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Fluidized Bed Steam Reforming of Organic and Nitrate Containing Salt Supernate

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Fluidized Bed Steam Reforming (FBSR) Technology for Organic and Nitrate Containing Salt Supernate

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ABSTRACT

About two decades ago a process was developed at the Savannah River Site (SRS) to remove Cs¹³⁷ from radioactive high level waste (HLW) supernates so the supernates could be land disposed as low activity waste (LAW). Sodium tetraphenylborate (NaTPB) was used to precipitate Cs¹³⁷ as CsTPB. The flowsheet called for destruction of the organic TPB by acid hydrolysis so that the Cs¹³⁷ enriched residue could be mixed with other HLW sludge, vitrified, and disposed of in a federal geologic repository. The precipitation process was demonstrated full scale with actual HLW waste and a 2.5 wt% Cs¹³⁷ rich precipitate containing organic TPB was produced admixed with 240,000 gallons of salt supernate. Organic destruction by acid hydrolysis proved to be problematic and other disposal technologies were investigated. Fluidized Bed Steam Reforming (FBSR), which destroys organics by pyrolysis, is the current baseline technology for destroying the TPB and the waste nitrates prior to vitrification. Bench scale tests were designed and conducted at the Savannah River National Laboratory (SRNL) to reproduce the pyrolysis reactions. The formation of alkali carbonate phases that are compatible with DWPF waste pre-processing and vitrification were demonstrated in the bench scale tests. Test parameters were optimized for a pilot scale FBSR demonstration that was performed at the SAIC Science & Technology Application Research (STAR) Center in Idaho Falls, ID by Idaho National Laboratory (INL) and SRNL in 2003. An engineering scale demonstration was completed by THOR[®] Treatment Technologies (TTT) and SRNL in 2006 at the Hazen Research, Inc. test facility in Golden, CO. The same mineral carbonate phases, the same organic destruction (>99.99%) and the same nitrate/nitrite destruction (>99.99%) were produced at the bench scale, pilot scale, and engineering scale although different sources of carbon were used during testing.

INTRODUCTION

An In Tank Precipitation (ITP) technology was developed at the SRS to remove Cs¹³⁷ from high level waste (HLW) supernates. During the ITP process monosodium titanate (MST) and sodium tetraphenylborate (NaTPB) were added to the salt supernate to adsorb Sr⁹⁰/Pu²³⁸ and precipitate Cs¹³⁷ as CsTPB, respectively. This process was demonstrated at SRS in 1983. The demonstration produced 53,000 gallons of 2.5 wt% Cs rich precipitate containing TPB, which was later washed and diluted to 240,000 gallons. This material is currently stored in SRS Tank 48. The washed precipitate was to ultimately be disposed in borosilicate glass in the Defense Waste Processing Facility (DWPF).

Due to safety concerns, the ITP process was abandoned in 1998, and new technologies were researched for Cs¹³⁷ removal. In order to make space in the SRS Tank farm, the Tank 48 waste

IT3'07 Conference, May 14-18, 2007, Phoenix, AZ

must be removed. Therefore, the Tank 48 waste must be processed to reduce or eliminate levels of nitrates, nitrites, and NaTPB in order to reduce impacts of these species before vitrification. Fluidized Bed Steam Reforming (FBSR) has been shown to adequately destroy the organics (NaTPB, CsTPB, and KTPB) and nitrates and convert them to alkali carbonates that are compatible with downstream processing via vitrification.

The FBSR technology is capable of destroying the alkali TPB, other organics, and nitrates to $(\text{Na}, \text{K}, \text{Cs})_2\text{CO}_3$, CO_2 gas, N_2 gas, and H_2O in the form of steam [1,2] at moderate temperatures. Other components in the waste are converted to oxides, silicates, phosphates, and titanates. The FBSR can be electrically heated (pilot scale units of 6" or less) or operated in an auto-thermal mode, whereby the energy needs are supplied by the incoming superheated steam and by the oxidation of organics from the waste and carbon reductants via the water gas shift reaction (WGSR). For engineering or production scale units, auto-thermal steam reforming is the preferred mode of operation.

The FBSR technology converts organic compounds to CO_2 and H_2O , converts nitrate/nitrite species to N_2 , and produces mineralized waste forms through reactions with superheated steam, which is the fluidizing media. The reforming process pyrolyzes organics. Pyrolysis is not combustion as little oxygen gas is present and the temperatures are moderate, 650-750°C. Therefore the FBSR technology at the Studsvik, Inc. commercial Erwin facility has been determined to be Environmental Protection Agency (EPA) Clean Air Act (CAA) compliant by Region IV EPA. In addition, pilot scale testing by INL at the SAIC STAR facility has demonstrated that the FBSR process is Hazardous Waste Combustor (HWC) Maximum Achievable Control Technology (MACT) compliant for Hg, Cl, CO, total hydrocarbons [1] and other heavy metal constituents [3].

The objectives of the current study were to demonstrate the following with a Tank 48 simulant at bench scale:

- destruction of TPB with the FBSR process operating between 650-725°C
- destruction of nitrate at >99% with addition of sugar or charcoal as a reductant
- destruction of anitfoam with the FBSR process operating between 650-725°C
- formation of Na_2CO_3 FBSR product to be compatible with subsequent vitrification
- assessment of the melting temperature of the FBSR products to evaluate impacts (if any) on vitrification melt rate
- optimization of the amount of reductant to ensure that excess reductant in the FBSR product would not adversely alter the REDuction/OXidation (REDOX) control in the DWPF melter [4]
- demonstration that bench scale studies can duplicate the complex reactions in pilot scale and engineering scale FBSR processes.

BACKGROUND

Studsvik built and tested a commercial Low-Level Radioactive Waste (LLRW) FBSR Processing Facility in Erwin, TN, in 1999 [5]. In January 2000, commercial operation commenced [1]. The Studsvik Processing Facility (SPF) has the capability to process a wide variety of solid and liquid LLRW streams including: ion exchange resins, charcoal, graphite,

sludge, oils, solvents, and cleaning solutions at radiation levels of up to 400R/hr. The licensed and heavily shielded SPF can receive and process liquid and solid LLRWs with high water and/or organic content.

The Erwin facility employs the THERmal Organic Reduction (THOR[®]) process, developed by Studsvik, which utilizes pyrolysis*/steam reforming technology. THOR[®] processes a wide variety of LLRWs in the unique, moderate temperature, dual-stage, pyrolysis/reforming, fluidized bed treatment system. The reforming process has demonstrated effectiveness in destroying organics and separating sulfur and halogens from inorganic waste materials. Of special relevance is the capability of the THOR[®] technology to convert nitrates to N₂ and sodium salts to sodium compounds that are suitable for disposal and/or subsequent vitrification.

In February 2002, THOR[®] demonstrated the capability of producing sodium aluminosilicate waste forms for Hanford's sodium-bearing low activity waste (LAW) [2]. Other demonstrations performed by THOR[®] showed that LAW waste could be transformed into carbonate, aluminate, or silicate feed material for the LAW Hanford melter. Addition of aluminosilicate clay during pyrolysis produces an NaAlSiO₄ mineral product. The latter has been shown to perform well as a final waste form [2,6,7,8,9,10].

In November 2002, THOR[®] was contracted to demonstrate the FBSR technology to produce a carbonate waste solid for INL's acidic and radioactive Sodium-Bearing Waste (SBW) [11]. This demonstration successfully converted the SBW to a Na₂CO₃ product that met the Waste Isolation Pilot Plant (WIPP) Waste Acceptance Criteria (WAC) for transuranic (TRU) waste. During the demonstration, data were collected to determine the nature and characteristics of the product, the operability of the technology, the composition of the off-gases, and the fate of key radionuclides (cesium and technetium) and volatile mercury compounds. The product contained a significant fraction of elemental carbon residues. Mercury was quantitatively stripped from the product but cesium, rhenium (Tc surrogate), and the heavy metals were retained. Nitrates were not detected in the product and NO_x destruction exceeded 98% [11]. The steam reformer off-gas was monitored and it was determined that no O₂ was present. The off-gas was mostly (76%) H₂O (wet, N₂-free basis). CO levels averaged 1.3%, while the measured CH₄ levels averaged 0.1%. A significant benefit of the FBSR process is that it produces zero-liquid releases. All water is released as water vapor.

EXPERIMENTAL

A simulant of the Tank 48 solution was prepared according to Table I. This slurry had approximately 13.7 wt% solids. Antifoam (IIT Corp. B52) was added at 100 ppm antifoam per wt% solids [12]. Five wt% Fe₂O₃ was added as Fe(NO₃)₃•9H₂O to provide an indicator of the REDuction/OXidation (REDOX) equilibrium that the sample experienced in sealed crucibles during the bench scale testing. Having ~5 wt% Fe₂O₃ present enabled the Fe⁺²/ΣFe ratio of the solid product sample to be measured from which the oxygen fugacity, $\log f_{O_2}$, $\log P_{H_2O} / P_{H_2}$,

* Pyrolysis chemically decomposes organic materials by heat in the absence of oxygen.

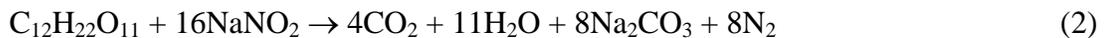
and $\log p_{CO_2} / p_{CO}$ of the reactions inside the sealed crucibles could be determined. All samples were analyzed for $Fe^{+2}/\Sigma Fe$ analysis by the Baumann method [13].

Table I. Tank 48 Simulant Recipe

Species	M/L
NaTPB	0.0728
NaOH	1.8425
NaNO ₂	0.4709
NaNO ₃	0.2753
Na ₂ CO ₃	0.1295
NaAlO ₂	0.1118
Na ₂ SO ₄	0.0071
Na ₃ PO ₄	0.0077
NaCl	0.0088
NaF	0.0059
KNO ₃	0.0779

The Tank 48 simulant was batched into stainless steel beakers. The slurry was carbonated with dry ice to convert the NaOH to Na₂CO₃ until a pH of ~9.5 was reached. This pretreatment from pH 13.3 to 9.5 also minimized foaming of the slurry. This ensured that once the carbonated material was put into a sealed crucible that a CO₂ atmosphere would be maintained. This served to duplicate the CO₂ rich atmosphere in the FBSR.

The reductant of choice for the bench scale tests was sucrose. A test matrix (Table II) was developed that varied three different levels of reductant based on the following stoichiometric equations:



Where the stoichiometric ratio of [C]:[N] for nitrate species is $12/9.6=1.25$ (Equation 1) and $12/16=0.75$ for nitrite species (Equation 2).

Three different levels of sucrose (none, 1/2X stoichiometric, and 1X stoichiometric) and three different reaction times (1/2 hour, 3 hours, and 48 hours) were tested. High purity (99.999%) Al₂O₃ crucibles were used to simulate Al₂O₃ bed material and to determine if the FBSR product was adhering to the simulated bed media. Temperatures of 650°C and 725°C were tested to see which levels of reductant optimized the WGSR at which temperatures.

The known melt temperature of alumina containing FBSR products are >1280°C [14,15]. Hence, the lower melting Na₂CO₃ and Na₂SiO₃ FBSR products were targeted for initial study [16]. Only the carbonate tests are discussed in this manuscript since the carbonate form was

chosen for subsequent pilot and engineering scale study. Since the simulant feed was precarbonated, no other additions were needed to optimize the Na_2CO_3 product. The carbonated slurries were dried to "peanut butter" consistency to ensure that some H_2O remained in the sample to create steam for the WGSR. Alumina crucibles were sealed with nepheline (NaAlSiO_4) gel that melts at a temperature lower than the test temperature. This prevents air inleakage during reaction but allows other gases to escape by slow diffusion through the gel. The sealed samples were placed in a calibrated furnace at the test temperature designated in Table II. This generated a combined atmosphere of steam, CO from decomposition of the sucrose and CO_2 thus duplicating the FBSR gas mixtures. The furnace was purged with 99.99% Ar to ensure that no O_2 mixed with any H_2 or CO escaped through the crucible seal.

Samples were analyzed by X-ray diffraction (XRD) to determine if the desired FBSR product was achieved. Samples were measured by High Pressure Liquid Chromatography (HPLC) to determine if the TPB was adequately destroyed by the FBSR reactions. Analyses were also conducted to determine if any secondary TPB reaction products were present, e.g., 3PB and 2PB. Total Carbon (TC), Total Inorganic Carbon (TIC), and Total Organic Carbon (TOC) were also analyzed.

Samples were measured by Ion Chromatography (IC) for NO_2^- , NO_3^- , and SO_4^{2-} to determine the fate of these anions and the percent nitrate destruction. Differential Thermal Analysis (DTA) was performed on selected products to determine the melting temperature. Details of all the analyses performed are given elsewhere [16].

DISCUSSION

Baseline Testing

A sample (T48-0) was tested as a baseline. The T48-0 sample was carbonated, antifoam and $\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ were added, and the sample was dried at 60°C . This sample was analyzed for TPB, anions, TC, TIC, TOC and REDOX as a baseline case (see Table III). These analyses demonstrated that there was 95,100 $\mu\text{g/g}$ of TPB (Table III) present in the samples after the carbonation and drying steps. The presence of the TPB was also confirmed by the measurement of TOC, which showed 19,500 $\mu\text{g/g}$ of organic carbon. Either the TPB or the antifoam (an organic) may have reacted with the $\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ because an all Fe^{+3} dried solution should have had a REDOX measurement of ~ 0 and the measurement was 0.44. This indicated that a considerable amount of Fe^{+2} was present or that the organics interfered with the REDOX measurement. Anion analysis of the base case indicated $<100 \mu\text{g/g}$ of NO_2^- and 163,000 $\mu\text{g/g}$ or 16.3 wt% of NO_3^- . This number was used with the measured NO_3^- data [16] to calculate the NO_3^- destruction values given in Table III.

Tetraphenylborate Destruction

Samples were tested at two different temperatures, 650°C and 725°C (Table II). Tetraphenylborate (TPB) was completely destroyed in all the samples tested, i.e., the TPB, 2PB and 3PB were all $<5 \mu\text{g/g}$ indicating that the thermal treatment destroyed all the TPB and its

derivatives. This was confirmed by the TOC analyses for all the samples thermally treated when <100 ug/g of TOC was observed. This indicates that FBSR is a viable technology for destruction of the organics in Tank 48.

Table II Simulated T48 Steam Reformer Optimization Matrix

Test ID	Temp (°C)	Time (Hours)	Sugar Stoichiometry	Phase(s) Desired
T48-0	60	0	0	N/A
T48-1	725	½	0	Na ₂ CO ₃
T48-2	725	3	0	Na ₂ CO ₃
T48-2B	650	3	0	Na ₂ CO ₃
T48-3	725	3	½	Na ₂ CO ₃
T48-4	725	½	1	Na ₂ CO ₃
T48-5	725	3	1	Na ₂ CO ₃
T48-5B	650	3	1	Na ₂ CO ₃
T48-13	650	48	1	Na ₂ CO ₃

Table III Simulated T48 Steam Reformer Analytic Results

Test #	Major Phase Desired	Major Phases Identified by X-Ray Diffraction	Minor Phases Identified by X-Ray Diffraction	NaTPB, 3PB, 2PB (ug/g)	Percent NO _x Destroyed
T48-0	Na ₂ CO ₃	Na ₃ H(CO ₃) ₂ (H ₂ O) ₂ , Na(NO ₃), NaNO ₂ , Na ₂ CO ₃ •H ₂ O	Na ₂ SiO ₃ , KAl(SO ₄) ₂ (H ₂ O) ₁₂	95,100 <5,<5	0
T48-1	Na ₂ CO ₃	Na ₂ CO ₃ •H ₂ O, Na ₂ CO ₃	Al(OH) ₃ (?), Ca ₈ Al ₂ Fe ₂ O ₁₂ CO ₃ (OH) ₂ •22H ₂ O	<5,<5,<5	30.1
T48-2	Na ₂ CO ₃	Na ₂ CO ₃ •H ₂ O, Na ₂ CO ₃	Al(OH) ₃ (?), Ca ₈ Al ₂ Fe ₂ O ₁₂ CO ₃ (OH) ₂ •22H ₂ O	<5,<5,<5	4.3
T48-2B	Na ₂ CO ₃	Na ₂ CO ₃ •H ₂ O, Na ₂ CO ₃	Al(OH) ₃ (?),NaNO ₃ , Ca ₈ Al ₂ Fe ₂ O ₁₂ CO ₃ (OH) ₂ •22H ₂ O	<5,<5,<5	24.5
T48-3	Na ₂ CO ₃	Na ₂ CO ₃ •H ₂ O, Na ₂ CO ₃	Ca ₈ Al ₂ Fe ₂ O ₁₂ CO ₃ (OH) ₂ •22H ₂ O	<5,<5,<5	99.5
T48-4	Na ₂ CO ₃	Na ₂ CO ₃ •H ₂ O, Na ₂ CO ₃	Ca ₂ SiO ₄ (?), Al(OH) ₃ (?)	<5,<5,<5	98.1
T48-5	Na ₂ CO ₃	Na ₂ CO ₃ •H ₂ O, Na ₂ CO ₃	Ca ₈ Al ₂ Fe ₂ O ₁₂ CO ₃ (OH) ₂ •22H ₂ O Al(OH) ₃ (?)	<5,<5,<5	97.5
T48-5B	Na ₂ CO ₃	Na ₂ CO ₃ •H ₂ O, Na ₂ CO ₃	NONE	<5,<5,<5	99.1
T48-13	Na ₂ CO ₃	Na ₂ CO ₃ •H ₂ O, Na ₂ CO ₃	NONE	<5,<5,<5	99.0

Carbonate FBSR Products

For all of the FBSR samples in which the desired product was Na₂CO₃ (samples T48-1 through T48-5B and T48-13), analysis by XRD indicated that a mixture of Na₂CO₃•H₂O (thermonatrite) and Na₂CO₃ (natrite) was formed regardless of temperature and residence time in the furnace (Table II and Table III). However, for the T48-13 sample that was heated at 650°C for 48 hours, the XRD analysis indicated no minor constituents. Therefore, it is believed that the minor constituents in sample T48-5B which was reacted for only 3 hours at the same temperature and conditions as T48-13 were due to incomplete reaction. Test T48-5B or T48-13 appeared optimal

IT3'07 Conference, May 14-18, 2007, Phoenix, AZ

for making the Na_2CO_3 FBSR product at 650°C with 1X stoichiometric sugar and 3-48 hour residence time, as no minor phases were identified as incomplete reactants. Only the two primary phases, Na_2CO_3 and $\text{Na}_2\text{CO}_3 \cdot \text{H}_2\text{O}$, were present in the T48-5B and T48-13 samples.

Nitrate and Sugar Destruction

In the sample test matrix (Table II), samples with the designation of B indicate comparison of duplicate samples at the two different reaction temperatures. These were designed into the test matrix to test the optimum NO_x destruction at the various temperatures, e.g. optimize the WGSR. Hence samples T48-2B and 5B were tested at 650°C , while samples T48-2 and 5 were tested at 725°C .

For two of the pairs of samples tested at the different temperatures, T48-2 and 2B and T48-5 and 5B, the desired FBSR product was Na_2CO_3 . Samples T48-2 and T48-2B had no sugar and samples T48-5 and T48-5B had 1X stoichiometric sugar. Comparison of the XRD spectra of the two tests without sugar demonstrates that the FBSR products reacted at 650°C contain undecomposed NaNO_3 which shows up in the XRD spectra and nitrate analyses while the sample reacted at 725°C does not have sufficient NaNO_3 for it to show up during XRD analysis. This finding indicates that nitrate destruction is less complete at temperatures below 725°C when sugar is absent. This was confirmed by nitrate analyses of the solid products [16]. For the sample pair T48-5 and T48-5B sucrose was present at 1X stoichiometry. These samples had 99.1% and 97.5% NO_3^- destruction at the 725°C and 650°C temperatures respectively (Table III). Likewise, the TOC analyses [16] indicated no residual TOC in the form of sucrose in the samples and the XRD spectra did not indicate any residual NaNO_3 (Table III). The small amount of TOC measured in all the samples [16] indicated that at $\frac{1}{2}$ to 1X sugar stoichiometry that most of the sugar added is consumed during denitration.

Particle Agglomeration to Simulated Al_2O_3 Bed Material

No adherence of the carbonate phases onto the Al_2O_3 crucibles was noted. Therefore, if the FBSR startup bed is Al_2O_3 there should not be any particle agglomeration with the Al_2O_3 [16].

FBSR Product Melt Temperatures

FBSR product sample T48-5B (primarily Na_2CO_3 made at 650°C) was measured by Differential Thermal Analysis (DTA) to determine the melting temperature. The melt temperature was 980°C . This melt temperature is compatible with melting of the carbonate phases directly. However, the SRL HLW melter uses a preprocessing strategy in the Sludge Receipt Adjustment Tank (SRAT) that destroys carbonate by addition of mixed formic and nitric acids that simultaneously controls the melter REDOX equilibria [4].

REDOX Measurements and the Water Gas Shift Reaction (WGSR)

An Electro-Motive Force (EMF) REDOX series that was recently developed for FBSR products [17] was used to calculate the $\log f_{\text{O}_2}$ from the measured REDOX of the FBSR product [16].

The average REDOX ratio for the FBSR samples tested at 725°C and 650°C show that $\log f_{O_2}$ values of -21 and -20 atm were achieved at the two different temperatures, respectively. The longest run, 48 hours, had the most oxidized REDOX value indicating a $\log f_{O_2}$ of only -18 atm. Because the crucibles were sealed, published correlations [18] relating $-\log f_{O_2}$, temperature, $\log p_{H_2O} / p_{H_2}$, and $\log p_{CO_2} / p_{CO}$ could be used to estimate the $\log p_{H_2O} / p_{H_2}$ and $\log p_{CO_2} / p_{CO}$ in the sealed crucibles. The $\log \log p_{H_2O} / p_{H_2}$ and $\log p_{CO_2} / p_{CO}$ are the partial pressures of the two half reactions for the WGSR. These negative $\log f_{O_2}$ values mean that no oxygen was present during the FBSR reactions. The $\log p_{H_2O} / p_{H_2}$ in the FBSR crucibles was between 0 and +1.0. The $\log p_{CO_2} / p_{CO}$ in the FBSR crucible studies was between 0 and +1.5. The positive values for $\log p_{H_2O} / p_{H_2}$ and $\log p_{CO_2} / p_{CO}$ indicate that the CO₂ and H₂O conditions of the FBSR process were adequately simulated although H₂ and CO were probably higher than in a pilot or engineering scale facilities where O₂ is used to complex H₂ as steam and generate heat.

Table IV. Measured REDOX Values

Test #	Temp. (°C)	Fe ²⁺ /ΣFe	Log Fe ²⁺ /Fe ³⁺
T48-1	725	0.70	0.37
T48-2	725	0.67	0.31
T48-2B	650	0.74	0.45
T48-3	725	0.83	0.69
T48-4	725	0.73	0.43
T48-5	725	0.62	0.21
T48-5B	650	0.86	0.79
T48-13	650	0.37	-0.23
Average	725	0.71	0.39
Average	650	0.66	0.28

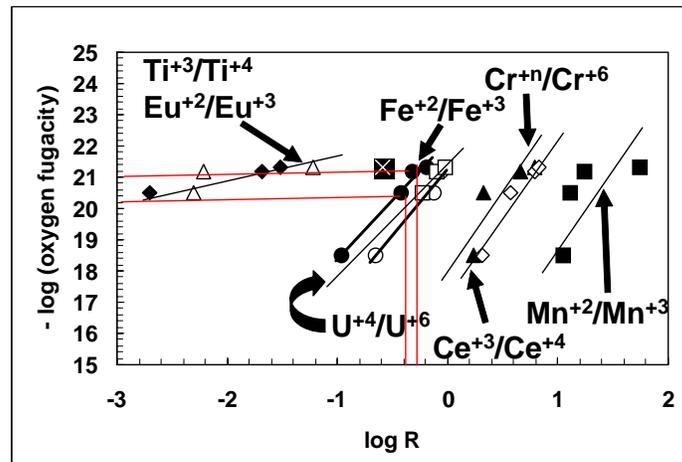


Figure 1. Electromotive Force (EMF) series developed by Schreiber for FBSR Reactions [17].

Pilot and Engineering Scale Validation

A program between SRNL and INL was initiated in 2003 to perform a proof-of-concept steam reforming test to evaluate the technical feasibility of steam reforming for pretreating the Tank 48 waste for vitrification [3]. The objectives of the tests included 1) >99 % destruction of TPB, nitrates, and nitrites, 2) acceptable bed performance (no agglomeration), 3) acceptable bed product that could become feed to the DWPF melter (sodium carbonate or sodium silicate with an acceptable melting point), and 4) use of sugar as a reductant for nitrate destruction in the absence of a catalyst because of its compatibility with DWPF processing. The demonstration was performed in a 6" diameter FBSR at the Science Applications International Corporation (SAIC) Science and Technology Applications Research (STAR) facility in Idaho Falls, Idaho. The pilot scale unit was externally heated and temperatures of 625°C, 650°C, and 750°C were tested. The 750°C campaign was unsuccessful due to bed agglomeration. At temperatures of 625-650°C all the test objectives were met [3] and no bed agglomeration was experienced.

A program between SRS and TTT was initiated in 2006 to perform engineering scale proof-of-concept steam reforming test to evaluate the performance of Tank 48 waste in a 15" diameter FBSR at Hazen Research Inc. in Golden, CO. The engineering scale performance was necessary to determine the organic and nitrate/nitrite destruction in an auto-thermally operated FBSR. When sugar was used as a reductant it did not supply the energy needs to sustain the water gas shift reactions (WGSR) and charcoal was used instead. The objectives of the test were the same as those of the 2003 STAR demonstration. All the test objectives were met at operating temperatures of 640-670°C without bed agglomeration.

CONCLUSIONS

The purposes of the current study, organic destruction and downstream processing of T48 waste slurry, were fulfilled as documented by the following:

- TPB was completely destroyed in all samples tested at the bench scale at temperatures between 650-725°C,
- >99% destruction of nitrate was achieved
- TOC analyses indicated that excess sugar was not present in the bench scale product which ensures the REDuction/OXidation (REDOX) equilibrium of the HLW melter can be maintained,
- TOC analyses indicated destruction of antifoam was also achieved,
- Na₂CO₃ was produced for all tests in which Na₂CO₃ was the desired product phase,
- Na₂CO₃ was shown to be compatible with the HLW melt processes,
- the sealed crucible studies demonstrated that bench scale studies can duplicate the complex reactions and the associated atmospheres in the FBSR process,
- test parameters from this study were used for pilot scale and engineering scale testing of the Tank 48 simulant which were both successful.

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