Millimeter-Wave Measurements of High Level and Low Level Activity Glass Melts

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Research Objective

The objective of this project is to develop on-line sensors for characterizing molten glass in high-level and low-activity waste glass melters using millimeter-wave technology. Existing and planned waste glass melters lack sophisticated diagnostics due to the hot, corrosive, and radioactive melter environments. Without process control diagnostics the Defense Waste Processing Facility (DWPF) at Savannah River, the Waste Treatment Plant (WTP) at Hanford, and planned melter upgrades operate by a feed forward process control scheme that relies on predictive models with large uncertainties. This scheme limits production throughput and waste loading. Also without on-line diagnostics melter operations are blind to anomalies such as foaming, combustion gas build up, noble metals accumulation, liquidus crystals, and salt layer formation, which can disrupt operations leading to costly down times. Using the unique capabilities of millimeter-waves on-line monitoring for important melt process parameters such as temperature profiles, emissivity, density, viscosity, and other characteristics will be developed. Once successfully developed and implemented significant cost savings would be realized in melter operations by faster production through put, reduced storage volumes (through higher waste loading), and reduced risks (prevention of anomalies).

Research Progress and Implications

As of the end of the first year of the project renewal period, laboratory experiments have been carried out and theory advances have been made in the millimeter-wave on-line monitoring technology. The experiments and modeling include: 1) acquisition of additional millimeter-wave viscosity data on two more glasses (TV and E glasses), 2) acquisition of millimeter-wave emissivity data on new refractory materials (K3, CrO_2, AZS), 3) advances in the analysis and modeling of the viscosity data, 4) the equations for thermal return reflection method for temperature and emissivity were derived, 5) a research paper written on the TRR method, 6) a new compact millimeter-wave receiver has been designed and fabricated, and 7) planning for a viscosity field test was started.

The experimental activities were carried out at a wavelength of 2.19 mm (137GHz) with a heterodyne receiver adapted for both passive and active probing measurements at the MIT millimeter-wave furnace test stand. A refractory mullite ($3Al_2O_3 \cdot 2SiO_2$) waveguide was lowered vertically through a hole in the top of the furnace, normal to the monitored surface and into near contact or immersion into the melt. The mullite waveguide diameter was larger (1 5/8”) for the emissivity and temperature measurements to lower waveguides transmission losses, and smaller diameter (1 1/8”) for viscosity measurements to reduce the speed of glass flow at viscosities < 100 Poise to be within the response of the electronics data acquisition system. Many data files have been acquired and are being analyzed.

In parallel with the data analysis, the analytical modeling has been advanced to better interpret the results. A significant advance this year has been to derive the thermal return refection method (TRR) equations for emissivity and temperature measurements. The TRR method is implemented by a beamsplitter that divides the thermal signal from the viewed sample into two components, one going to the receiver and the other to a side mirror. The side mirror can be removed or blocked. When the side mirror is blocked the thermal measurement is like a conventional radiometric measurement. When the side mirror is unblocked the part of the thermal signal transmitted through the beamsplitter is redirected at the sample. If the sample is not an ideal blackbody, its reflection will cause an increase in the receiver signal that is dependent on the magnitude of the sample reflectivity. This in turn is directly related to the emissivity. *The implications of this emissivity monitoring capability are that many critical melter parameters such as foaming, noble metals accumulation, liquidus, and salt layer formation could all be monitored since each of these materials has a different emissivity from the desired glass product.* Currently there are no methods for such measurements in melters.

Another development this year has been an advance in hardware. A compact millimeter-wave receiver using a subharmonic mixer and a quasi-optical 4-port waveguide block for the TRR method was designed and built. The use of a subharmonic mixer and 4-port waveguide block makes the receiver system more compact and reduces costs. The plan is to make the receiver compact enough so that it can be attached to the end of the waveguide and move with it as the waveguide is inserted or retracted from the melter for the field test. *The implications for DWPF and WTP are that the millimeter-wave hardware would be easy to install and maintain outside the biological shield.* Highly trained person to maintain alignment would not be needed.

Planned Activities

The development of the millimeter-wave on-line glass process monitoring technology will continue into project years 2 and 3. The TRR analytical model for thermal analysis will be advanced to include the effects of receiver reflection and non-optimum beamsplitter components. An experimental determination of these instrumentation optical coupling constants will be made and evaluation methods to minimize uncertainties will be explored. The new compact millimeter-wave receiver system will also be tested and debugged. More high temperature millimeter-wave data of glasses and refractory materials will be acquired and analyzed. New data analysis software will be developed to speed the analysis of viscosity data. In particular, the continued advances will be partially focused on preparing for a viscosity monitoring field test. New hardware components to interface with the field melter will be fabricated. A glass frit representative of the field test material will be first tested in the laboratory to determine optimum instrumentation parameters. The applicability of millimeter-wave monitoring capability to critical melter parameters such as foaming, liquidus, and salt layer formation will be explored.

Information Access

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2. S. K. Sundaram, W. E. Daniel, P. Woskov, J. Machuzak, "Cold Cap Monitoring Using Millimeter-Wave Technology", Proceedings of the American Ceramic Society, April meeting, Indianapolis, 2001.
3. P. Woskov and S. K. Sundaram, "Thermal return reflection method for resolving emissivity and temperature in radiometeric methods", *J. Appl. Phys.*, **92**, 6302-6310, December (2002).