INSTRUMENTATION CONCEPTS FOR NUCLEAR WASTE GLASS MELTERS

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ABSTRACT

Several instrumentation concepts are being developed at the Pacific Northwest Laboratory (PNL) for process control of high-level waste glass melters. These systems include an infrared imaging system, a glass level monitor, a feed crust stability sensor, and in-melter thermocouple arrays. These instrumentation systems provide redundant indications of the melter operating status and can detect potential process upset conditions such as glass foam and high feed rates. The systems are designed to withstand the melter operating environment of high temperatures and radiation levels, and corrosive gases and slurry.

INTRODUCTION

Facilities for solidification of high-level, liquid nuclear waste are expected to be operational by 1990 at several sites.[1] These facilities will encapsulate the wastes in borosilicate glass using the slurry-fed ceramic melter process. Development of this melting technique in the U.S. began in 1974 at PNL.[2] The PNL melter technology has been transferred to the Savannah River, South Carolina, and the West Valley, New York sites in support of these solidification facilities, and is currently being adapted for the proposed plant in Hanford, Washington.

In the slurry-fed melting process, the liquid wastes are mixed with glass-forming chemicals. This waste slurry is pumped directly onto the glass surface of an electrically heated glass melter. The slurry dries into a semi-rigid crust which in turn melts, yielding the waste glass product. The glass is poured into steel canisters, allowed to cool, and then transported to a repository for disposal.

Several instrumentation concepts are under development for process control of the remote melters. These instruments provide multiple indications of the melter operating status, such as the glass depth, and enable operators to detect the onset of process upset conditions. Such conditions include excessive generation of glass foam, molten salt phase separation from the glass, excessive glass or slurry feed accumulation in the melter, formation of a rigid feed crust over the entire glass surface, and glass temperatures out of the nominal operating ranges. The instruments must also withstand the melter operating environment, i.e., high temperature and radiation levels, corrosive gases, glass formulations specifically designed for high metal oxide solubilities, and acidic feed slurries.

The instrumentation packages currently being development at PNL include an infrared melter imaging system, an electronic glass level monitor, a pneumatic feed crust stability sensor, and in-glass thermocouple arrays. These systems are shown in a typical melter in Fig. 1.

This paper presents these instrumentation concepts, describes their associated equipment, and discusses their current states of development.

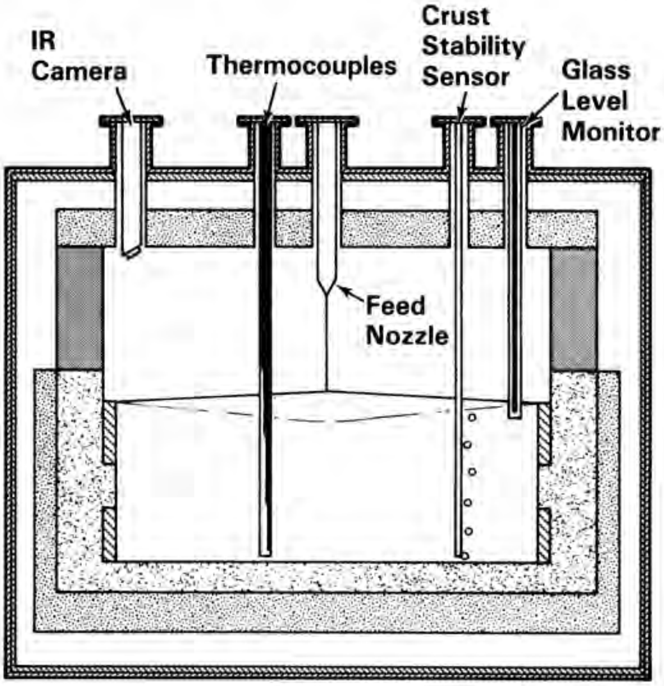

Fig. 1. Typical PNL melter shown with instrumentation packages installed.

INFRARED IMAGING SYSTEM

The trend in melter design development is toward reducing the need to rely primarily on visual interpretation to determine the operating status of the melter. However, visual observation of the feed crust will continue to be important in monitoring melter operations.

The closed-circuit infrared (IR) imaging system shown in Fig. 2 generates a picture of the crust that directly relates to the temperature and emissivity of the internal melter features. Because the melter operates under extremely low light conditions (no features of the melting cavity are discernable by the naked eye), earlier PNL imaging systems based on the visible spectrum gave lower-resolution melting cavity images.

Fig. 2. Infrared camera assembly.

The PNL system creates the IR images by filtering light entering the camera to remove wavelengths shorter than about 0.7 μm. This process removes most of the visual spectrum. The IR images improve the operator's ability to differentiate between the feed slurry and the dried feed crust, also aiding estimation of glass surface area covered by the crust.

The camera assembly can be remotely installed with an overhead crane. The optics for this system are contained in a periscope section that extends into the melting cavity, as shown in Fig. 3. The actual camera is located above the melter where additional radiation shielding can be provided. The camera design is similar to the television monitor being tested at the Savannah River Laboratory (SRL).[3]

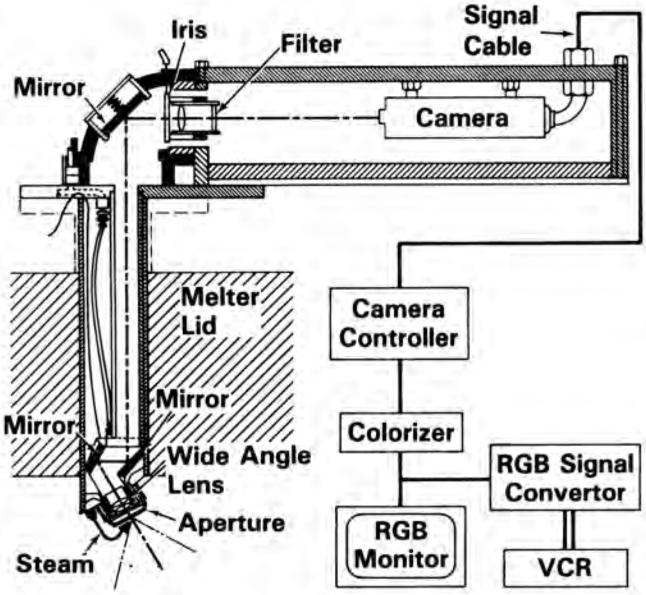

Fig. 3. Melter imaging system.

The camera assembly is air-cooled to prevent lens distortion or other damage from the temperature changes caused by cycling the melter from operating to idling. Approximately 18 scfm of airflow are required to maintain the operating temperatures of the camera in the range of 60 to 130°C. The air is divided into two circuits: One to cool the camera and most of the optics, and one to cool only the wide-angle lens assembly. This split limits the camera-cooling air flow into the melter to less than 2 scfm. This flowrate is adequate to prevent feed spatters from entering the camera aperture to obstruct the field of view. The remaining cooling air is exhausted outside of the melter. This camera and periscope design has been successfully demonstrated for over 1100 hours in prototypical PNL melters.

Because the periscope is cooled, glass volatiles condense on the periscope's exposed surfaces. Experience with the system has shown that a steam jet periodically directed at the lens aperture is adequate to remove the condensates.

The IR system uses a high-resolution camera and vidicon (picture-generating) tube that have been proven to be very resistant to gamma radiation damage. Experiments conducted at SRL have shown that the camera and tube will survive cumulative gamma exposures in excess of 5×10^7 rads.[3]

The camera signal can be processed outside the melter cell to convert the black and white picture into an eight-color display. The color bands represent various temperature ranges inside the melter; thus, both quantitative and qualitative information can be obtained from the picture. The melter images are also recorded on video tape for future reference and data analysis.

GLASS LEVEL MONITOR

The operator must know how much glass is in the melter in order to calculate the total glass production, to verify other indications of the canister glass content, and to ensure that glass is not drained from the melter during canister changeouts. Dip tubes have been used for this purpose in the past, but the erosion and corrosion of these devices caused the indicated level to drift from the actual position.

An electronic monitoring system is being developed to improve the long-term accuracy of the glass level output. The system requires only two Inconel® conductors inside the melter and will be much less sensitive to corrosion-induced errors. This instrument may also eventually be capable of estimating the thickness of a glass foam layer and detecting molten salt phase separation.

The electronic level monitoring system is shown in Fig. 4. The system determines the position of the glass surface by measuring the time required for an electric pulse to travel along the conductors and be reflected by the glass surface interface back to the source. The time required for the pulse to be reflected from the glass is a function of the position of the glass surface and the dielectric constant of the media surrounding the conductors. This technique is called time-domain reflectometry and is conceptually similar to wire-guided radar. The outputs from this system,

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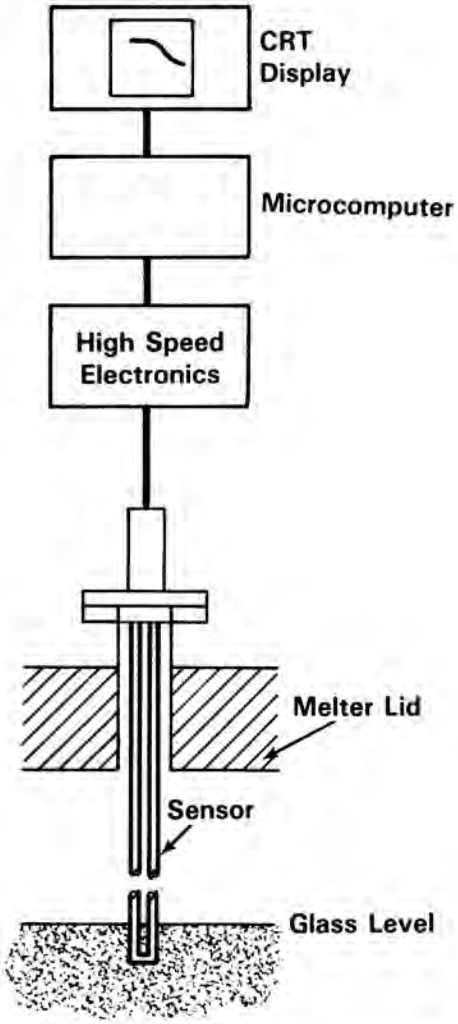

Fig. 4. Electronic glass level monitoring system.

shown on a CRT, include the glass depth and a curve indicating the impedance of the conductor along its length.

The shape of the impedance ratio curve is indicative of the physical conditions present at the glass surface. For example, if a glass foam layer is present, the impedance of the material between the two Inconel® sensor rods would be higher than for glass interface only, and the reflected pulse would be relatively less distinct. This is indicated by a lower slope of the impedance ratio curve, as shown in Fig. 5. Similarly, for a molten salt layer, the impedance would be lower than for glass and the impedance ratio curve would indicate a higher slope.

Preliminary tests with this instrument under simulated conditions have shown that the liquid level can be determined to within 5 mm. This system can also recognize that second phases are present at the glass surface, but further testing is required to quantify and prove the reproducibility of the results.

CRUST STABILITY SENSOR

Behavior of the feed crust is one of the most important factors in overall melter performance. If the slurry feed rate to the melter is too fast, the crust enlarges until it contacts the melter walls, forming a continuous bridge across the glass surface.

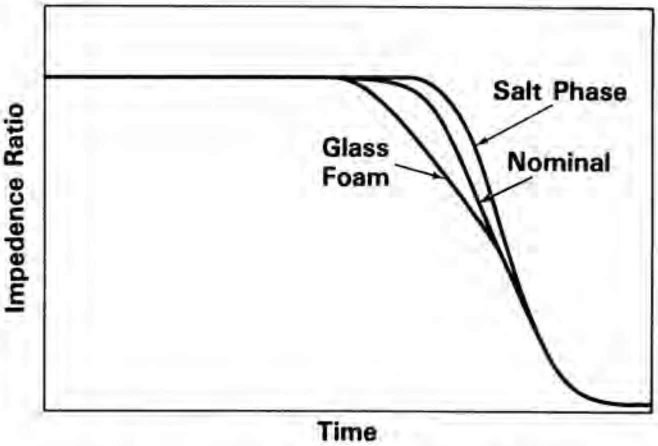

Fig. 5. Impedance ratio curves from glass level monitor.

A decomposition gas bubble then forms between the bridge and the glass. The gas pressure increases until the feed bridge ruptures, which allows slurry to flow through the hole in the crust onto the glass surface. This produces rapid evaporation of the slurry with undesirable fluctuations in melter pressure and off-gas flow. In contrast, if the feed rate is too slow, the melter will not be operating at maximum efficiency.

A pneumatic sensor has been developed to increase the capability of monitoring the melting stability. This sensor system is a combination of dip tubes and differential pressure cells as shown in Fig. 6. It records the glass weight factor and specific gravity, and the relative pressures at the 20-cm and 50-cm

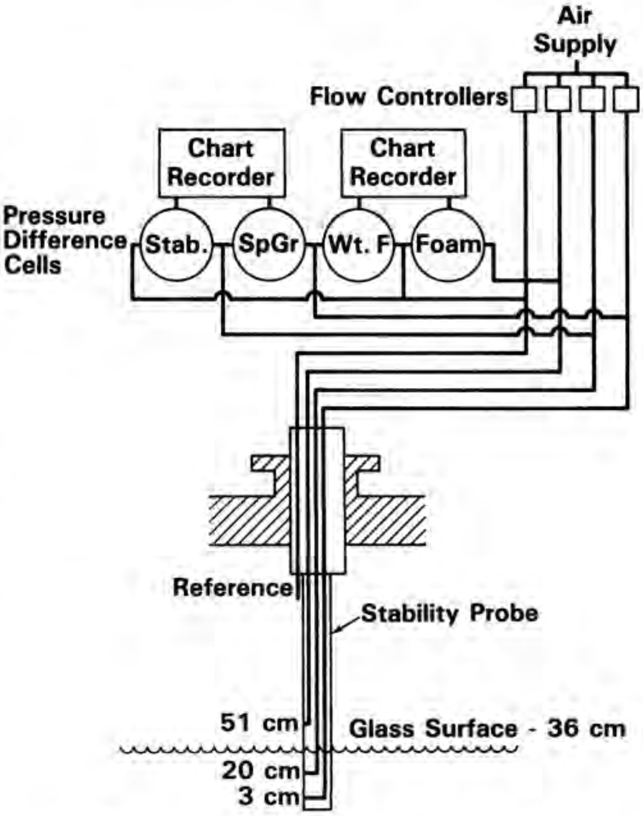

Fig. 6. Crust stability sensing system.

levels. The relative pressure is actually the pressure difference between these positions and the melter plenum. The pressure at the 20-cm level is defined as the stability sensor; the 50-cm position is the foam indicator.

The feed crust stability sensor has proven to be an excellent indicator of overfeeding periods by detecting gases under the bridged crust. The additional pressure exerted by these gases is recorded by the stability sensor as a higher back pressure in the dip tube. A typical section of a recorder chart is shown in Fig. 7. The initial portion of the stability sensor chart indicates uniformly increasing dip tube pressure as the glass level rises between batch glass transfers to the canister. The rapid pressure fluctuations characteristic of overfeeding conditions are obvious in the last portion of the chart. Researchers at SRL have reported similar dip tube pressure responses during overfeeding periods.[4]

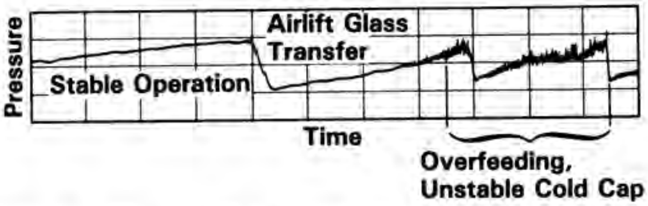

Fig. 7. Output from the crust stability system showing nominal and overfeeding responses.

A pressure difference between the melter plenum and the foam detection port indicates that glass foam has risen to about 15 cm above the nominal glass level. Dried feed and glass have partially obstructed the foam indication pressure tap of this device, periodically creating false foam indications. These false readings, however, are easily detected by viewing the melting cavity or by observing the impedance ratio curves from the level detection system. Foam detection is important because foam acts as an insulating layer between the glass and the feed crust, reducing the melting rate. Glass foam can also lead to crust instability.

This instrument is an example of the multiple indications of process upsets provided by the systems described in this paper. The operator is able to observe the feed crust behavior via the IR camera, but the stability sensor is believed to provide an earlier indication of overfeeding than visual observations provide. In addition, the output from the stability sensor relies less on operator interpretation than does the picture of the melting cavity. Though the glass level data provided by the dip tubes in this system are known to be questionable over the long term due to sensor corrosion, this system can be used to check the electronic level detection output and to determine the operating status of both these instruments.

IN-MELTER THERMOCOUPLES

The PNL melters are equipped with numerous thermocouples to provide additional monitoring capability for the melting process. Thermocouples are placed in thermowells for corrosion protection and located both in the glass and in the plenum space. The in-glass thermocouples provide the temperature data required for melter power system control. The thermocouple data have also been shown to confirm, by temperature variance, glass transfers to the canister, feed crust bridging, and glass foaming.

The glass thermowells in the PNL Pilot-Scale Ceramic Melter[5] (PSCM) have thermocouples installed at the 4-, 8-, 15-, 23-, 30-, 38-, and 46-cm levels. Nominal glass level in this melter is 36 cm. The remainder of this section discusses thermocouple data collected during PSCM experiments.

The off-gas temperatures in PNL melters generally range from 300 to 450°C as measured by the plenum thermocouples. This temperature is easily affected by overfeeding and foaming conditions. During overfeeding, this temperature to rapidly falls below 250°C; during severe glass foaming the off-gas temperature climbs above 450°C. These temperature observations can be used to confirm the other foaming and overfeeding indicators described for the preceding instrumentation systems.

The temperature data from near the floor of the melter, at the 4-cm level, can be used to indicate glass foaming and verify glass flow from the melter to the canister. Temperature at this location rapidly increases during both of these events as shown in Fig. 8. (The thermowell was located near the glass transfer nozzle for this experiment.) The first three temperature spikes show when glass batches were transferred to the canister. The final broad temperature peak in the figure was caused by a glass foaming event. This type of data suggests that large temperature increases near the floor of the melter that are not associated with glass transfer operation can indicate the onset of foaming.

Foaming conditions generally increase the temperatures at all of the thermocouple positions, although not necessarily as markedly as at the 4-cm level. In particular, the 38- and 46-cm thermocouples indicate temperature increases as the foam rises to these positions. This is especially apparent if the feed crust has been adjacent to the thermowells prior to the foaming event. Fig. 9 shows glass temperature profiles in a melter prior to and during foaming. The shape of the temperature profiles remains relatively constant during normal operations as can be seen for the first several curves in the figure. The large temperature increases at the 38- and 46-cm levels during foaming are apparent in this figure. It also shows that the temperature profiles tend to flatten out during the foaming periods. This is expected because the foam insulates the glass surface, thereby greatly reducing heat loss from the melter.

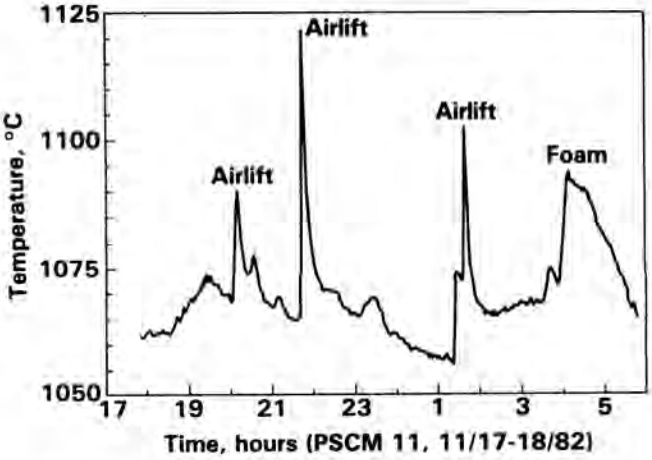

Fig. 8. Temperatures from near the melter floor showing glass transfers and foaming.

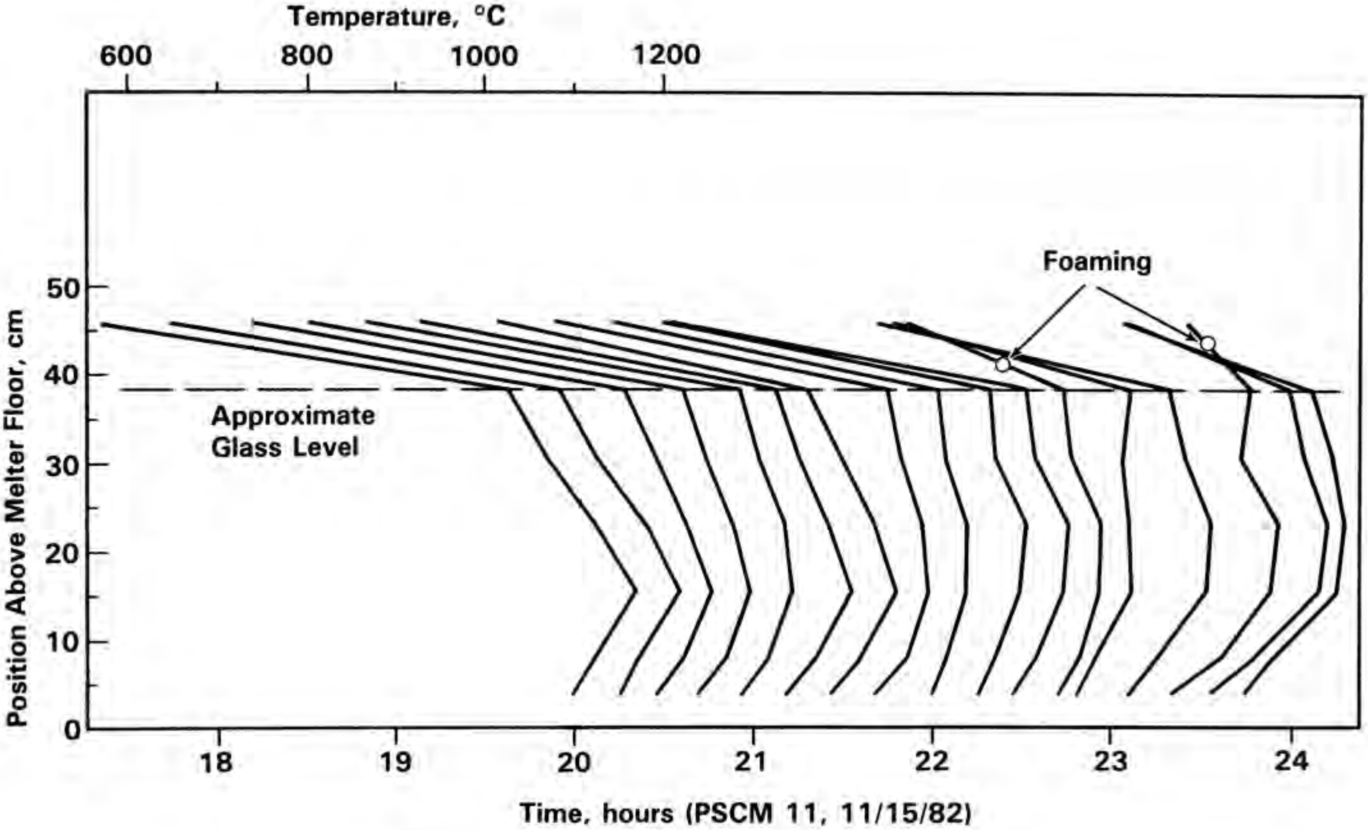

Fig. 9. Vertical temperature profiles in PSCM glass melter. Profiles are shown at 15-minute intervals. The temperature scale is for the first profile. To determine the temperatures in the other profiles, offset the temperature scale to the right for the appropriate distance for the profile of interest. For example, to determine the temperatures of the third profile, offset the temperature scale by the length associated with 45 minutes along the time scale.

In addition to rising during foaming, glass temperatures increase when the feed crust bridges. In order to distinguish between foaming and bridging, the operator monitors the response of the feed crust stability sensor, the IR system, and the off-gas temperature trends.

Evaluations are continuing on how to best interpret the temperature data to gain further insight into the operational status of the melter.

CONCLUSIONS

Until recently, melter operators have relied heavily on visual observations of the melting cavity for process control. The instrumentation systems described herein are based on analysis of how changes in melter operational characteristics predict process upset conditions. The instrumentation systems were designed to detect these operational changes by providing multiple indications of the potential upsets. The tests completed to date with these instruments have shown that they are adaptable for long-term radioactive service, providing the information required for safe and efficient operation of remote melters.

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