The off-gas containment hood is designed to collect off-gases emanating from the melt and direct them to an off-gas treatment system. The hood is operated at a slight vacuum (2.5 to 5.0 cm of water) created by an induced draft blower. An air inlet line is provided through which air is drawn into the hood, thus providing oxygen for the combustion of pyrolysis gases released from the melt. Off-gases collected in the hood are directed to an off-gas treatment system that collects any residual noncombusted gases, in addition to particulate entrained in the off-gas flow.

BACKGROUND

The overall objective of the two 1990 intermediate-scale field tests at INEL was to assess the general suitability of the ISV process to remediate waste structures representative of those found at the INEL Radioactive Waste Management Complex (RWMC). The RWMC encompasses 144 acres in the southwest section of INEL. The Subsurface Disposal Area (SDA) of the RWMC served as a disposal area for radioactive (intermediate- and low-level solid and mixed wastes and transuranic and mixed-fission products) and nonradioactive hazardous wastes. Buried waste at the SDA were primarily generated by the DOE Rocky Flats Plant and INEL operations.

The solid radioactive waste stored at the SDA is mixed with nonhazardous waste, including broken equipment, lumber, paper, rags, plastic, and other solid debris. In addition, significant amounts of organic wastes generated by Rocky Flats Plant operations are contained in 55-gal drums and buried in several pits. The successful application of ISV to the wide variety of buried waste at the SDA will provide the baseline for which the ISV technology may be extended to buried waste at other sites.

1990 INTERMEDIATE-SCALE FIELD TESTS AT INEL

The intermediate-scale field tests conducted in June and July 1990 at INEL were designed to assess the feasibility of using ISV to remediate SDA buried waste. The waste materials and containers used in these tests simulated those found in INEL buried waste. However, because the tests were designed to assess overall process performance, no radioactive or hazardous waste materials were used. Application of ISV to the SDA would utilize a full-scale field unit; therefore, since this was an intermediate-scale field test, the waste forms used were scaled versions of actual SDA waste. Waste container dimensions were reduced in proportion to the reduced electrode spacing between the two scales (the intermediate-scale unit utilized a shorter electrode spacing in order to provide the same power density to the melt (kW/m^2) as anticipated for a full-scale unit).

Test 1 involved 0.6 m of soil overburden and 1.8 m of a randomly disposed box and can layer mixed with fill dirt. Test 2 involved 1.2 m of soil overburden, 0.6 m of a three-layered stacked can region, and 0.9 m of a stacked box region. The contents of the cans and boxes for both tests were from one of the following categories: combustibles (e.g., paper, wood), sludge (mainly water), metals, and concrete/glass. Test 1 is more representative of the conditions expected to exist at the SDA. The stacked can region of Test 2 represented the greater potential challenge to the ISV process in that such a region may contain a reduced amount of soil relative to the waste fraction. Additionally, a stacked region could challenge the capability of the off-gas processing system if several containers were breached at about the same time.

Figure 1 illustrates the effect on the off-gas hood vacuum during a dynamic gas release from the melt during Test 1. Note that prior to, and after, the transient pressure event, the vacuum in the off-gas hood remains relatively constant. The time period from when vacuum in the hood began to decrease until the vacuum stabilized is approximately 1.7 minutes (each minor division on Fig. 1 is roughly 18 seconds). A similar transient pressure event was observed for Test 2 and is illustrated in Fig. 2. Again, the duration of the transient pressure event is long (approximately 2.3 minutes). The long duration of the observed transient events (on the order of minutes) indicates that the underlying mechanism is not a detonation. Transient pressure events for such a high-energy mechanism would be expected to last on the order of seconds, not minutes.

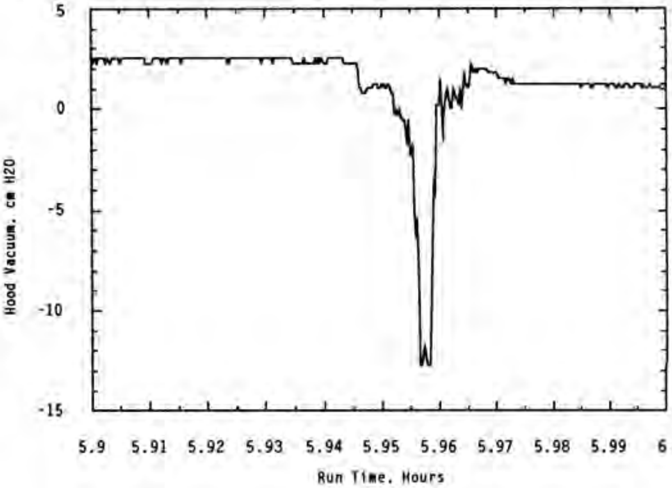

Fig. 1. Hood vacuum as a function of time for 1990 INEL field test-Test 1.

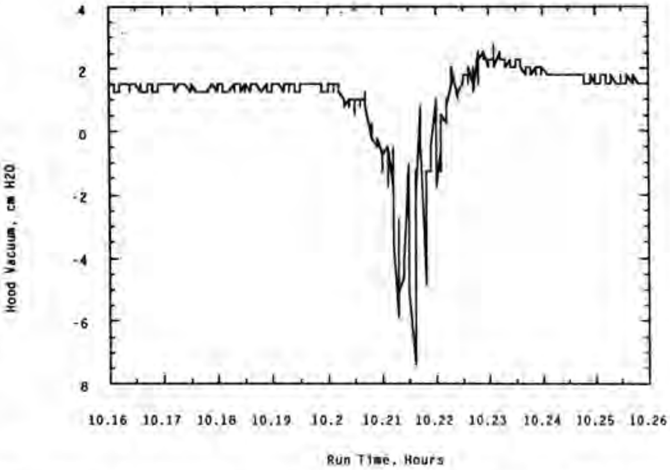

Fig. 2. Hood vacuum as a function of time for 1990 INEL field test-Test 2.

TRANSIENT EVENT MECHANISMS

Figure 3 illustrates the different flow streams that may enter and exit the off-gas hood. The off-gas hood has a fixed volume, with only the off-gas exit stream controlled by a mechanical device (i.e., the induced draft blower of the off-gas treatment system). Air inlet flows are proportional to the pressure difference between the inside and outside of the off-gas hood. Since the off-gas hood is maintained at a slight vacuum, the preferential air flow is into the off-gas hood. Gas addition to the off-gas hood from the ISV melt is a function of the pressure difference between the inside of the off-gas hood and the melt (and soil). However, because conditions in or

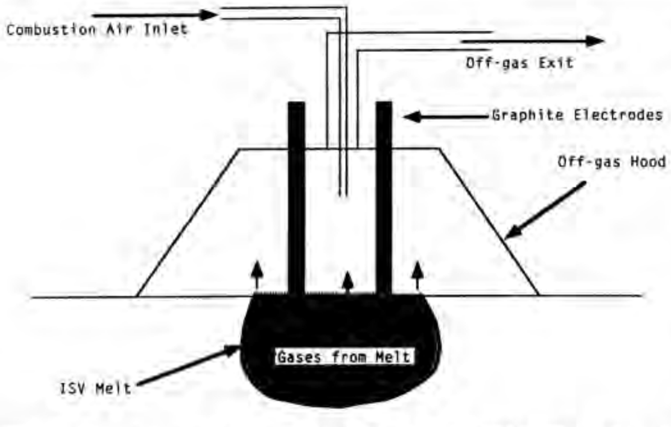

Fig. 3. Gas stream inlets and outlets for the ISV off-gas hood.

around the ISV melt may suddenly change the pressure of gases in the melt and soil, the gas addition to the off-gas hood may also suddenly change. Understanding the interdependencies between these flow streams and conditions in the off-gas hood is necessary for understanding the mechanisms by which transient events occur in the off-gas hood.

Material and energy addition to the ISV off-gas hood from the melt is a normal part of the ISV process. For processing of contaminated soils, this rate of addition from the melt is essentially steady and occurs at a rate that the off-gas hood is capable of handling while still maintaining a slight vacuum. However, the dynamic nature observed during the processing of buried waste has the potential for transient events that exceed the capacity of the off-gas system and allow the off-gas hood to positively pressurize.

The mechanisms by which the off-gas hood may become positively pressurized include the following:

- Net energy increase of gases in the off-gas hood
    - Addition of hot gases from the ISV melt
    - Combustion of pyrolysis gases in the off-gas hood
    - Increased radiant and convective heating of gases in the off-gas hood due to changes at the melt surface
- Net increase in number of moles of gases in the off-gas hood
- Net increase in both energy and number of moles of gases.

The off-gas hood is much like a tank filled with gas. At steady state, with inlet and outlet streams equivalent, the tank will remain at a constant pressure. However, with an increase in either the flow of material into the tank or the temperature of the gases within the tank, or an increase in both material flow and temperature, the tank pressure will increase. For the ISV off-gas hood, as with the tank filled with gas, the increase in pressure is proportional to the magnitude, but more importantly to the rate, at which energy and/or material is added to the off-gas hood.

Understanding the relative importance of the different pressurization mechanisms for ISV processing of buried waste requires further study. Measurements of the air inlet flow rates and state (i.e., temperature and pressure), outlet flow rate and state, and state of gases in the off-gas hood are needed to establish the interrelationship of these parameters, and to provide an estimate of the flow rate and state of gases from the melt. In addition, measurements of the state of gases within buried waste forms and the surrounding soil are needed for modelling efforts directed at predicting the off-gas rate from the melt.

SUPPRESSION SYSTEMS

PNL and INEL are working to develop a fundamental understanding of the mechanisms by which transient events occur in the off-gas hood as a result of processing buried waste. In addition, PNL is pursuing engineered suppression systems designed to buffer and/or eliminate the transient events in the off-gas hood (i.e., pressure and/or temperature spikes) caused by dynamic gas releases from buried waste forms. These suppression systems are based on the mechanisms discussed in the previous section. Concepts designed to remove energy and material from the off-gas hood at a faster rate upon demand (e.g., additional off-gas exit capacity) require little testing. The design of such systems requires the establishment of expected limits for the ISV processing of buried waste. A limit will be established once the mechanisms leading to pressurization of the off-gas hood are better defined.

One very promising suppression system being pursued by PNL is a water spray system designed to combat the energy addition pressurization mechanism. The water spray system uses the latent heat of vaporization for water as an energy siphon. Energy added to the off-gas hood is used to vaporize water instead of being added to the gases in the off-gas hood. As energy is transferred from gases within the off-gas hood to the added water, the temperature decreases. As a result of this temperature decrease, the pressure within the off-gas hood also decreases (this follows the ideal gas law relationship where pressure is proportional to temperature for a given volume and number of moles). Although the conversion of water to steam would intuitively suggest an increase in pressure, the benefit from a cooler off-gas temperature in the hood is more than adequate to compensate.

The technical basis for the water spray system is illustrated by the equations and example for the intermediate-scale unit that follow. Eq. (1) is used to calculate the amount of energy that water added to the off-gas hood would remove from the gases within the off-gas hood

$$\Delta Qw = \Delta KE+\lambda m+\Delta U \qquad \text{(Eq. 1)}$$

where Qw is the energy gained by the water, KE is kinetic energy, m is the number of moles of water added, λ is the latent heat of vaporization for water, and U is internal energy. The energy gained by the added water come from the gases in the off-gas hood. As a result, the temperature of the gases in the off-gas hood will decrease according to Eq. (2).

$$\Delta H=nCp(T_i-T_f) \qquad \text{(Eq. 2)}$$

H is enthalpy, n is the moles of gases in the off-gas hood, Cp is heat capacity and T_i and T_f are the initial and final temperature of the gases, respectively.

Solving Eq. (1) and Eq. (2) simultaneously so that the energy gained by the water added is equivalent to the energy lost by the gases in the off-gas hood leads to the final temperature in the off-gas hood as a result of water addition. Using this final temperature in Eq. (3), the final pressure in the off-gas hood can be determined.

$$(P_i-P_f)V=(n+m)R(T_i-T_f) \qquad \text{(Eq. 3)}$$

P is pressure in the off-gas hood, V is the volume of the hood, R is the ideal gas law constant, T is the temperature of the gases in the off-gas hood, and n and m are moles of gas and water, respectively. For illustration, the intermediate-scale off-gas hood is 27.6 m^3 in volume and normally operates at a temperature of 573K and a pressure of 100.57 kPa. Using the ideal gas law, these conditions lead to 583 moles of gas present in the off-gas hood. If one mole of water is added to this system, Eqs. (1) to (3) predict that the final temperature in the off-gas hood will be 569K and the final pressure 100.08 kPa. The pressure drop of 0.49 kPa (100.57 kPa - 100.08 kPa) represents an increase in the off-gas hood vacuum of 5 cm of water. The one factor missing from the above equations is time. Proof-of-principle testing was performed to estimate the unknown time factor.

Figure 4 illustrates the engineering-scale equipment used for proof-of-principle testing of the water spray suppression system. A spray nozzle mounted in the center of the engineering-scale off-gas hood delivers a fine mist water spray at a rate of 37 ml/min. The off-gas hood of the engineering-scale unit is instrumented to measure inlet and outlet flowrates, temperatures of inlet and outlet streams, and the pressure and temperature in the off-gas hood. At various times during the engineering-scale OAT, the water spray system was activated and the response in the off-gas hood measured. Figure 5 illustrates the pressure and temperature responses for two separate, 10-second trials of the water spray system (each minor mark on the time axis represents 15 seconds). One very striking observation illustrated by Fig. 5 is the reproducibility of the results for each water spray trial. Further work is needed to determine if the magnitude of the temperature and pressure responses are consistent with those predicted by Eqs. (1) to (3). However, the fact that the system responded to the water spray system in the manner predicted shows that the water spray suppression system has great merit.

Figure 6 illustrates the pressure, inlet flowrate, and outlet flowrate responses for the two 10-second water spray trials. The outlet flowrate is relatively constant because this flowrate is drawn from the off-gas hood mechanically and is not a function of conditions within the off-gas hood. However, as Fig. 6 illustrates, the inlet flowrate is very much a function of conditions within the hood. For both water spray trials, the inlet flowrate is at first increased upon initiation of the water spray and then equilibrated at a lower flowrate after the water spray trial is terminated. This result is not unexpected since an increase in vacuum will increase the driving force for pulling air into the system. However, the addition of water to the off-gas hood has increased the number of moles in the off-gas hood, and a new equilibrium is established with a lower inlet air flowrate. The relationship between conditions in the off-gas hood and flowrates in and out of the hood need to be better understood before a fundamental understanding of transient event mechanisms can be achieved.

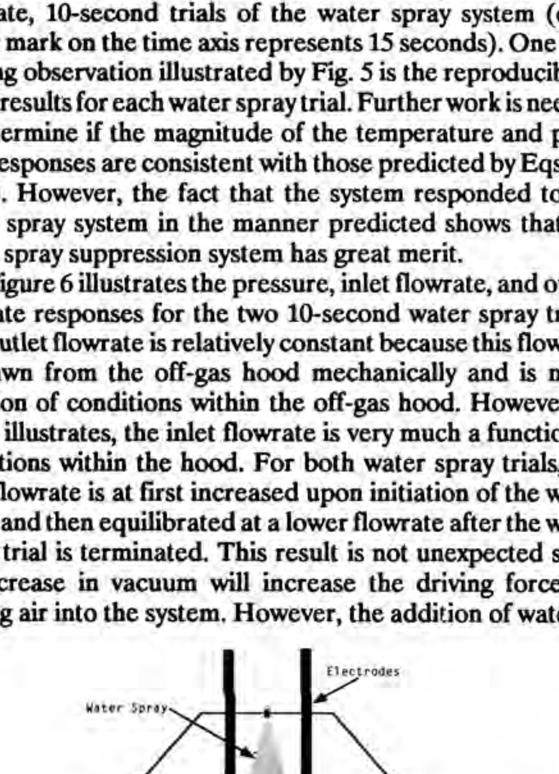

Fig. 4. Side view of PNL ISV engineering -scale system.

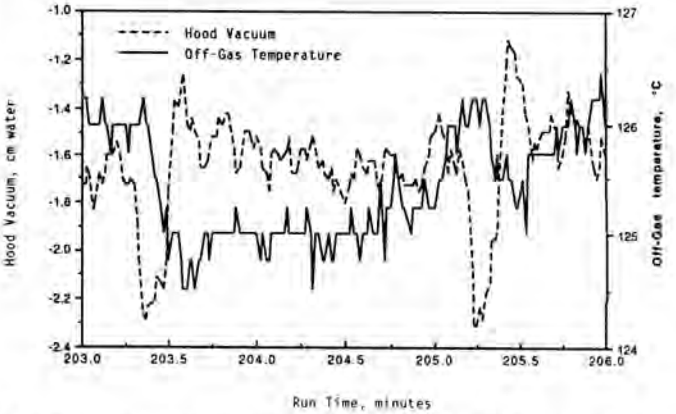

Fig. 5. Water spray suppression system trials-pressure and temperature responses.

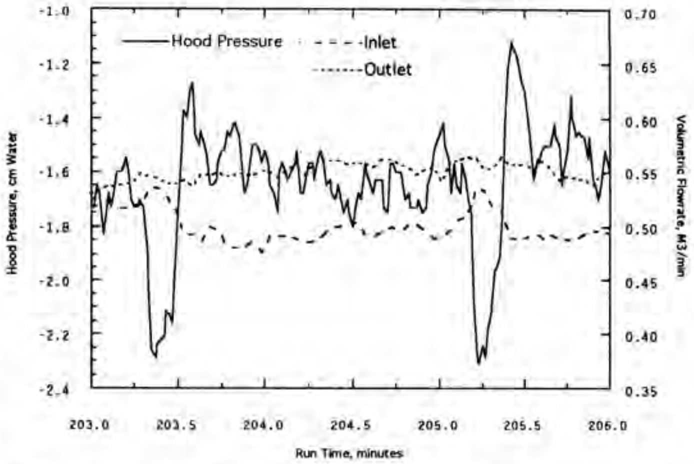

Fig. 6. Water spray suppression system trails-pressure and flowrate responses.

CONCLUSIONS

Based on analyses of test data to date, the following points can be made relative to 1) off-gas containment issues related to ISV processing of buried waste, and 2) the design of engineered suppression systems to counter transient events related to ISV processing of buried waste.

Resolution of the containment issue for ISV processing of buried waste will require a fundamental understanding of the mechanisms leading to transient temperature and pressure events in the off-gas hood. Identifying the relationship between the conditions within the off-gas hood and the streams flowing into and out of the hood is necessary for this fundamental understanding. In addition, an understanding of the relationship between the rate of gas release into the off-gas hood from the melt and the parameters in the ground (e.g., gas release rate from buried waste forms, temperature of gases traveling to the melt surface) is needed to completely resolve the containment issue.

Engineered suppression systems based on added flow capacity out of the off-gas hood are anticipated to require little proof-of-principle testing. The design of such systems requires an understanding of the mechanisms for transient pressure and temperature events in the off-gas hood. In addition, the relationship between these mechanisms and the type of buried waste material needs to be determined so that a suppression system is adequately sized.

Proof-of-principle testing of a water spray suppression system designed by PNL to combat transient events in the off-gas hood showed that the system has great promise. Numerous trials of the water spray system during the OAT of PNL's engineering-scale unit showed that the use of the system leads to an increase of vacuum in the hood. Benefits from the water spray system are anticipated to be greater for a field-scale unit since temperatures in the off-gas hood for a field-scale unit are greater than that achievable in the off-gas hood of the engineering-scale unit.

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