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High Temperature Inspection System

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Abstract

The Remote and Specialty Equipment Section (RSES) of the Savannah River Technology Center has developed a High Temperature Inspection System (HTIS) for remotely viewing the interior of the Defense Waste Processing Facility (DWPF) melter pour spout. The DWPF is a vitrification facility at the Savannah River Site where radioactive waste is processed, mixed and melted with glass frit in an electrically heated melter, and poured into canisters for long-term storage. The glass mixture is transferred from the melter to the canisters via the pour spout, a vertical interface between the melter and the canisters. During initial operation of the melter, problems were experienced with wicking of the glass stream to the sides of the pour spout resulting in pluggage of the pour spout. A removable insert was developed to eliminate the wicking problem. Routine cleaning of the pour spout and replacement of the insert requires that the pour spout interior be inspected on a regular basis. The HTIS was developed to perform the inspection.

The HTIS provides two video images: one view for aligning the HTIS with the pour spout and the other for inspecting the pour spout wall condition and other surfaces. The HTIS is carried into the melter cell using an overhead crane and is remotely connected to the cell's telerobotic manipulator (TRM). An operator uses the TRM to insert the HTIS into the 2-inch (5.08 cm) diameter pour spout, rotate it 360 degrees, and then remove it.

This application created many challenges for the inspection device, especially regarding size and temperature. The HTIS design allows the video cameras to stay below a safe operating temperature during use in the 1100 degrees C environment. Many devices are designed to penetrate a wall and extend into a heated chamber only a few inches, but the HTIS is inserted into the heated chamber 22 inches (55.88 cm). Other devices can handle the insertion length and small diameter, but they are not designed to handle the high temperature. This paper will discuss the development, unique features, and field use of the HTIS.

1. Introduction

The DWPF was built to process and vitrify high-level radioactive waste for long-term storage. The waste is received into the facility, processed, and mixed with borosilicate glass frit. The glass-waste mixture is fed into the melter where it is heated at 1100 degrees C, and the molten mixture is poured into stainless steel canisters for storage. The mixture is vacuum-transferred from the melter through a heated pour spout into the canister. Figure 1 shows a photograph of the melter pour spout.

During initial operation of the melter, problems were experienced with wicking of the glass stream to the sides of the pour spout resulting in pluggage of the pour spout. A removable insert was developed to eliminate the wicking problem. A cross-sectional view of the pour spout with the removable insert installed is shown in Figure 2. The pour spout is 22 inches (55.88 cm) in length, and the diameter is graduated from 2 inches (5.08 cm) at the top, to 3 inches (7.2 cm) in the middle, and to 4 inches (10.16 cm) at the bottom. The wicking problem was occurring at the sharp edge, called the knife edge, of the 2-inch (5.08 cm) to 3-inch (7.2 cm) interface. The removable insert changed the interface so that the step was 2-inch (5.08 cm) to 4-inch (10.16 cm) allowing enough clearance between the glass stream and the wall to prevent wicking. The HTIS provides a real-time view of the pour spout lining, the condition of the knife edges, and the interface between the insert and the pour spout.

Figure 1: DWPF Melter Pour Spout

Figure 2: Cross-sectional View of Pour Spout

2. Design Constraints

The environment of the pour spout creates a challenge for any inspection system due to the high temperature, the extreme brightness caused by the high temperature, radioactive contamination, and the radiation field. The temperature of the pour spout is the same as the operating temperature of the melter and cannot be reduced for inspection purposes; therefore, the inspection must be performed at operating temperature.

Several constraints were placed on the inspection system because of the melt cell configuration. All operations within the melt cell are performed remotely by an operator looking into the cell through a shielded window. The only means of inserting any tool into the pour spout is the TRM, which also provides the electrical and pneumatic connections for tools. The available connections limited the options for the inspection tool. The HTIS was made to be remotely coupled to the TRM, electrically, pneumatically, and physically. The only available cooling for the HTIS is facility air, approximately 90 psi, provided through the arm.

Another difficulty of this application is that changing the insert and inspecting the pour spout requires a stop in production of the melter, which is only allowed for a short time. This brief window of opportunity means that the HTIS is assembled and tested in our mockup facility prior to use, but there is only one attempt allowed for the inspection. After that attempt, production is restarted, and the next outage will not be for several months. Any changes to the HTIS after use in the pour spout must be done in a maintenance cell where radioactive contamination can be controlled.

3. HTIS Design

The basic components for visual imaging are two ¼"-diameter color video cameras with fixed focal length lenses and NTSC video outputs. The cameras are 2-part units including the camera head with attached cable and camera control unit (CCU). The CCU's are housed in a separate enclosure, along with temperature displays. Figure 3 is a photograph of the HTIS and attached enclosure.

Figure 3: High Temperature Inspection System

The cameras are positioned within the HTIS such that one camera, the axial camera, views directly up the spout and the other, the radial camera, views the walls of the spout via a right-angle mirror. The limited electrical connections from the TRM include a 12Vdc power connection and two video cables. Although the camera has many available adjustments to enhance the image, no adjustments are possible once the HTIS is connected to the TRM. To compensate for the brightness within the spout, optical filters and special lenses are applied to the cameras to achieve an acceptable image.

The rated maximum operating temperature of the cameras is 50 degrees C, requiring that the HTIS interior be maintained at or below this temperature during normal use. Several features make it possible to keep the internal temperature below a safe level while the external temperature is 1100 degrees C: an outer reflective shield, insulation, and internal air flow.

The HTIS shield outer diameter is 1 ½ inches (3.81 cm), which allows it to clear the 2-inch (5.08 cm) diameter section of the pour spout. The shield is made of Inconel 690, a material which can withstand 1100 degrees C and resist oxidation for an extended period of time allowing the surface to remain reflective. The insertion distance required to reach the areas to be viewed is 22 inches (55.88 cm), and the HTIS is 24 inches (60.96 cm) in length.

Several components within the HTIS provide most of the insulation for the unit. The insulation, air flow, and reflective shield allow the interior to remain at or below 50 degrees C for approximately 30 minutes of use, which is more than enough time to perform the pour spout inspection. The temperature of both cameras is monitored using thermocouples, and the temperature is displayed on panel meters installed in the control box.

The HTIS can survive for longer than 30 minutes at 1100 degrees C and has been used continuously for 2-hours in the mockup. The internal temperature exceeded the safe operating limit; and although the internal components were not damaged, it is expected that continued operation above the limit would shorten their life expectancy.

4. Testing and Field Use

The HTIS is carried into the melt cell using an overhead crane and interfaces with the TRM inside the cell. The HTIS is vertically positioned on the TRM end effector, and the associated enclosure is hung on the side of the TRM. The required power input, cooling air input, and video outputs are fed through the TRM.

Several generations of the HTIS have been used in the DWPF pour spout. The units were irreparably damaged during use due to either a cooling problem or due to rough handling with the TRM. The final generation has been assembled and is ready to be used in the pour spout.

Preparing the HTIS for use in the field was a challenge in regards to setting the cameras up to handle the extreme brightness of the pour spout. A mockup of the pour spout was fabricated for testing purposes. The mockup size and temperature exactly duplicate the actual pour spout; however, testing has proven that the brightness level of the actual pour spout is higher than that of the mockup. When the HTIS was first developed, the camera settings were adjusted to obtain the best image in the mockup, but when used in the field, the images were washed out due to extreme brightness.

As previously mentioned, changing the insert and inspecting the pour spout requires a stop in production of the melter, allowing only one attempt at the inspection. There is no room for field adjustments. This was a major challenge initially, but based on our field experience, we are now able to compensate for the difference in brightness levels using special lenses and filters.

Because of the heat, the majority of the brightness was caused by infrared light. Reflective material was placed over the windows to block the infrared light. Also, we procured specially made lenses with irises installed since the lenses available for the ¼" cameras are not normally supplied with a built-in iris. The addition of an iris further reduced the light intensity and increased the depth of field of the cameras.

A second challenge was keeping the internal components cool. When the first HTIS was used, the axial camera was damaged due to insufficient cooling. Improvements in cooling the unit have resulted in a longer operating time within the pour spout and extended life of the cameras. The internal components were rearranged to improve air flow through the unit. As well, the infrared reflective material placed over the windows blocks direct heat. A third change was remaking the shield from a more oxidation-resistant material to keep the shield as reflective as possible for as long as possible. These improvements allow the unit to remain in the pour spout for much longer than is required.

5. Conclusion

As the DWPF Melter continues operating, the conditions of the pour spout and liner will continue to degrade. The HTIS is currently the only tool available for evaluating the pour spout interior, and this evaluation capability will allow the melter to be used for the full extent of its life.

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