VITRIFICATION OF A REPRESENTATIVE SIMULANT OF DWPF SB4-TYPE WASTE IN A CCIM – INDUSTRIAL SCALE DEMONSTRATION ON THE CEA MARCOULE PLATFORM - 10063

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ABSTRACT

The Cold Crucible Induction Melter (CCIM), which is able to operate at high temperatures, offers the potential for significant cost savings in vitrification projects through increased waste loading and throughputs. As part of a strategy to demonstrate and implement processes to accelerate the High-Level Waste (HLW) cleanup mission at Savannah River Site (SRS), DOE-EM awarded two separate phases of an Advanced Remediation Technology (ART) contract to AREVA Federal Services LLC (AFS), to demonstrate the maturity of the CCIM technology, the level of improvement that can be expected when operating this technology at SRS, and the feasibility of deploying the CCIM in the Defense Waste Processing Facility (DWPF) melter cell.

This paper presents the very promising results of an extended duration industrial scale demonstration performed in 2009 on the Marcoule (French Atomic Energy Commission: CEA) large size CCIM platform with a representative SB4-type simulant of DWPF melter feed.

The selected waste loading was 46 wt%, limited by nepheline and liquidus considerations. This value is 35% higher than the waste loading achieved at the DWPF with the actual SB4 waste.
Over the two weeks of the demonstration, a total of 4,066 L of feed were processed. About 2259 kg of glass were produced, and poured in 32 pouring operations. The 650 mm-diameter CCIM was operated at 1250°C. In these conditions, the maximum throughput was determined to be 75 L/hr of feed, or 40.4 kg/hr of glass product.
The glass product was visually homogeneous and well formed, with some spinel crystals. Its composition was very consistent over the run demonstrating the ability of the melter to produce a well controlled wasteform. The operation parameters all indicated that no spinel crystals accumulation liable to hinder operation had occurred during the whole run duration.

INTRODUCTION

DWPF has been operating since 1996, using a Joule-heated Melter (JHM) to vitrify HLW coming from the US DOE SRS tank farms. The vitrified waste is poured into canisters as a borosilicate glass waste form for ultimate disposal at the Federal Repository.

The CCIM, which is able to operate at higher temperatures, offers the potential to increase waste loading while maintaining the throughput rates of the JHM. Therefore, application of the CCIM to HLW will allow DWPF to complete its mission earlier, enabling faster closure of the SRS Tank Farm. Additionally, the decrease in total glass volume generated by CCIM will lead to fewer canisters to be handled, transported, and stored, thus decreasing risk and life-cycle cost. The resistance of this melter to corrosive molten waste forms and its ability to operate at high temperatures also provides increased flexibility towards waste composition. This provides a potentially strong advantage for dealing with the effluents that will be generated at the end of the mission, when most tanks and equipments are rinsed and decontaminated prior to final closure. Finally, the CCIM's modular and compact design, coupled with longer life-time (its corrosion is lower), will require fewer change-outs during operations. Less secondary waste would be created by melter change and/or decommissioning actions, and there would be a clear disposal path for such secondary waste. Taken together, CCIM can thus significantly cut the life cycle costs and risk associated with the SRS tank farms, DWPF and future HLW disposal operations.

As part of a strategy to demonstrate and implement processes to accelerate the HLW cleanup mission at SRS, DOE-EM awarded two separate phases of an Advanced Remediation Technologies (ART) contract to AREVA Federal Services LLC (AFS, formerly AREVA NC, Inc.), to demonstrate the maturity of the technology, the level of improvement that can be expected through the use of this technology, and the feasibility of deploying the CCIM in the DWPF Melter Cell.

The results and conclusions of the ART CCIM Phase I studies performed in 2007 was that CCIM vitrification technology is a credible mature technology that could accelerate DWPF glass production [1, 2].
The ART CCIM Phase II-A validation program completed in 2009 included:

- lab studies and lab-testing activities to select a simulant, to formulate the recipe for its fabrication, and to formulate a corresponding glass and frit
- pilot-scale demonstrations under representative conditions on existing CCIM pilot platforms, both at INL and CEA's Marcoule site.

This paper presents the very promising results of the extended duration industrial scale demonstration performed in 2009 on the Marcoule (CEA) large size CCIM platform with a representative SB4-type simulant of DWPF melter feed.

DESCRIPTION OF THE PLATFORM

The demonstration platform is self-contained and comprises all the systems and components necessary to perform large-scale demonstration runs: a melter feed system, a 650-mm diameter CCIM, a glass pouring station, a canister filling station, a complete off-gas treatment system, and related auxiliary equipment, including the control system. The platform is installed on four floors covering 160 m² at ground level. Figure 1 is a picture of the CFA industrial-scale demonstration platform equipped with a 650 mm diameter CCIM at CEA Marcoule, France.

Fig.1: General View of the CCIM Demonstration Platform- CEA Marcoule

The melter feed system includes a feed tank with of a high flowrate (>5 m^3/hr) recirculation loop. From the recirculation loop, the melter feed surrogate is transferred to the CCIM via two parallel feed lines. For the ART CCIM Phase II-A program the feed was a solution loaded with around 620 g of solids/l: 19 wt% of glass frit (74-177 µm) and 26 wt% of undissolved chemicals (10 µm).

The melter is powered by a ~270 kHz, 600 kW high frequency generator delivering power into a copper inductor wrapped around the melter. The high specific power directly transferred by induction to the melt allows high operating temperatures and the cooling of the melter wall produces a solidified glass layer that protects the melter's inner wall from corrosion and high temperature effect (See Fig. 2). In addition, mechanical stirring of the melt guarantees homogeneity of temperature and composition and enables high throughputs.

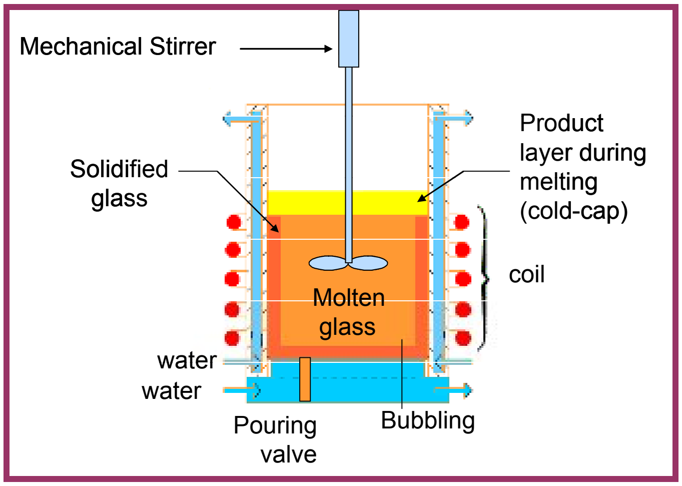

Fig.2: Basic Principles of the Cold Crucible Induction Melter

The melter selected for the demonstrations is an existing 650-mm diameter cold-crucible induction melter that had been used previously on another platform at Marcoule. This melter was an early version used for development, and not representative of the robust design which has been qualified for radioactive operations in the La Hague vitrification plant.
A viewing system which includes a video camera and a viewing port is mounted onto the dome of the CCIM and provides remote monitoring of the cold cap.
The off-gas flows through a dust scrubber, a condenser, and a washing column. An axial flow liquid ring pump extracts the off-gas and provides for a slightly negative pressure in the system. The configuration of this off-gas treatment system is similar to the La Hague HLW vitrification facilities and is different from the DWPF OGTS (Off-gas Treatment System).
A detailed description of the CFA industrial-scale demonstration platform has been presented in a previous paper [2].

ART CCIM PHASE II-A DEMONSTRATIONS

Organization

The ART CCIM Phase II-A demonstration program involved several laboratories and organizations both in the USA and in France, to perform complementary tasks under the supervision and coordination of AFS, with oversight by DOE-EM:

- SRNL, in charge of providing data pertaining to SRS waste composition and characteristics, to perform the original glass formulation work in collaboration with the CEA, and to characterize the glass product from both INL and the CEA demonstrations
- INL, in charge of performing specific off-gas characterization measurements on their engineering scale platform equipped with a 270 mm CCIM
- CEA, in charge of performing an industrial scale demonstration on their Marcoule site platform equipped with a 650 mm diameter CCIM, and also some specific glass characterization to assess processability in a CCIM.

After the selection of a target feed for the demonstrations, SRNL initiated the glass formulation work to recommend a frit and a target waste loading for the demonstrations [3]. In parallel, it was necessary to define the simulant feed to be used for the demonstrations at INL and the CEA. SRNL developed a fabrication recipe including the acidification steps used at the Chemical Processing Cell of the DWPF.

The first demonstrations (Off-Gas System Evaluation demonstrations) took place at INL in December 2008 and January 2009, on the engineering scale platform fit with a 270 mm diameter CCIM. A detailed demonstration report was established [4].

Industrial scale demonstrations were then performed on the Marcoule large scale platform equipped with a 650 mm diameter CCIM, in February, March and April 2009.

Feed and Glass Selection

In order to explore the Heavy Metal-rich portion of the expected DWPF feeds, an aluminum-rich sludge surrogate was selected for this demonstration. The composition was close to Sludge Batch 4 that had been recently processed at the DWPF; however the surrogate did not contain uranium, lead and mercury, which are not accepted on the Marcoule platform.

During a previous program completed in 2007 at Marcoule [1, 2], two demonstration runs had been completed on the 650 mm-diameter CCIM demonstration platform with an SB3 surrogate. This surrogate represented a low solids, iron-rich SRS sludge in the alkaline form.

In order to be fully convincing, the demonstrations in 2009 had to be performed with a simulant that was representative of an actual DWPF melter feed on both the chemical and rheological aspects. It was then necessary to simulate a feed that had undergone all the steps of the current pretreatment performed in the Chemical Processing Cell (CPC) at DWPF. This pretreatment involves acidification by nitric and formic acids and reflux boiling, to adjust the feed rheology and glass redox, and finally addition of frit to the resulting slurry.

The only proposed difference arose from different redox requirements in the CCIM, since the melting temperature is higher than at DWPF and since the redox control set-point is different. The adaptation of the DWPF flow-sheet to the CCIM requirements was studied at SRNL and reflected in the surrogate recipe.

On a formulation standpoint, this Al-rich SB4 feed posed several new challenges: the high Al content led to an expected more viscous, less reactive feed; the glass region was close to the nepheline-formation region, and thus created a specific formulation challenge to increase the acceptable waste loading; this glass was also prone to spinel-type crystallization, as are all DWPF glass compositions. SRNL performed a formulation study [3] and recommended a composition adapted to these various constraints. Based on these results of the glass formulation testing it was recommended that the Frit 503-R6 composition (B_2O_3 = 14 wt%; Li_2O = 9 wt%; Na_2O = 3 wt%; and SiO_2 = 74 wt%) was utilized.

The target waste loading was 46 wt% (to be compared to 34 wt% obtained at DWPF with the same type of waste, that is an increase of 35 % of the waste loading). In order to demonstrate the advantages of high temperature processing while remaining in a reasonable range for retrofitting into an existing facility, the target melting temperature was set at 1250°C.
The glass compositions, target and estimated based on as-analyzed frit and surrogate sludge, are given in table I.

Table I: Glass Composition

Oxide (wt%)	Target glass composition	Estimated based on as-analyzed frit and surrogate sludge
Waste loading	**46 wt%**	
Al_2O_3	12.96	12.74
B_2O_3	7.56	7.11
BaO	0.04	0.04
CaO	1.41	1.56
Ce_2O_3	0.11	
Cr_2O_3	0.10	0.08
Cs2O		0.49
CuO	0.03	0.01
Fe_2O_3	14.74	13.80
K_2O	0.03	0.03
Li_2O	4.86	4.63
MgO	1.41	2.18
MnO_2	2.94 (MnO)	3.42
Na_2O	11.13	10.67
NiO	0.84	0.74
P_2O_5		0.01
SO_4	0.44	0.41
SiO_2	41.34	40.67
TiO_2		0.03
ZnO	0.03	0.02
ZrO_2	0.05	0.04
Cl		1.32
Total	100.000	

In order to obtain reliable decontamination data for the melter (see the paragraph *Assessment of Cesium volatility*), the simulated melter feed surrogate was spiked with $CsNO_3$ to obtain a targeted Cs_2O content of 0.5 wt% in the glass.

Major results of demonstration

The main objectives of the Phase II-A demonstration runs at Marcoule were to:

- demonstrate the ability of the CCIM vitrification technology to provide improved performance in terms of waste loading and waste throughput when compared to the existing JHM operated at DWPF,
- produce a glass that is acceptable for geological disposal,
- provide data needed for the Phase II-A engineering design studies.

During the first week in February 2009 (Run 1), the system was operated to determine the correct settings for the platform with this feed and glass, and to demonstrate the safety of processing feed with a significant formates content. An extended duration run was then performed over two weeks in March (Run 2-1) and April (Run 2-2). Between those two weeks, the melter was cooled while containing a heel of 116 kg of glass in order to preserve the eventual crystal deposits that might have accumulated. The OGTS was left untouched to preserve the steady state equilibrium in the effluents. Over those two weeks, a total of 4,066 L of feed were processed. About 2,259 kg of glass were produced (equivalent to more than one DWPF canister) and poured batchwise in 32 pouring operations.

A maximum feed rate of 75 L/hr was determined at 1,250°C (see table II). With this specific feed composition, the maximum feed rate value of 75 L/hr (feed flux of 225.9 L/hr/m²) at 1,250°C corresponding to a glass production rate of 40.4 kg/hr (or a glass flux of 121.7 kg/hr/m²) and a waste throughput of 18.6 kg/hr (waste flux 56.1 kg/hr/m²), that is about 84% of the DWPF SB4 average waste throughput [5].

Table II. Calculation of Throughputs Achieved During Demonstration Run

Indicator	**Feed rate** (L/hr)	**Feed flux** (L/hr/m²)	**Maximum Glass throughput @ 538 g/l** (kg of glass/hr)	**Maximum Waste Oxide throughput @ 46 % WL** (kg of waste oxides/hr)	**Specific Glass throughput** (kg of glass/hr/m²)	**Specific Waste Oxide throughput** (kg of waste oxides/hr/m²)
Performance	75	225.9	40.4	18.6	121.7	56.1

These maximum values were sustained for a total of 36 hours. It can then be concluded that this rate is close to an actual maximum throughput in operation.

Glass product characterization

Samples from the pours performed during the whole run were analyzed for chemical composition, crystallization and durability.

Several samples were analyzed by SRNL via dissolution and ICP-AES (ICP-MS for cesium) and by the CEA via X-ray Fluorescence. The chemical analyses indicate that the glass product composition is very consistent throughout the run, with very little variations: among the 32 pouring operations, the glass from the pours #10, #25 and #26 were analyzed and it was found that for the major components (Al, B, Ca, Fe, Li, Mg, Mn, Na, Si) the relative concentration variation don't exceed 3 %. This observation confirms the ability of the CCIM technology to produce a very stable and consistent product.
To identify the major crystalline phase, SRNL performed X-ray Diffraction (XRD) measurements on some poured samples and the CEA characterized the same poured samples by optical microscopy (SEM and EDS). Both the SRNL analyses and the CEA observations show that the poured glass product was

essentially amorphous with crystals distributed evenly in its bulk. It contains some fine spinel-type crystals (10 µm or less) that seem to have been formed in the melter and then were readily eliminated by pouring.
The operational data indicated that no spinel crystals accumulation liable to hinder operation had occurred during the whole run duration :

- The electrical and thermal parameters of the CCIM did not show any sign of detrimental accumulation of crystals at the bottom of the melter,
- The composition of the glass product did not change much over the run and showed no sign of depletion in spinel-forming elements that could be associated with significant accumulation in the melter; and
- Pouring was straightforward, after more than 100 hours of total operation, including cooling of the CCIM and re-start with a full load of glass.

These spinel crystals are not detrimental to glass durability, as shown by PCT (Product Consistency Test). The glass product samples were subjected to standard PCT leach testing at SRNL, in the as-sent condition and after heat treatment following the MCCC program (Modified Centerline Canister Cooling curve derived from the DWPF CCC curve by offsetting the starting point of the cooling profile because DWPF melter operates at 1,150°C and the CCIM at 1,250°C). All the glass product samples proved to be very durable and passed the PCT criterion by more than one order of magnitude when compared to the performance of the Environmental Assessment glass. The performance of the glass product is maintained after a MCCC-type heat treatment, indicating that no detrimental crystallization is liable to occur during cooling in the canister.

These results confirm the ability of the melter to produce a consistently durable glass waste form.

Assessment of Cesium volatility

Cesium is known for having a semi-volatile behaviour during vitrification. It can therefore be concluded that, for cesium, most of the entrainment outside of the melter results from volatilization.
A preliminary evaluation of cesium volatility and particulate carry-over is feasible based on glass analysis. The method consists in analyzing the glass product to compare its cesium contents to that expected from the feed composition. Some feed from the recirculation loop of the platform was sampled (this represents the feed that actually reaches the melter). This feed sample has been vitrified in a crucible in the CEA laboratory, and the resulting glass was analyzed by both SRNL and the CEA, with their respective methods. The comparison of the various results is given in table III. For both laboratories, the apparent Cs loss is around 10%, very similar to what has been observed at INL [4].

Table III: Determination of Cesium Volatility by comparison with the Vitrified Feed Sample.

Laboratory	SRNL	CEA
Method	Dissolution + ICP-MS	XRF
Range of Cs_2O contents in the glass product	0.30 %	0.32 – 0.34
Average	0.30 %	0.326 %
Cs_2O content of the vitrified feed sample	0.33 %	0.36 %
Difference	- 0.03	- 0.034
Cesium (Volatility + Particulate Carry-Over)	**10 %**	**10,4 %**

Another method consists in evaluating the decontamination factors from the various OGTS components by analyzing the effluents that they produce and by combining these analyses with the values of the measured flowrates during a period of steady state operation. By this method, it has been found that the melter decontamination factor (DF_{melter}) for cesium was 4.2. This suggests that the overall carry-over of cesium (volatilization + particulate carry-over) is around 24 % (see fig.3).

The formulas used are:

$$(Volatility \quad + \quad Particulate\ Carry\text{–}Over) = \frac{1}{DF_{melter}} \qquad \text{(Eq. 1)}$$

The Decontamination Factor (DF) of a device is the ratio of the mass of the element X coming in the device to the mass of the element X flowing out of the device in the gas flow.
So the Melter Decontamination Factor for an element X is:

$$DF_{melter} = \frac{Q_{feed} C_{feed}}{Q_{ds} C_{ds} + Q_c C_c + Q_{wc} C_{wc}} \qquad \text{(Eq.2)}$$

With :
Q_{feed} : Feed rate (l/hr)
Q_{ds} : Volume flow flowing out of the Dust-Scrubber (l/hr)
Q_c : Volume flow flowing out of the Condenser (l/hr)
Q_{wc} : Volume flow flowing out of the Washing-Column (l/hr)
C_{feed} : X Concentration in the feed (g/l)
C_{ds} : X Concentration in the Dust-Scrubber liquid (g/l)
C_c : X Concentration in the Condenser liquid (g/l)
C_{wc} : X Concentration in the Washing-Column liquid (g/l)

It's assumed that the concentration of the element X is equal to zero in the gas flow flowing out of the washing column.

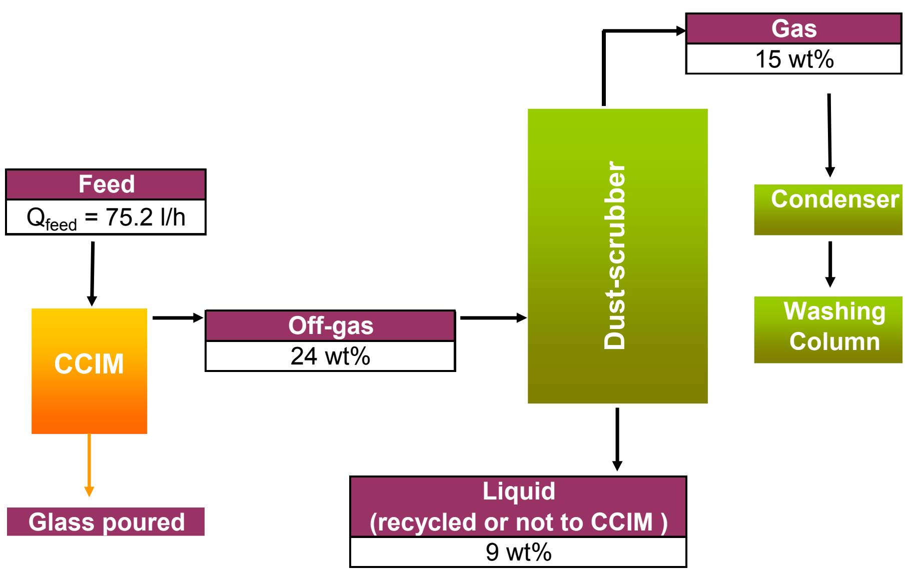

Fig. 3. Cesium Flow Sheet in weight percent, melter operated at 1,250°C, feed rate set at 75 L/hr (average values over 12 hours)

It should however be noted that the decontamination factor of the condenser and the washing column were not analyzed. Cesium volatility for the overall off-gas treatment system is expected to be lower.

Moreover it is known that recycling from the dust-scrubber can have a favorable impact on cesium balance. In normal industrial operations, the dust-scrubber would be continuously fed with a small flow of fresh water, and the excess liquid, loaded with the collected material, would be recycled to the melter with the main feed. This represents around 10% of the feed. For these SB4 demonstration runs the excess liquid was not recycled to the melter but was diverted to a specific tank. If the dust-scrubber effluents had been recycled to the melter the overall cesium carry-over would have been around 17%.

The value of 24% determined above is significantly different from the value obtained with the vitrified feed sample (10%). This may suggest that the first method may be subjected to some bias, most probably because some of the cesium is volatilized during the crucible vitrification of the feed sample. The measurement uncertainties for cesium in glass may also be significant. Although there remains some uncertainty about the actual degree of Cs volatilization, it can be concluded that, in the conditions of the test, it has most probably been between 10% and 24%.

In order to explain this somewhat high value, it should be reminded that the OGTS of the platform was operating close to or even above its design limit: the feed rate (75 L/hr) was only 5 L/hr below the maximum design liquid feed rate for the dust scrubber, and, at the same time, 30 Nm^3/hr of dilution air was injected in the melter for safety reasons (see the “Hydrogen” paragraph). The resulting gas flow in the melter and in the dust scrubber was very high, and this is expected to have increase significantly cesium entrainment from the melter and decreased the dust-scrubber efficiency in trapping particulate material.
To confirm this assumption, it can be reminded that, during the SB3 testing in 2007 [2], where this air injection was not required, estimated Cs volatility ranged between 7 and 12 %, more in the range of the values observed on the INL platform [4]. One can then conclude that the value of 24 % observed for cesium on the industrial scale platform with the formate-loaded simulant is absolute upper bound linked to the injection of a high air flow in the melter plenum. This condition does not represent the condition liable to be encountered in the industrial facility.

Hydrogen

In order to ensure representativeness, the proposed melter feed contained significant amounts of formate ions. This situation created a new operating basis for the CEA platform, which had not been designed to handle such high amounts of formats in the feed. Indeed, the decomposition of these formates in the melter may generate some hydrogen and other flammable gasses. It was thus necessary to ensure that nowhere in the system the flammability limit could be reached.

Among the provisions to ensure safety, it was required by the Marcoule site Health and Safety (H&S) authority that H_2 concentrations in the off-gas be monitored continuously on the platform and set a limit to not exceed (2 volume % of the offgas; wich is 50% of the lower flammability limit of 4%), and that a minimum flow of dilution air be added in the melter plenum.

During the run, the minimum dilution air flow was kept at 30 Nm^3/hr. H_2 and CO were continuously measured at the outlet of the condenser and temperatures at various other locations in the OGTS were recorded.
During steady state operation at 75 L/hr, it was observed that, at the outlet of the condenser the average hydrogen level was around 0.25 % with the highest peaks remaining at 1.3 %, that is well inside the acceptable range. The measured hydrogen levels were impacted by the feed rate, and the corresponding offgas temperature levels. As expected, it was found that H_2 evolution was higher when the feed rate increased.
Once the cold cap was established, the average proportion of formate hydrogen from the feed converted to H_2 was less than 9%, a value which agrees quite well with the results measured at INL [4]. See table IV.

Table IV: % H_2 and % CO in the Non Condensable Off-Gas, and Percentage of the Formate H Converted to H_2, as a Function of the Actual Feed Rate to the CCIM

	Minimum	Maximum	Average
	Feed rate 21.5 L/hr		
% H_2	0	0.07 %	0.04 %
% CO	0	0.08 %	0.07 %
% of formate H converted to H_2	0	19.85 %	4.33 %
	Feed rate 48 L/hr		
% H_2	0.06 %	0.20 %	0.11 %
% CO	0.14 %	0.26 %	0.21 %
% of formate H converted to H_2	2.89 %	9.16 %	5.46 %
	Feed rate 64.5 L/hr		
% H_2	0.07 %	0.35 %	0.24 %
% CO	0.15 %	0.31 %	0.21 %
% of formate H converted to H_2	2.44 %	12.10 %	8.40 %
	Feed rate 75 L/hr		
% H_2	0.11 %	1.30 %	0.25 %
% CO	0.09 %	1.32 %	0.25 %
% of formate H converted to H_2	3.58 %	40.12 %	8.40 %

These results confirm that most of the formates are converted mostly to CO_2 and H_2O in the melter.
These results were encouraging since they gave indications that the formate oxidation reactions seemed to happen quite fast in the melter, leaving only a small fraction of flammable decomposition products.

CONCLUSION

The combined effort of ART CCIM Phase II-A provided significant data confirming the maturity of the CCIM technology, and demonstrated the potential benefits that would result from deploying this technology at DWPF.

To complement the preliminary data obtained in 2007 with a non acidified, iron-rich, SB3 simulant, the demonstrations were focused on an formated, nitric acid aluminum-rich, SB4 type melter feed, thus bracketing most of the future sludge compositions that will be vitrified at the DWPF. Both high iron and high alumina, and both acidified and non-acidified feeds are acceptable.

The glass product poured batchwise in more 32 occasions displayed a very consistent composition and quality, confirming the ability of the CCIM technology to control and produce a consistent and homogeneous glass product.

The waste loading achieved during this demonstration (46 wt%) was 35 % higher than the corresponding waste loading achieved at the DWPF with the same type of waste [5]. This confirms the results obtained in 2007 with a SB3 type feed, where the waste loading was 52 %, 37 % higher than the corresponding waste loading achieved in the DWPF with the same waste type [5]. Since these results were obtained with two compositions situated at the opposite ends of the SRS waste composition range, it can be expected that, as an average, the waste loading to be expected from the implementation of this high temperature technology would be at least 30% higher than that achievable in the DWPF. This can also be translated as a reduction by 30% in the number of glass canisters to be produced.
In addition to this increase in waste loading, the CCIM technology also provides the potential for increased throughput with smaller volume occupancy. The throughput achieved during phase II-A with a 650 mm diameter CCIM can be expressed in various ways:

- 75 L/hr of feed, or 19.8 gallon/hr (0.33 gpm),
- 40.4 kg/hr (89.1 lb/hr) of glass. For comparison, the average throughput at the DWPF is around 65 kg of glass per hour, to fill one canister per day [5]. The maximum melt rate at the DWPF was around 72 kg/hr (159 lbr) [5]. The achieved throughput was thus about 62 % of the average DWPF glass production capacity, or about 56% of the maximum DWPF throughput,
- Since the waste loading is about 35 % higher than the waste loading achieved in the DWPF for the same waste type, the waste throughput was about 1.35 x 0.62 = 84 % of the average waste throughput for the same waste type at the DWPF, or 1.35 x 0.56 = 76 % of the maximum waste throughput at the DWPF,
- The specific glass throughput was 121.7 kg of glass /hr/m² (268 lb/hr/m²). This value is 430% of the maximum DWPF specific throughput, or 477 % of the average DWPF specific glass throughput.

During the industrial scale demonstration, more than 4 m^3 of feed were vitrified, producing 2,259 kg of glass (that is the equivalent of 1.3 DWPF canisters). The feeding phase lasted for more than 80 hours and maximum feed rate of 75 L/hr was sustained for 36 hours, confirming the ability of the platform to maintain this throughput in industrial conditions. One can conclude from these figures that the scale of the demonstration was truly industrial, with a glass throughput higher than ½ the average values for the DWPF (almost $^2/_3$).

AFS has proposed further studies under ART CCIM Phase II-B, aimed at running a full scale demonstration of the CCIM technology applied to representative waste of the DOE complex. This proposal is currently under consideration by DOE-EM. Should this project continue to Phase II-B, a significant part of the scope may be to focus on the actual size/throughput effect with a larger CCIM which could have a between 1 and 1.3 m inner diameter.

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