Application of Joule Heated Ceramic Melter (JHCM) Technology for Stabilization of Radioactive waste in the United States

November 3, 2015

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Introduction / Agenda

Purpose:
To share the U.S. operating plant experience in thermal treatment of radioactive liquids, sludges, and slurries through vitrification utilizing Joule Heated Ceramic line Melter (JHCM) technology.

Agenda:
– Background
  • Vitrification process
  • What is a JHCM
  • Technology Development History
  • Tailoring the technology to the waste (process optimization)
– Selected Projects
  • West Valley Demonstration Project Vitrification Plant
  • Defense Waste Processing Facility
  • M-Area Waste Treatment Project
  • Waste Treatment Plant – LAW Plant
Vitrification Process

- **Waste Preparation**
  - The waste is received and sampled to confirm composition
  - Solids content is adjusted (evaporation or dilution)
  - Glass forming chemicals are added (Silica, Borax, Sodium carbonate, etc.)
  - Waste feed is continuously added to the melter

- **Vitrification**
  - Water is evaporated
  - Salts melt and decompose
  - Oxides react and melt to form molten glass
  - Organics are pyrolyzed and oxidized
  - Most metals, if present, are oxidized
    - There are limits on amount and particle size
  - Most species are incorporated into silicate glasses as their oxides; exceptions include Cl, F, I which are only incorporated to a limited extent.
  - Volatile species (such as H₂O, CO₂, NOₓ, etc.) are completely lost to the off-gas stream
    - Typically contributes to significant volume reduction
  - Other species are retained in the glass melt to varying extents

- Glass is discharged into containers and cooled forming final disposal package
What is a JHCM

- Joule Heated Ceramic Melter (JHCM) description:
  - Refractory/Ceramic lined vessel for corrosion resistance
  - Sealed vessel (radionuclide/hazardous material confinement)
  - Submerged, permanent electrodes
    - The glass is the heating element
    - A/C power
  - Vertical Melting process
    - Feed introduced from above
    - Reacts on the surface of the glass
    - Glass discharged from near base of glass pool
  - Actively mixed glass pool to increase processing rate
  - Glass production rate (and waste treatment rate) directly proportional to melt pool surface area (t/m²/d)
JHCM: Other Facts

• JHCM “Hardware” versus “Software”
  – Hardware – physical equipment (i.e., the melter)
  – Software – Glass formulation
    • The facility performance can be enhanced through improved glass formulations that are essentially transparent to the engineered facility
    • Waste types/composition can be changed without physical changes

• The benefits of JHCM
  – One step processing (organics destroyed, metals oxidized, all integrated into highly stable glass matrix)
  – Very large waste volume reductions are possible (30 to 50% typical, >85% possible)
  – Reactive properties of the waste are removed
  – Exceptional stability of final waste package

• A note about the cost of vitrification
  – Cost is almost exclusively governed by waste properties and facility design requirements. Not the technology!
    • Level of confinement and shielding required
    • Facility safety related functions
  – For example, the Hanford Waste Treatment Plant (WTP) costs:
    • Facility = $15,000M
    • 4 melters = $60M (0.4%)
JHCM Development History

There are more than 4 decades of development and operating experience using JHCM vitrification for treating sludge/slurry waste in the U.S.
Tailoring the technology to the waste

- JHCM technology can be tailored to the waste through variations in the glass forming additives. Widely varying waste composition can be accommodated within an existing facility.
  - Higher waste treatment rate capability translates into cost savings through small plant size and/or reduced operating time
  - Increased waste loading (fraction of glass originating from waste) increases waste treatment rate and reduces volume for disposal
  - Increased glass production rate increases waste treatment rate
  - Both factors depend on waste composition and glass composition
  - Optimization of glass composition can have drastic effects on overall process economics
    - Such changes are easy to implement since they do not require hardware changes
    - Complicated by numerous components present in typical wastes
    - Problem in constrained optimization of multiple properties with respect to numerous composition variables
    - Typically requires large data sets and development of glass property-composition models

\[
\text{Waste Treatment Rate} = \text{Glass Production Rate} \times \text{Waste Loading in Glass}
\]
Tailoring: Glasses Characterized Example

Hanford WTP LAW Vitrification:

- 538 LAW glasses, designed, fabricated and characterized
- Combination of statistical and active design
- Multiple properties relating to product quality and processability
- Data set used to develop glass property-composition models for those properties
Tailoring: Glass Property Model Example
West Valley Demonstration Project (WVDP)

• Project: Privately owned commercial nuclear fuel reprocessing plant
  – Operate from 1965 – 1972 using PUREX/THOREX process
  – Abandon in 1980 and taken over by US government for cleanup

• Waste
  – Volume – 2500 m³ of HLW stored in UGSTs
  – Activity – 888,000 TBq
  – Hazardous content: Low levels of Hg
  – Chemical form – Sludge high in OH⁻, nitrate, nitrite, chromium, sulfates, halides, organics, etc.
WVDP: Process

• Waste Pretreatment
  – Sludge washed for partial sodium removal (increase waste loading)
  – Ion Exchange (Zeolite) to remove Cs, Pu from liquids.
    • Zeolite blended with sludge for vitrification
    • Effluent cemented for disposal
  – Acidic THOREX stream neutralized and blended into sludge
  – Resultant waste stream was a blend:
    • PUREX sludge
    • THOREX sludge
    • Spent Zeolite media
WVDP: Vitrification Process

- Vitrification Process
  - Waste concentration and glass former addition
  - Vitrification and glass discharge
  - Melter emissions treatment
  - Container sealing and decontamination
  - Remote operation and maintenance
WVDP: Vitrification Plant Layout
WVDP: Melter

- **Melter parameters:**
  - 2.2 m² glass surface area
    - ~ 0.9 t glass per day
  - Three air-cooled Inconel 690 electrodes
  - Three-phase power
  - Fused-cast refractory lining
  - Water cooled welded SS shell
  - Two glass discharge chambers
  - Sloped bottom
  - Passive thermal expansion control
WVDP: Status

- 6 years of vitrification operations:
  - 1996 - 2002
- Bulk of waste processed in first two years
- 275 canisters of glass produced (~545 t glass)
- Borosilicate glass waste form
  - Glass formulation developed at Catholic University, Vitreous State Laboratory
  - Glass oxide basis:
    - ~19% PUREX
    - ~5% THOREX
    - ~17% Spent zeolite ion exchange media
- All waste processed and vitrification facility decommissioned
- Facility D&D completed; Facility reused for site D&D
Savannah River

• What is the Savannah River site
  – U.S. Department of Energy nuclear weapons material production site
  – 310 square miles
  – Construction started in 1951

• What is on the site
  – Five large production reactors
  – Two reprocessing facilities
    • Processes used: PUREX and others
    • Tritium production facilities
  – 36 t of weapons grade plutonium produced
Savannah River Waste

- The radioactive waste
  - 136,260 m³ of highly radioactive waste
  - 10.4 million TBq of radioactivity
  - 150,000 t of chemical wastes
    - including nitrate, nitrite, mercury, cyanide, etc.
  - 24 “Single-Shell” Tanks
    - 2,839 to 4,921 m³ capacity
    - 11 have leaked (one to environment)
  - 27 “Double-Shell” Tanks
    - 4,921 m³ capacity

- All Tank waste to be treated
  - Waste is separated into HLW and LAW fractions
    - Sludge washing to remove sodium
    - Liquid
      - Adsorption/filtration for TRU removal
      - Solvent extraction for Cesium removal
  - HLW is being vitrified in the Defense Waste Processing Facility (DWPF)
  - LAW treated through cementation
  - Waste to be processed in a 40 year treatment campaign
Savannah River Process

Tank Farm Storage & Evaporation (14.8 EBq)

Waste Removal & Pretreatment

Extended Sludge Processing

Washed Sludge

Salt Processing

Cesium & Actinides

Low Level Filtrate

Tank Closure

Grout (44 PBq)

Saltstone

Canisters of Vitrified Glass (14.7 EBq)

GWSB (Awaiting Federal Repository)

Final Processing

Vitrification
DWPF: Vitrification Process

- Vitrification Process
  - Washed sludge received and concentrated (mercury removal)
  - Glass frit is added and resulting slurry fed to melter
  - Vitrification and glass discharge
  - Melter emissions treatment
  - Container sealing and decontamination
DWPF: Treatment Technology

- Melter Parameters:
  - Weight: 58 t
  - Exterior dimension (frame): 6.4m (L) x 3.4m (W) x 4.0m (H)
  - 2.6 m² molten glass surface area
  - 2600 L molten glass pool volume
  - Design production capacity 2 t/d (33-45 wt% waste loading)
    - Production rate recently enhanced through active glass pool mixing retrofit
  - Installed in remotely operated cell
DWPF: Status

• Status
  – Commissioned 1996 and in continuous operation for 19 years.
  – 20 years of operation remaining to complete waste treatment
  – 10,000 t HLW glass produced (3,965 canisters)
  – ~26,000 t of glass total to complete treatment (~8,600 canisters)
M-Area

• Title: Savannah River site Materials Area (M-Area) mixed waste treatment project

• Waste
  – 2,500 m³ of Low Level mixed waste (RCRA listed plating line waste)
  – Waste contained in 11 tanks
  – Composition: sludge containing diatomaceous earth and perlite
  – Alkaline waste, high in Na, Al, P, U, Ni, nitrate

• VSL-EnergySolutions team won competitive procurement, 1995 – 1999
  – R&D, flow-sheet, glass formulation, design, build, operate, deactivate
  – Fixed price
M-Area: Vitrification Process

• Glass formulation
  – Borosilicate glass formulations developed by Catholic University, Vitreous State Laboratory
  – High waste loadings (50-70%)
  – Chemical passivation to reduce refractory and electrode corrosion by high Na glass melts
  – Excellent product leach resistance

• Vitrification process:
  – Waste retrieved from tanks, combined with glass forming chemicals, and fed to melter
  – Vitrification and glass discharge
    • Glass formed into gems and collected in 270 L drums
  – Melter emissions treatment
M-Area: Melter

- Slurry-fed JHCM
  - Mixed LLW + raw chemicals
- 5.0 m² glass surface area
  - Capacity: 5 t glass per day
- Air bubbler array to increase throughput
- Three electrodes
- Two-phase power
- Two air-lift discharge chambers
- Active thermal expansion control
- K3 contact refractory, AZS backup, H plenum, E riser
- Glass containment via thermal profile
- Glass discharged through “Gem” machines (product was glass marbles)
M-Area: Operation

- 44 Feed batches; 102 m³ batch size
  - 489 t of glass product produced
- Very reliability plant operation
  - 80% total cumulative lifetime plant availability
- 2,800 270-liter drums were filled (70% volume reduction)
  - Glass sampled from 5 drums from every batch and subjected to TCLP
  - Every batch met requirements
M-Area: Status

- Status
  - Waste form delisted by U.S. EPA, allowing on-site disposal as LLRW
  - Facility D&D completed with area restored to brown field
  - Vitrification technology transferred to and implemented at WTP
Hanford

• **What is the Hanford site**
  – U.S. Department of Energy nuclear weapons material production site
  – 500 square miles
  – Construction started in 1944 (Pu for Nagasaki bomb)

• **What is on the site**
  – Nine large production reactors
  – Five reprocessing facilities
    • Processes used: Bismuth phosphate, Uranium recovery, REDOX, PUREX, Cs/Sr recovery, & others
  – 111 t of weapons grade plutonium produced
Hanford

- What happened to the waste
  - The short answer is that it is all still there stored in underground tanks
  - 213,000 m³ of highly radioactive waste
  - 6.5 million TBq of radioactivity
    - 1000 kg of Plutonium in waste
  - 218,000 t of chemical wastes
    - including nitrate, nitrite, chromium (-6), sulfates, halides, organics, etc.
  - 149 “Single-Shell” Tanks
    - 190 to 4,000 m³ capacity
    - 67 known or suspect leaking tanks
    - 4,000 m³ and 37,000 TBq leaked to the soil
  - 28 “Double-Shell” Tanks
    - 4,000 to 4,400 m³ capacity
    - 1 confirmed leaking into secondary containment

- All Tank Waste to be Vitrified
  - Waste to be separated into HLW and LAW fractions
  - HLW and LAW to be vitrified by separate facilities
  - Waste to be processed in a 30 Year treatment campaign
Hanford Waste Treatment Plant (WTP)

- Meet WAC
- Maximize Waste Loading
- Manage Sulfate
- Manage Halides
- Glass Product Stays at Hanford

**LAW**
Vitrification (90+% of waste mass)

**Supernatant** - NaNO₃

**Pretreatment**
- Ultrafiltration
- Ion Exchange (Cs)

**Maximize Mass**

**SLUDGE**

**HLW**
Vitrification (90+% of waste activity)

**Sludge**

- Meet WAC
- Maximize Waste Loading
- Maximize Melter DF’s
- Manage Noble Metals
- Glass Product to be transferred to Yucca Mountain or Alternative
WTP: Design Requirements

• WTP elected to vitrify waste utilizing JHCM
• WTP processing requirements were extremely challenging
  – HLW glass production rate – 6 t/d @ 0.4 t/m²/d rate
  – LAW glass production rate – 30 t/d @ 1.0 t/m²/d rate
• The state of technology at the time (1998) in US
  – HLW – 1 MT/day from DWPF and WVDP (2.5 m² of glass pool area)
  – LAW – 5 MT/day from SRS M-Area facility (5 m² of glass pool area)
• Key issues that needed to be solved:
  – Very large physical melter size scale up
    • HLW – 2.2 to 4 m²; LAW – 5 to 10 m²
  – Very large processing rate scale up
    • HLW – 1.0 to 6 MT/day; LAW – 5 to 30 MT/day
  – Troublesome waste components
    • HLW – Pt/Rh/Ru, PO₄, Bi, Cr, S; LAW – S, Cl, and much Na
  – Widely varying waste composition (BiPO₄, Redox, & Purex processes; Uranium and Thorium fuel source)
WTP: LAW Vitrification Process
WTP: LAW Facility Layout
WTP: Treatment Technology - LAW

- LAW Production = 30 t glass/day (achieved through active glass pool mixing technology)
  - Weight: 299 t
  - Exterior Dimensions: 9m (L) x 6.6m (W) x 4.8m (H)
  - 10 m² glass pool surface area
  - 7630 L molten glass pool volume
  - Design production: 2 melters at 15 t/d each (35-45% waste loading)
  - Installed in gallery (melter provides shielding)
WTP: LAW Status

• Status
  – Construction of the plant continues
  – Highly successful development program
    • Glass formulations have been developed by the VSL for all waste streams
    • Large increases in glass waste loadings have been achieved reducing the final waste volume for disposal
  – Hot operations scheduled for 2022
    • LAW facility to start first
    • Followed by pretreatment and HLW
  – Glass to be produced
    • LAW – 527,838 t (95,825 LAW containers) – Local shallow burial
    • HLW – 31,968 t (10,586 HLW canisters) – Geologic repository
Waste Treatment Plant (WTP)

- The numbers:
  - $15,000,000,000 and >20 years to design/build
  - 263,000 cubic yards of concrete (26,300 concrete trucks)
  - 930,000 feet of piping (170 miles)
  - 40,000 tons of structural steel, enough to build three Eiffel Towers
  - 5,000,000 feet of cable and wire (900 miles)
LAW Facility

- LAW Vitrification Facility
  - 89% design complete
  - 86% procurement complete
  - 67% construction complete
Conclusion

• Conclusions
  – JHCM has successfully treated sludge/slurry wastes at production scale
  – Substantial cost savings have been achieved through waste volume reduction
  – The treated waste forms are highly stable and have meet all disposal requirements

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