Infrared Imaging for the Control and Optimization of Waste Treatment by Vitrification - 9322

Keith S. Witwer, Troy L. Duncan, Edward R Selle, Mark D. Storaasli
AMEC Nuclear, GeoMelt Division
1135 Jadwin Ave, Richland, WA, USA

ABSTRACT

The U.S. Department of Energy (DOE) Office of River Protection (ORP) contracted with AMEC, GeoMelt Division (GeoMelt), to develop and demonstrate its Bulk Vitrification (Bulk Vit) technology using the In-Container Vitrification™, a.k.a. ICV™, (ICV) process. This process is being evaluated as a potential supplemental treatment process for a large fraction of the DOE Hanford Site low-activity waste (LAW).

The ICV process is a batch or hybrid batch-feed thermal waste treatment process that is performed in a refractory-lined steel container. Waste and glass-formers (if needed) are placed into the ICV container and are melted using Joule (resistive) heating. Most waste constituents are either destroyed or decomposed during treatment and any remaining hazardous constituents, such as radionuclides, are encapsulated in the highly durable glass product.

GeoMelt recently demonstrated Bulk Vit to the DOE at full-scale using a 24-ft x 8-ft x 8-ft ICV melter, processing 56 metric tons (MT) of liquid Hanford LAW waste simulant and glass formers in a single contained melt. This test, the most recent of five full-scale tests for the project, called Test FS-38D, also incorporated a full-scale liquid waste drying system, which dried and mixed the liquid LAW simulant with glass forming minerals prior to vitrification. After drying and mixing, the waste simulant was then periodically fed to the ICV melter, where it was vitrified into a borosilicate glass block weighing 44 MT.

Accurately monitoring and controlling the amount of waste material added to the ICV is an essential and sometimes challenging task. It was determined during early project testing that direct visual observation of conditions within the melt container was needed to ensure that feed was being properly supplied and optimally distributed and incorporated across the melt surface. Standard video systems have historically been used for GeoMelt operations, but only with marginal results. Little or no lighting, high particulate concentration, and high concentration of condensing gasses such as NOx inside the container plenum are demanding conditions for a video system. Efforts were undertaken prior to Test FS-38D to identify and demonstrate an improved monitoring system for future Bulk Vit operations.

Infrared imaging was investigated with the expectation that the challenging environmental conditions could be overcome. IR systems are able to operate with no supplemental lighting and some have the unique ability to resolve and image in dusty or opaque gas environments. In addition, these IR systems can provide both qualitative and quantitative measurements of waste and molten glass temperatures during waste processing.

A Mikron Infrared Inc. imaging system was selected as the best candidate for the Bulk Vitrification system, and was demonstrated during engineering-scale testing. The system was then implemented during full-scale Test 38D, and met or exceeded all test objectives. The system was able to provide excellent imagery throughout the test period, and it enabled operations personnel to precisely control the feed addition to the ICV container. The primary test objectives for FS-38D were met in large part due to this newly implemented monitoring system, and the equipment has been included in the Hanford Demonstration Bulk Vitrification System (DBVS) final design package.

INTRODUCTION

Waste processing using the GeoMelt technology is typically performed using either a Staged, a feed-while-melt (FWM), or a hybrid staged/FWM process. In the Staged method, all of the waste to be treated is placed, or staged, into a refractory lined ICV melter prior to application of electrical current. After staging, the waste is processed (melted) and the resulting product is a size-reduced, solid glass monolith, typically 40 to 60% smaller in volume than before treatment. In the FWM method, additional waste is added (fed) to the melter after some, or all, of the original staged material has been treated. Waste continues to be added and treated until the container is filled with glass to a prescribed height. Both treatment methods have distinct advantages, and both methods are best managed with the aid of a real-time monitoring system that views the interior of the ICV container during processing.

The melting progress inside the ICV interior can be ascertained using secondary system indicators such as temperature, electrical, and offgas sensors. However, visual observation of the melter interior enables operations personnel to directly evaluate key process elements, including the condition of the waste surface, internal refractory wall and the carbon electrode surface, to name a few. Traditional closed-circuit video systems provide this capability, but they are prone to several limiting factors, including the need for an integral or separate lighting system, inability to see a broad range of surface temperature changes, and sensitivity to airborne particulate or vapors that obstruct the field of view (and which is further exacerbated by the reflection caused by the lighting source.) The degree of need for direct observation of the ICV interior is partially dependent upon on the type of waste to be treated.

DOE’s Demonstration Bulk Vitrification System (DBVS) project, performed at the Hanford Site in southeastern Washington State, uses the GeoMelt ICV process for treating liquid radioactive low activity waste (LAW). Specifically, GeoMelt’s FWM process is used to treat LAW in a 24-ft long by 8-ft wide by 8-ft tall container, as shown in Figure 1. As shown, two cameras, located at opposite ends of the container, provide complete coverage of the ICV interior, and provide some redundancy in the event of a camera malfunction.

The LAW treated in the DBVS project contains a high concentration of nitrate salts, such as sodium nitrate and sodium nitrite. Because these salts melt at a lower temperature than silica and other glass forming minerals, they have a tendency to segregate and migrate away from the glass formers during the heating process. Bagaasen [1] discussed this phenomenon, and early DBVS full scale testing [2] demonstrated its negative affects. Several mitigating steps were identified and successfully implemented in follow-on DBVS engineering [3] and full-scale [4] testing. One key mitigating action that was identified was to more closely control the volume of waste staged on the melt surface at any given time. This ensured that the volume of available waste salts were limited, preventing excessive molten salt concentration, especially near the refractory walls. A consistent and reliable video monitoring system was integral to controlling this waste addition process. A summary discussion of this recent full-scale test was published in the WM08 proceedings [5].

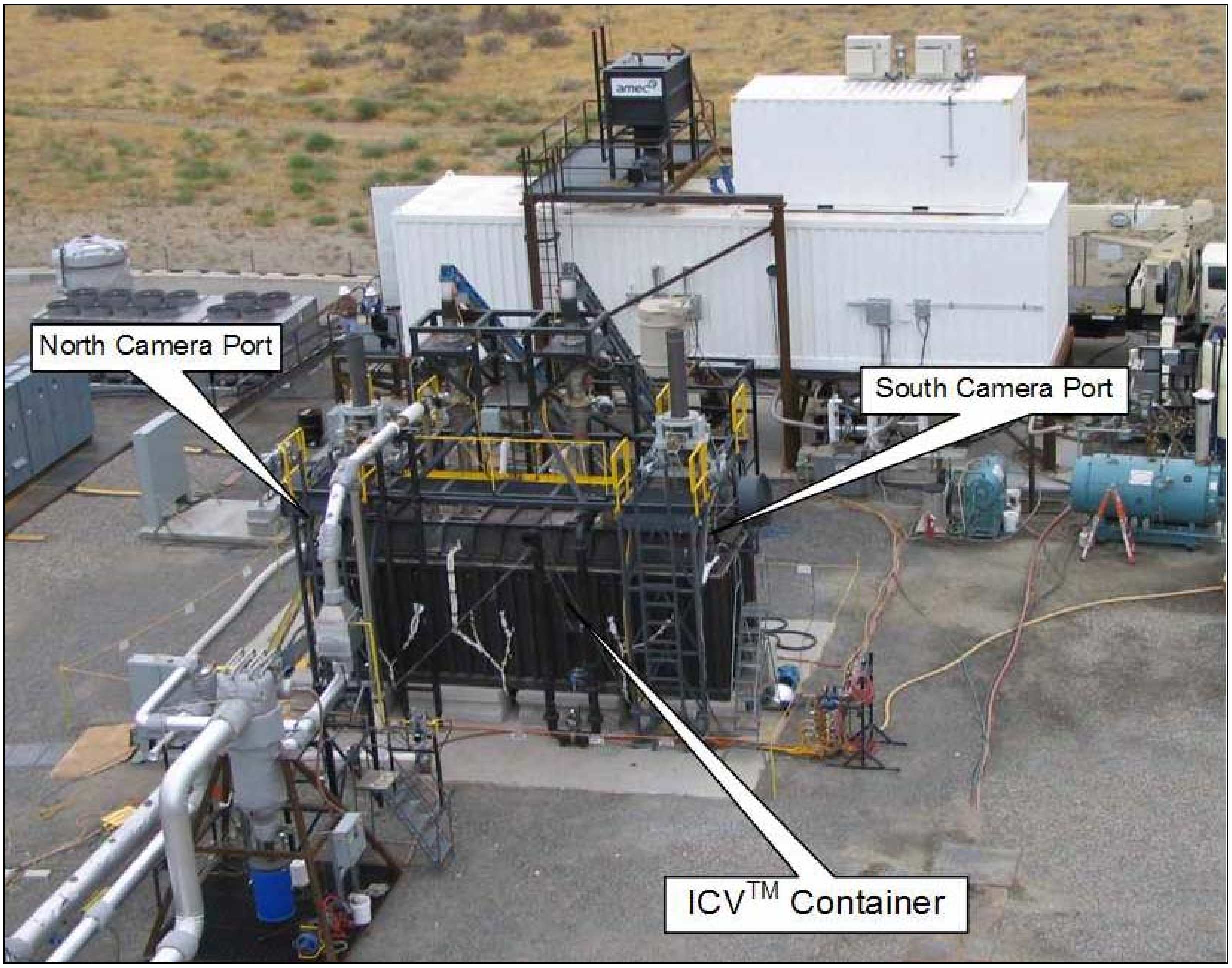

Fig. 1. View of GeoMelt ICV Container and Camera Port Locations

STANDARD VIDEO SYSTEM CAPABILITIES AND LIMITATIONS

Closed circuit high-resolution video systems have historically been used for GeoMelt operations, for both domestic and international projects. These systems have provided remote monitoring of key process components, including the ICV container (internal and external) and other support equipment that can be difficult or unsafe to access when melt power is energized. Figure 2 shows images taken of the interior of the DBVS ICV during Test FS-38C in 2006, using a standard video camera, aided by a 250W halogen light source. These images were taken under conditions with ample lighting and minimal airborne particulate, and are relatively clear and show more detail than most images obtained during waste processing with this type of video camera. More often than not, however, the off-gas vapors and/or particulates originating from the waste effectively blind the camera, making it unusable for a large fraction of the waste processing cycle.

Note the bright red spot in the left-hand photo. This spot is a halogen light located at the opposite end of the ICV container, used to provide illumination for a second video camera, also located at the opposite end of the ICV container (reference Figure 1). Although the airspace inside the melter lid is relatively clear, there is still significant attenuation of the light source, as seen in this photo. The DBVS project especially challenged the video system because of the long and narrow viewing region (~22 x 7-ft) for the camera(s), the high particulate generated in the viewing region during feed addition, and the highly opaque NOx vapors produced during decomposition of the nitrate and nitrite salts. The airborne particulate and vapors effectively blinded the camera, making it unusable, which also effectively handicapped operations personnel's ability to manage the feed addition to the ICV on several occasions.

Fig. 2. Photos of standard video camera images.

Efforts were undertaken after Test FS-38C to significantly improve or replace the video system. Although the lighting source was enhanced prior to FS-38C, it provided little improvement to the overall video quality. Several vendors were contacted for advice, and it became evident that many of the previous image problems could be overcome by use of an infrared imaging system.

INFRARED IMAGING SYSTEM

Theory of Operation

All bodies radiate energy to their surroundings proportional to their absolute temperature. Although the emitted radiation of a body includes all wavelengths, the region in which the amount of radiation is significant to industrial temperature measurement extends from 0.3µm to about 20µm. Wavelengths from 0.4µm to 0.7µm make up the visible region and wavelengths longer than 0.7µm make up the infrared region; which humans, and typical closed circuit video systems, cannot see.

Since infrared radiation is emitted by all objects based on their temperatures, thermography, or thermal imaging, makes it possible to 'see' one's environment with or without visible illumination. The amount of radiation emitted by an object increases with temperature; therefore thermography allows one to see variations in temperature. When viewed by a thermal imager, warm objects stand out well against cooler backgrounds. An IR, or thermal imaging, camera detects the electromagnetic radiation that is impossible to see in real life, builds a picture in the viewer, and records a visible picture. In addition to being ambient light level independent, thermal imagers are also able to penetrate obscurants such as smoke or opaque vapors.

Thermal imaging allows the user to both qualify and quantify temperature differences observed in its viewfinder. Qualitative temperature differences can be observed as changes in color or shades of gray, or both. Quantitative differences can be obtained by first calibrating the imaging system against a known emissivity of the material of interest. For example, a steel plate at a given temperature will emit a different amount of infrared radiation than a concrete block at the same temperature. By programming the imager with the emissivity of the object, relatively accurate temperature measurements (+/- 2%) can be obtained. Often times, the emissivity of a particular object is unknown and must be determined empirically. This can be done by use of direct temperature measurement, such as with a thermocouple. The imager is then calibrated such that the temperature of the object shown in the imager matches the temperature indicated by the thermocouple.

Engineering-scale testing using an infrared imaging system.

We obtained a commercially available infrared imaging system, for use by AMEC during early scoping tests. These tests were performed using an engineering-scale GeoMelt system, as shown in Figure 3.

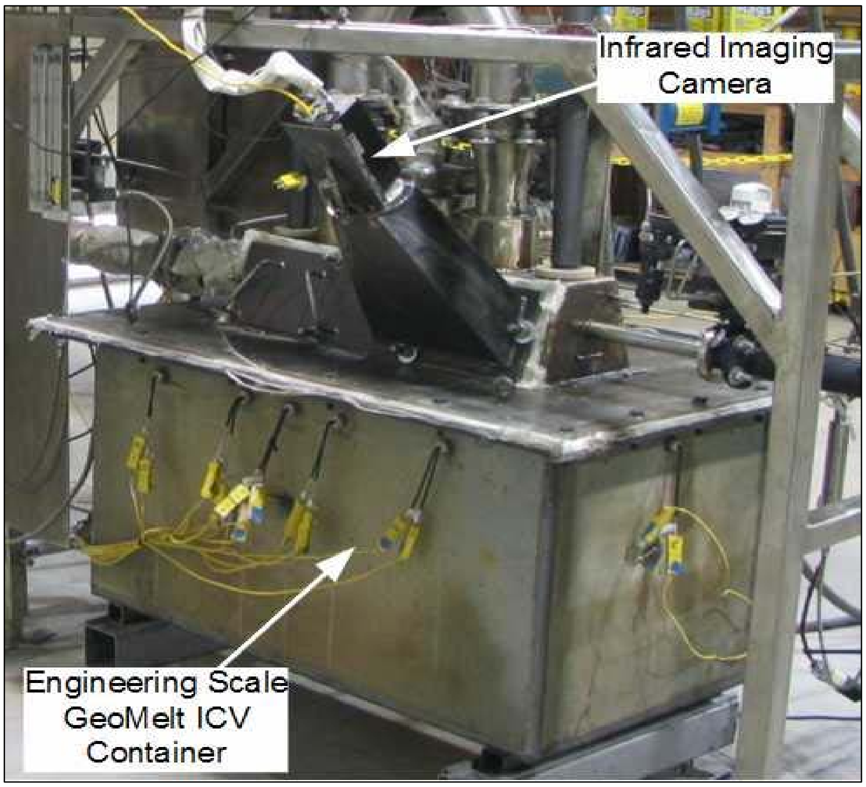

Fig. 3. Engineering-scale GeoMelt ICV melter and position of infrared camera.

The IR camera was shown to provide real-time process data and enabled control of the rate of waste feed simulant addition to the melter. The engineering-scale testing also provided the opportunity to determine actual emissivity values of various materials within its field of view, including the alumino-silicate-based refractory wall, the unprocessed Hanford LAW simulant staged above the molten glass, the molten glass surface, the carbon electrodes, and the steel hood structure. Each of these materials was monitored with the IR camera, at key temperatures, while concurrent temperature measurements were recorded using type-K thermocouples. As mentioned, these direct temperature measurements were then used to set the emissivity values for those materials, within the system software, which then enabled accurate quantitative temperature measurements with the IR camera. This emissivity data would be used during follow-on full-scale test FS-38D.

Full-scale testing using the IR Imaging System

Based on the successful results from engineering-scale testing, the IR imaging system was procured for the DBVS project. The IR system and a standard video system were both installed, at opposite ends of the ICV container, for use during FS-38D. The standard video camera was subsequently not used for the majority of the test because of its limited functionality. The standard video system was repeatedly blinded by the NOx vapors and feed particulate, making observation of the ICV interior nearly impossible.

Conversely, the IR imaging system worked very well and was able to resolve video images through the airborne NOx and feed particulate, enabling operations staff to manage the unprocessed feed above the melt surface as planned. The IR system provided both a qualitative measurement of melt exposure and a quantitative measurement of material temperatures. Figure 4 shows images taken with the IR system at various stages of the test, from top to bottom, left to right. Starting from the top, the first image shows the ICV container prior to loading waste simulant, at ambient temperature conditions. Although the image is grainy, it does show the ability of the IR camera to resolve details at temperatures well below its intended temperature range. Note that the ICV container was covered and had no illumination when the image was recorded. The next image shows the pre-staged feed material. The image appears to glow; however, this glow was not visible with the standard video system, but was visible with the IR camera, which detected the relatively higher temperature (150 to 180°C) feed pile. As the feed pile began to melt through, the hotter molten material, below the surface, is exposed, as seen in the next image. At this point, the feed pile is approximately the same temperature as the previous image; however, the auto-gain feature of the camera self-adjusts to compensate for the higher temperature evident in the newly exposed lower region, making the upper region of the pile appear cooler. Feed additions to the melt caused significant amounts of particulate to circulate within the plenum space. A typical feed addition is seen in the next image, in which the plenum space can be seen filling with particulate and NOx. At this point, a typical video system would be completely blinded and unusable.

Feed piles were managed such that buildup along the CRB walls was minimized. Typical feed piles, showing their position relative to the refractory walls, are shown in the next two images. These images show a typical reaction of nitrate with cellulose in the feed pile. Before adding a final “clean-glass” feed, the S-109 feed was allowed to incorporate fully into the molten glass, as is shown in the last image. Based on readouts from the IR imaging system, the melt surface temperature before adding the clean-glass feed was from 650 to 750°C. This surface temperature is typical with an internal glass melt temperature of approximately 1325°C.

Proprietary software, used with the IR camera, enables the creation of regions of interest (ROIs) in various shapes. With these, an operator is able to retrieve temperature range details confined within each ROI. The emissivity of multiple ROIs can be set independently, and a temperature indication for each ROI is displayed directly on the computer monitor. Each ROI has a minimum and maximum alarm set point that can be configured to generate software and digital output alarms. Although not used for DBVS operations to date, the software can be configured to send corresponding signals to a PLC or SCADA system, which would trigger external alarms or implement control logic for a system – e.g., melt input power.

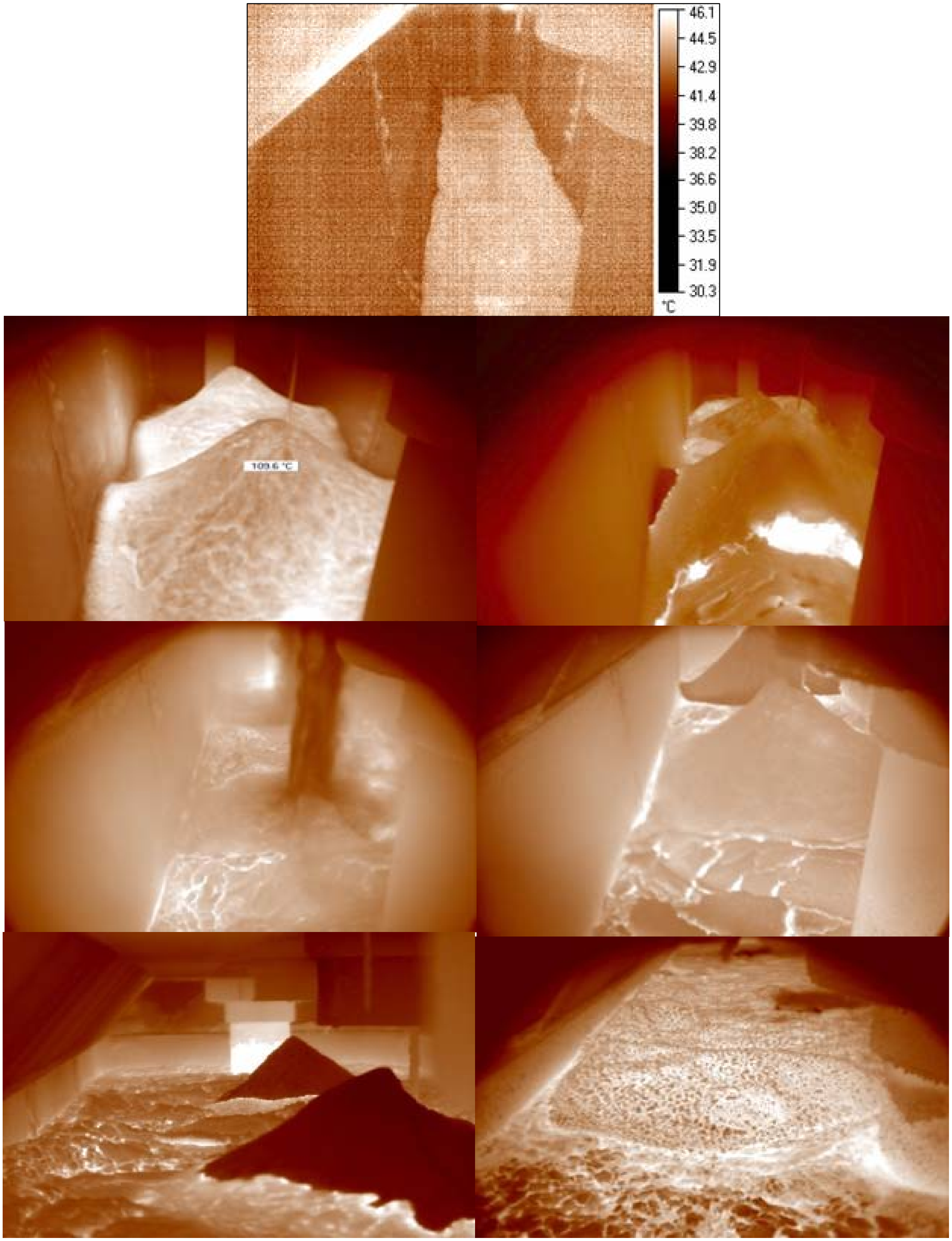

Fig. 4. Still images of DBVS ICV container using a thermal imaging system.

CONCLUSIONS

IR imaging was successfully demonstrated during engineering scoping tests and during DBVS Test FS-38D. It enabled observation of the GeoMelt ICV container throughout the entire testing period and enabled accurate control of feed addition to the melter. This control enabled management of the cold cap (unprocessed feed pile) above the melt such that previous problems with migration of molten ionic salts, such as sodium nitrate and sodium nitrite was significantly reduced. Post melt examination of the refractory walls confirmed the elimination of molten ionic salt migration into the refractory. The IR imaging system has been incorporated into the final design of the Demonstration Bulk Vitrification System for use on the Hanford Nuclear Site.

REFERENCES

1. BAGAASEN, et al, “Transport of Technetium and Rhenium Into Refractory Materials During Bulk Vitrification”, WM-6312, Waste Management 2006 Conference, (2006).

2. WITWER, et al, DBVS FS-38C Test Report, AMEC Doc 34006-RT-0003, Richland, WA (2007).

3. FINUCANE, et al, ES-30J, K, & -31F Engineering Scale Test Report, AMEC Doc 30686-RT-0001, Richland, WA (2007).

4. WITWER, et al, DBVS FS-38D Test Report, AMEC Doc 30686-RT-0003, Richland, WA (2007).

5. WITWER, et al, “Hanford’s Supplemental Treatment Project: Full-Scale Integrated Testing of In-Container Vitrification and a 10,000 Liter Dryer”, WM-8293, Waste Management 2008 Conference (2008).