This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-96SR18500 with the U. S. Department of Energy.

CHARACTERIZATION OF OFF GAS FLOW SURGES IN THE DWPF MELTER (U)

T. Bond Calloway, Jr., Chris T. Randall and Victor R. Buch
Westinghouse Savannah River Company
Savannah River Technology Center
Aiken, SC 29808

Presentation to American Institute of Chemical Engineers Spring 1999 Conference, Houston TX, March 15 – 19, 1999

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-96SR18500 with the U. S. Department of Energy.

ABSTRACT

The Defense Waste Processing Facility (DWPF) is currently producing radioactive canisters containing vitrified high level waste. A slurry of high level waste and glass frit is fed into a joule-heated melter where the mixture is dried, calcined, and melted. The off gases produced are treated in an off gas system designed to remove radioactive particulate and volatile components before exhausting clean gases to the environment. Surges in the flow of off gas can occur by various means, and must be accommodated by the melter off

gas system. A method for calculating the magnitude of off gas surges is presented and applied to actual plant data. The melter off gas control system is shown to mitigate the effects of most flow surges without significant impact to plant operations.

INTRODUCTION

The Defense Waste Processing Facility, located on the DOE owned Savannah River Site, near Aiken, SC, is currently treating and immobilizing high level nuclear waste generated during the production of nuclear weapons materials for the Department of Energy. After almost three years of radioactive operations (April 1996 to February 1999), the DWPF has produced 565 canisters (through 2/1/99) of high level radioactive waste that have been vitrified into durable borosilicate glass. The DWPF uses the vitrification process to effectively immobilize the waste in a glass matrix. A joule-heated melter is used to melt the waste and borosilicate glass frit slurry. Normally, the liquid waste slurry forms an insulating layer (cold cap) on the molten glass pool that prevents the slurry from directly contacting the molten glass. The slurry is boiled, calcined, and dissolved in the molten glass pool.

Off gas flow surges can occur in radioactive waste melters for several, often interrelated, reasons:

- The liquid slurry can flow off the cold cap (or a crack can develop in the middle of the cold cap) allowing the slurry to come in direct contact with the molten glass pool. The slurry will then flash into steam and other non-condensable gases. These types of surges occur as a matter of routine, and the DWPF off gas system is designed to handle these surges.

- Structurally unstable cold caps containing glass foam can occur when the melter feed is more oxidizing than desired. The foam, which forms between the molten glass pool and the boiling feed, can collapse causing the slurry to come in direct contact with molten glass. Further, it is believed that where the foam exists heat transfer into the cold cap from the melt pool is reduced. This makes the melt pool temperatures more difficult to control. Wide swings in molten glass pool temperature can cause oxygen to be released from the glass in the pool, upsetting the cold cap, and substantially adding to the off gas flow surge.

- The waste/frit slurry can cover the entire melt pool surface to the extent that calcine gases are trapped beneath the cold cap. This condition occurs when the slurry feed rate is higher than the actual melt rate for an extended period of time.

- The sudden release of oxygen from the melt pool can produce an off gas surge. After decomposition of sulfates, nitrates, and carbonates, and incorporation of waste oxides in the melt, any mechanism that causes a change in the thermodynamic equilibrium of the glass in the melt pool (typically temperature or pressure) can cause spontaneous release of large volumes of oxygen [Lorey 1966, Goldman 1986]. This situation is typically characterized visually by violent churning of the molten glass at the melt pool surface and may produce large quantities of glass foam. The cold cap is broken up rapidly and contributes additional off gas flows out of the melter.

- The conditions described above can occur together in various combinations.

Early Pacific Northwest and Savannah River Laboratory (PNL & SRL) experiments on large scale melters characterized melter off gas flow surges by measuring the off gas velocity just downstream of the melter [Goles 1982, Randall 1982]. The SRL studies used a Pitot tube to measure the off gas velocity during normal and peak off gas flow periods. However, the Pitot tube, or other flow measurement devices, were not considered robust enough to be installed permanently in the DWPF melter off gas system. Additionally, the need for direct flow measurement was not sufficient to warrant a development program for a robust flow measurement device. The main focus of the SRL studies was to establish a design basis for the surge magnitude and duration so that the design of the DWPF off gas system could be completed. The design basis for the DWPF off gas pressure control system is:

> "The Melter pressure control system should be capable of containing periodic off gas excursions of seven times the average Melter condensable flow rate lasting a maximum period of one minute or an off-gas excursion of 2.5 times average Melter flow rate where the flow rate is 2.5 times for one minute. Total duration is 8 minutes without exceeding emergency seal pot setting" [4].

During DWPF cold (non-radioactive) operations and early in DWPF radioactive operations, the DWPF Melter system experienced off gas flow surges similar to the ones experienced in the early PNL and SRTC studies. However, the magnitude and duration of the surges could not be measured directly. During a surge in the DWPF melter, pressure was used to qualitatively judge the magnitude of the surge. Surges were judged to be relatively large if the pressure exceeded the alarm set point (-0.5 inwc). Large surges can cause shutdown of the melter feed, switchover to the backup off gas system and inadvertent glass pours. Very large surges (> 2 inwc) are relieved to the Melt Cell through a Seal Pot spreading contamination to Melt Cell equipment. While the Melt Cell is a shielded and remotely operated area of the plant, spread of contamination is not desirable from a maintenance perspective. Melter pressure is controlled using a standard PID algorithm with some additional features that are designed to rapidly bring the melter pressure back to a normal operating set point (-5 inwc) whenever the system is outside the normal operating range of - 2 to -10 inwc.

Consequently, a need was recognized by plant operating personnel to quantify the magnitude and duration of these surge events. The main objective of this work was to develop a quantitative method for calculating the magnitude of a DWPF melter off gas flow surge. Plant data recorded during a DWPF surge event was used to calculate the magnitude of a surge event.

A simplified diagram of the DWPF Melter Off-Gas System is shown in Figure 1.

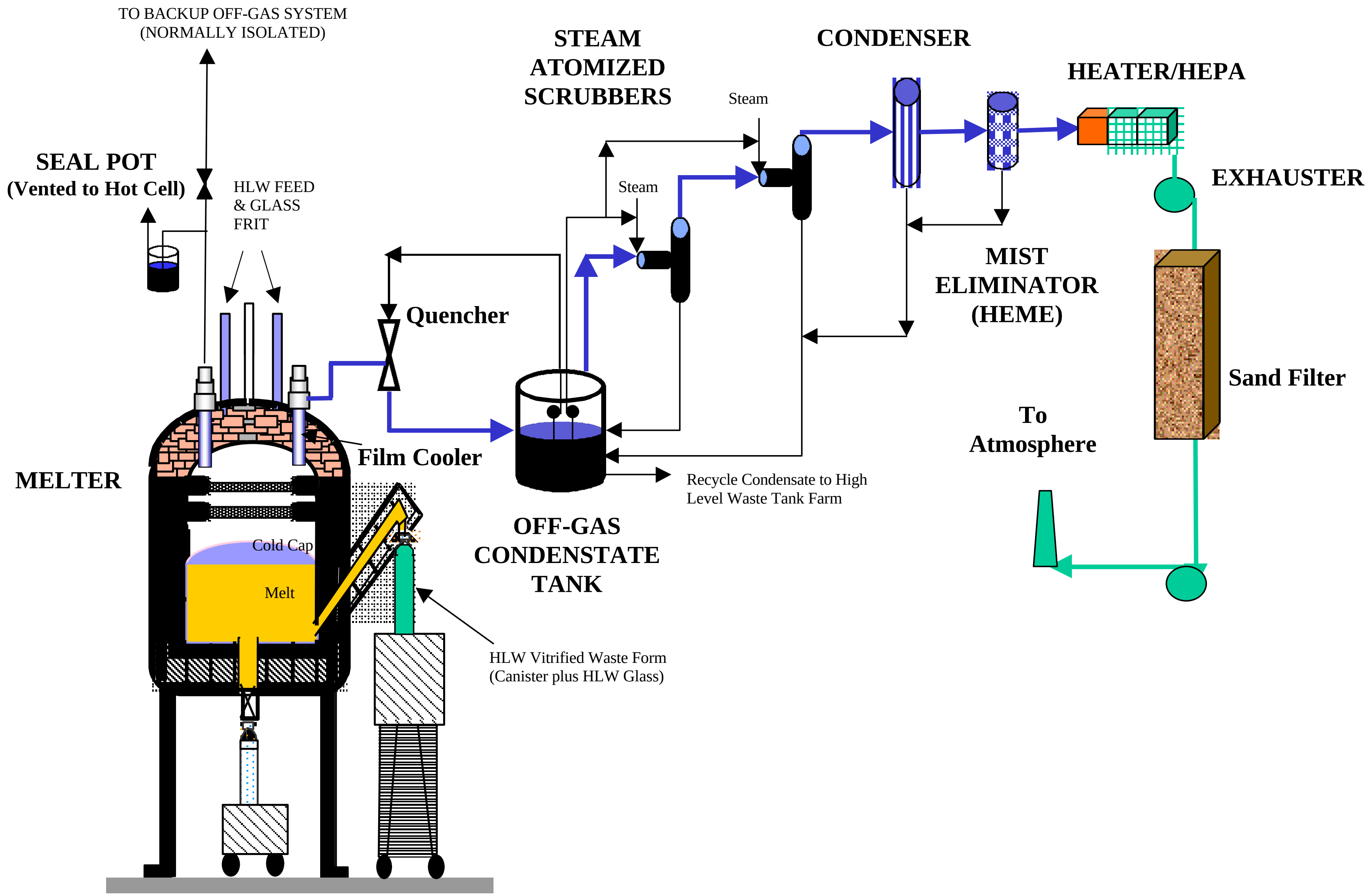


FIGURE 1
DWPF MELTER OFF-GAS SYSTEM

DISCUSSION

The design basis recorded in the DWPF Basic Data Report [4] is based on a test conducted in 1982 on the Large Slurry Fed Melter (LSFM) at SRTC's TNX Semi-works Facility [Randall, 1982]. The purpose of the TNX testing was to provide a recommendation for the maximum expected surge for input into the design of the off gas system. The TNX testing used a Pitot tube and a thermocouple located in the off gas line between the LSFM and the off gas quencher to measure the velocity and the temperature of the off gas being generated from the LSFM. The following equation was used to describe the surges measured in the LSFM:

$$\text{Surge Magnitude} = \frac{(\text{Peak HT} - \text{Base flow})\ \text{ft/s}}{(\text{Calculated Off Gas Rate})\ \text{ft/s}} \qquad (1)\ [\text{Randall, 1982}]$$

where, Peak HT equals the velocity measured by the Pitot tube at the highest point during the surge, Base Flow equals the total off gas velocity during normal feeding conditions (normal off gas due to purge air, purge steam, off gas due to feed and air in-leakage; off gas due to the surge conditions is not included), and Calculated Off Gas Rate equals the expected off gas generated due to slurry being fed into the Melter (not including purges). <u>Therefore, the Surge Magnitude is equal to the change in off gas flow as compared to the off gas flow generated from the slurry fed into the melter</u>.

Although the DWPF does not have a means to directly measure velocity in the Melter-to-Quencher off gas line, other plant instruments can be used to calculate the velocity in this line. Since the feed rate and purge flows are directly measured, equation (1) can be used to calculate the flow surges experienced in the Melter to date.

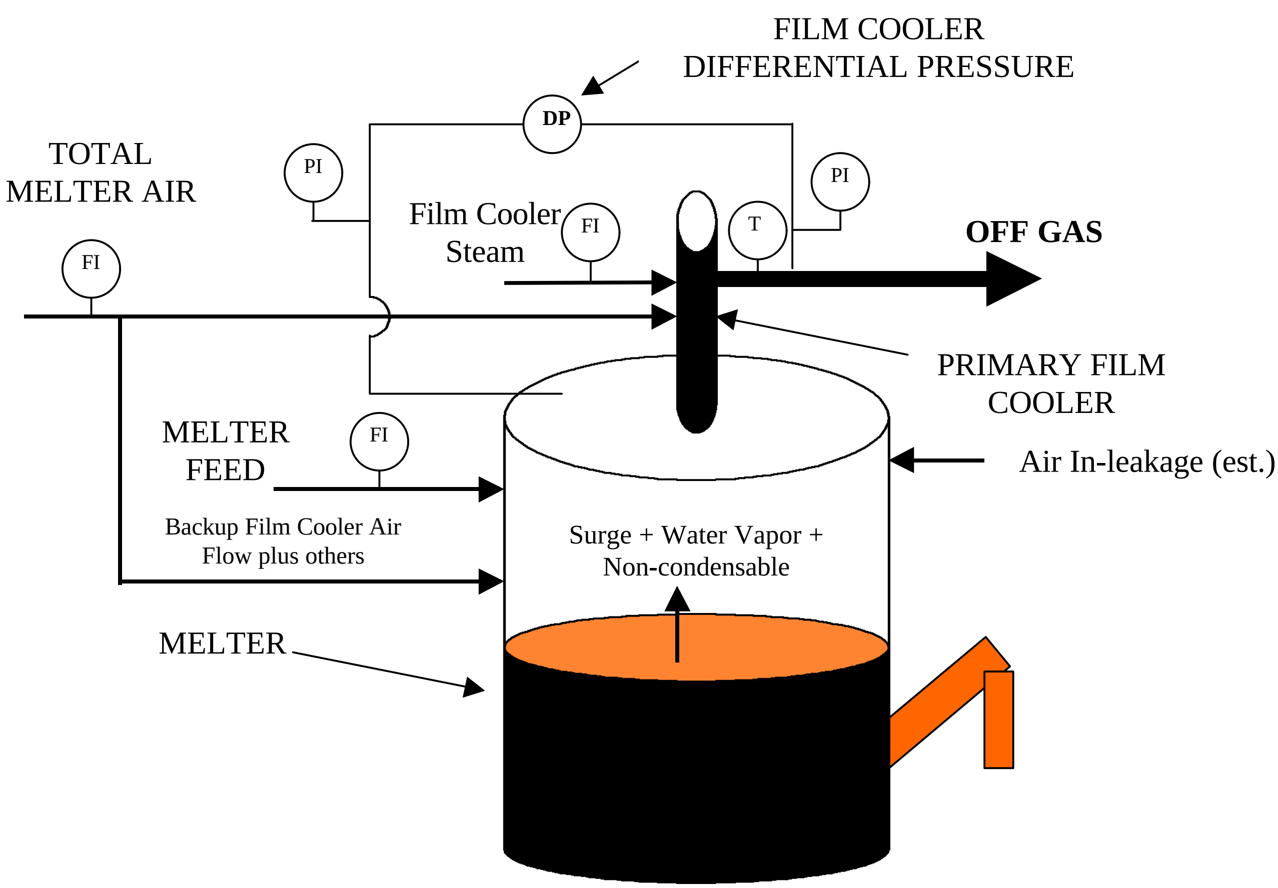
The off gas rate due to feed can be calculated as follows:

$$\text{Calculated Off Gas Rate(ft/s)} = \text{Off Gas Rate (water in feed)} + \text{Off Gas Rate (noncondensibles)} \qquad (2)$$

The off gas rate due to water in the feed can be calculated from the Melter Feed flow rate indicator, the specific gravity of the melter feed and the total weight percent solids as measured by the DWPF production laboratory. The measured Film Cooler Exit gas temperature and pressure, in combination with the gas constant, molecular weight of water and pipe inner diameter, are used to convert the volumetric flow rate into velocity. In the 1982 tests, non-condensable gases were a small fraction of the total off gas from the feed. Thus, the methods provided by Randall did not account for non-condensable generated from the feed. This yielded conservative estimates for the Surge Magnitude. Current DWPF feeds, however, contain higher concentrations of nitrate and formic acid, so an estimate of the non-condensable was generated for this calculation. Non-condensable could be calculated from the weight percent of calcine solids in the melter feed. However, since this value was not known at the time, the DWPF design basis material balance was used to estimate the non-condensable generated during the melting process. The value was adjusted for feed rate.

Once the Calculated Off Gas Rate from equation (1) has been determined, the Base Flow can be calculated from known plant instrumentation. Base Flow equals the total off gas velocity during normal feeding conditions (no surges, purge air, steam & feed are included). Figure 2 is a summary diagram that describes which values are required to determine the Base Flow during normal feeding conditions. The Base Flow is calculated as follows:

Base Flow = Air to the Melter/Film Coolers + Film Cooler Steam + Air In-leakage + Equation (2) (3)



MELTER FILM COOLER DIFFERENTIAL PRESSURE FIGURE 2

Air in-leakage values are assumed to be fixed at approximately 100 lb./hr. This assumption is consistent with the DWPF design basis and with the actual values (< 200 lb./hr with the Melter thermally cold) determined during startup testing. The density of air is calculated at the temperature and pressure of the Primary Film Cooler Exit line and the Base Flow is converted to velocity.

Since the differential pressure between the Melter and Film Cooler Exit line is measured and recorded via the DWPF Distributed Control System (DCS), the following relationship can be used to approximate the flow coefficient for flow through the film cooler

$$\text{Flow Coefficient } (k) = \frac{\text{Base Flow (non-surge period)}}{\sqrt{\Delta \text{p}}} \tag{4}$$

where Δp equals the Film Cooler Differential Pressure and Base Flow (non-surge period) equals the result of equation (3). Once the flow coefficient has been calculated for the system, the surge velocity can be calculated for any given differential pressure during a surge. For these calculations the flow coefficient was averaged for the period just prior to the surge events.

$$\text{Peak HT} = \text{Flow Coefficient (k)}\sqrt{\Delta \text{p at peak of Surge}} \tag{5}$$

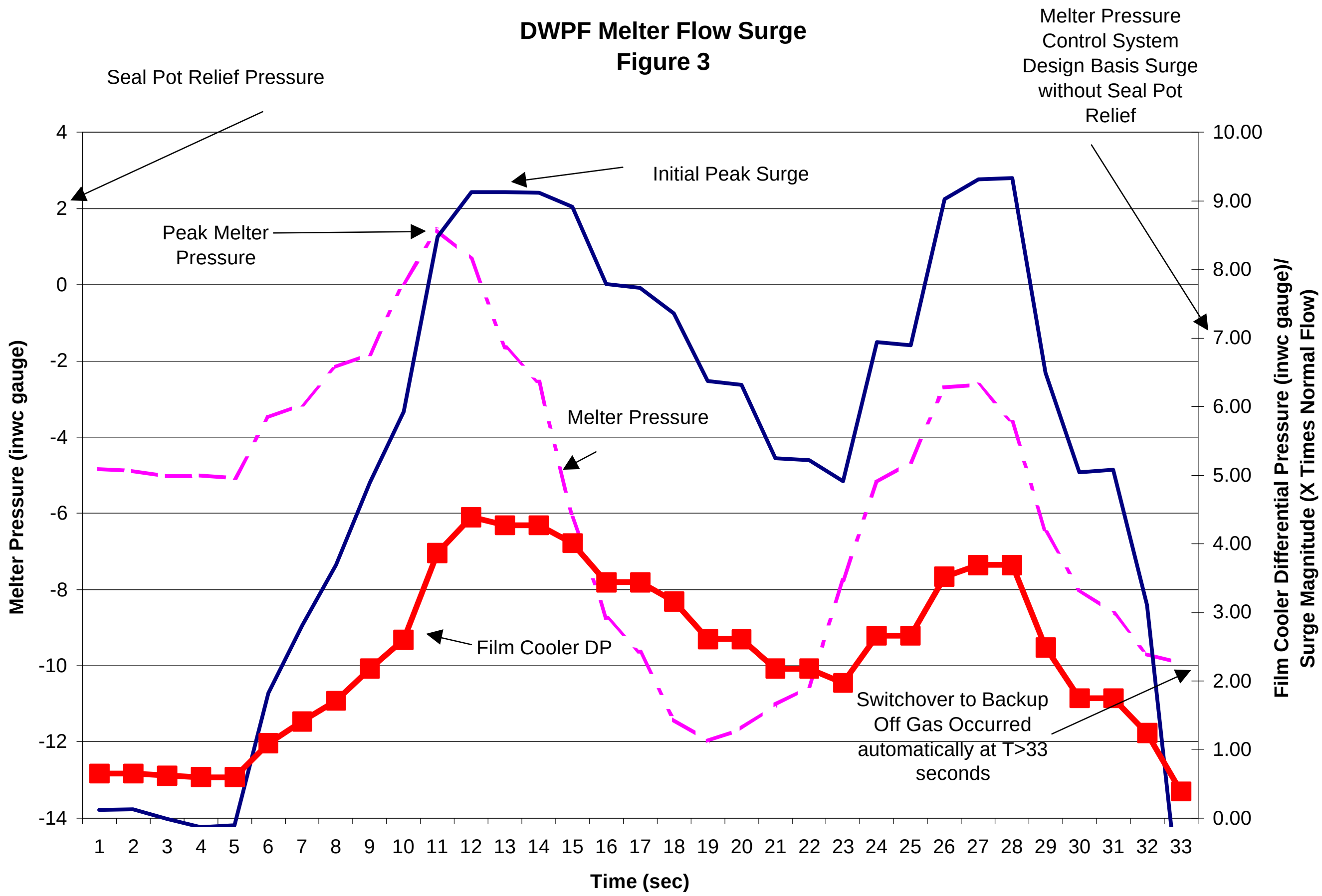
$$\text{Surge Magnitude} = \frac{(Eq.(5) - Eq.(3))\ \text{ft/s}}{(Eq.(2))\ \text{ft/s}} \tag{6}$$

It is important to note that a basic assumption for these calculations is that the flow coefficient remains constant during the surge event. This is in fact not the case because temperature and pressure will change very rapidly during this event. Additionally, the average molecular weight changes as the ratio of steam to air, oxygen, etc. changes. Therefore, this method only approximates the magnitude of the surge. However, the results from these calculations have proven very interesting and provide a means to gauge the performance of the DWPF Off-Gas System during upset conditions. Additionally, this method could be calibrated for a given melter system by injecting a known amount of condensable and non-condensable gas into the melter system.

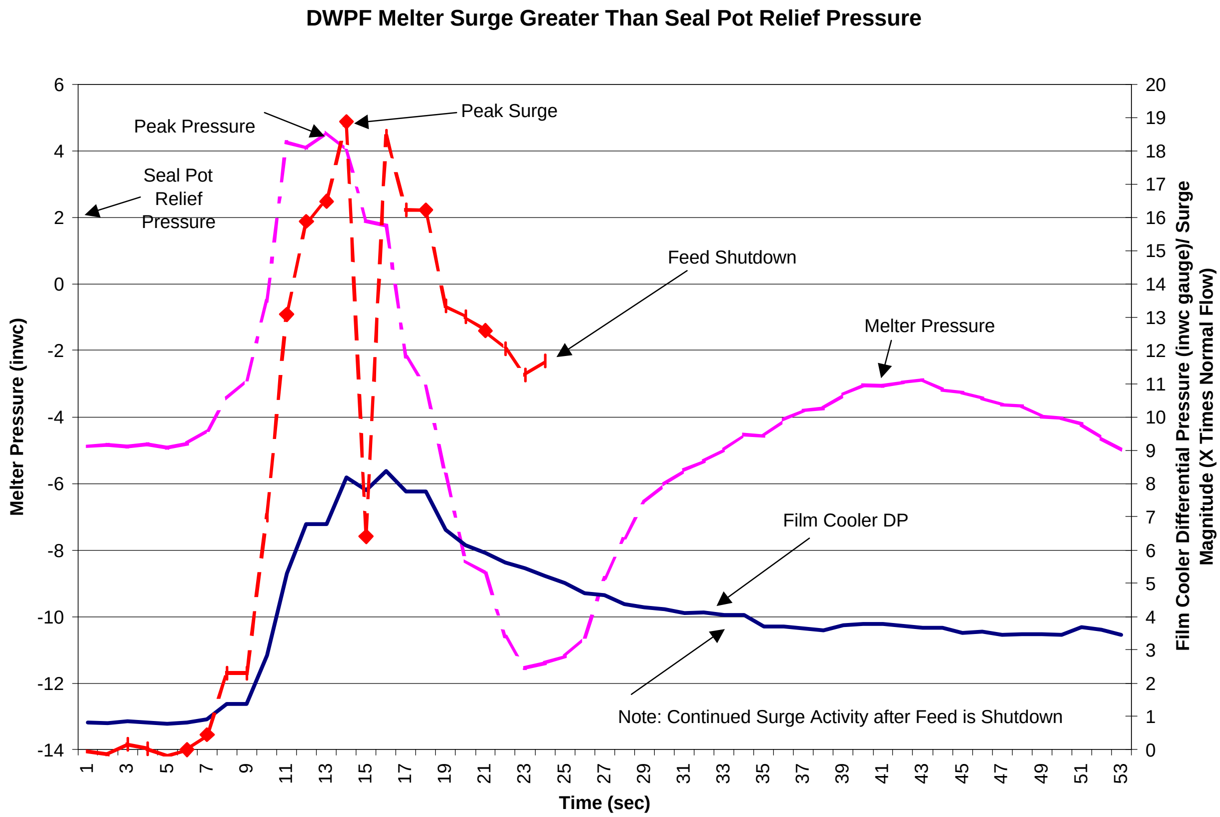
RESULTS-SUMMARY

During DWPF cold chemical runs, surge events were recorded using a special data acquisition system. Two of these events are presented in Figure 3 and 4. The surge shown in Figure 3 was calculated by the method above to be in excess of 9 times the normal off gas flow velocity. The peak pressure did not exceed the seal pot relief pressure of 2 inwc. gauge. The second surge shown in Figure 3 is slightly higher than the first surge event. This is mostly due to the fact that the Melter Feed rate was decreased during that period of time. The surge shown in Figure 4 was calculated to be in excess of 19 times the normal off gas flow velocity. The peak pressure did exceed the seal pot relief pressure of 2 inwc. gauge. The surge shown in Figure 4 is especially interesting because the event was also recorded on a video camera. The videotape shows violent motion of the melt at the melt pool surface.

While the surge shown in Figure 3 was not large enough to relieve through the seal pot, the Melter Off-Gas control system automatically diverted off gas to the Backup Off-Gas System and slurry feed to the Melter was shutdown. The Melter Off-Gas System performed as designed.



It should also be noted that the composition of the melter feed has been adjusted since DWPF cold chemical runs to reduce the oxidizing nature of the feed. This has improved the stability of the cold cap and reduced the tendency of melt to release oxygen due to change in temperature or pressure.



CONCLUSIONS

A method for calculating melter off gas surges in the DWPF melter has been presented. This method provides a quantitative way to monitor the surge activity in the DWPF Melter system that can be easily implemented in a radioactive production environment. The DWPF Melter Off-Gas system was designed to handle surges in excess of 7 times the normal flow rate without relieving through the seal pot. The data provided by this paper indicates the DWPF Melter Off-Gas system has performed according to the design.

ACKNOWLEDGEMENT

This paper is a result of the work of the many individuals who worked to make radioactive operation of DWPF a reality. The paper was prepared in connection with work done under Contract no. DE-AC09-96SR18500.

REFERENCES

[1] J. T. Carter, K. J. Rueter, J. W. Ray and O. Hodoh, **Defense Waste Processing Facility Radioactive Operation - Part II Glass Making**; WSRC-MS-96-0798; Westinghouse Savannah River Company, (December 1996)

[2] Goles, R. W. and G. J. Sevigny; **Off-Gas Characteristics of Liquid-Fed Joule Heated Ceramic Melters;** Paper presented at the 17^{th} DOE Nuclear Air Cleaning Conference, Denver CO, August 2-5, 1982

[3] Randall, C. T. and W. P. Colven; **Off-Gas Flow Surges From the Slurry Feed Melter**; DPST-82-966, Savannah River Laboratory, 11/1/82

[4] WSRC-RP-92-1186, **Basic Data Report Defense Waste Processing Facility Savannah River Site 200-S Area (U)**, July 1992

[5] Lorey, F. D.; **Reboil Phenomena in Glass**, Bull. Of the Am. Ceram. Soc., 45[11], 1012-1013 (1966)

[6] Goldman, D. S.; **Melt Foaming, Foam Stability and Redox in Nuclear Waste Vitrification**, J. Non-Cryst. Solids, 94, 292-298 (1986)