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# **Solvent Hold Tank Sample Results for MCU-19-557-558-559 (July 2019), MCU-19-560-561-562 (August 2019), MCU-19-566-567-568 (September 2019): Quarterly Report**

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March 2020

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March 2020

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## EXECUTIVE SUMMARY

A trend summary of three sets of Solvent Hold Tank (SHT) monthly samples MCU-19-557-558-559(July), MCU-19-560-561-562 (August), and MCU-19-566-567-568 (September) are reported. Most of the conclusions are based on the September SHT sample (MCU-19-566-567-568). Analyses of the September SHT sample (MCU-19-566-567-568) indicated that the Modifier (Cs-7SB) and the Extractant (MaxCalix) concentrations were slightly below their nominal recommended concentrations (169,000 mg/L and 46,800 mg/L respectively) by 1% and 2% respectively but consistent with previously observed levels during normal operations. The Suppressor (*N,N',N''*- tris(3,7-dimethyloctyl)guanidine or TiDG) concentration has remained steady since the June 2019 measurement at 800 mg/L, which is above the minimum recommended concentration (479 mg/L).

The SemiVolatile Organic Analysis (SVOA) did not detect any impurities. However, the Fourier-Transformed Hydrogen Nuclear Magnetic Resonance (FT-HNMR) analysis detected presence of phthalates at a few ppm. The impurity concentration was highest in the August sample and consistently detected in the July and September samples (but always registered as a few ppm or less). Another impurity observed in the samples was mercury. Based on the September SHT sample, up to  $14 \pm 3$  microgram of mercury per mL of solvent was detected. The higher mercury concentration in the solvent (as determined in the last three-monthly samples) is possibly due to the higher mercury concentration in Salt Batches 9 and 10.

The gamma concentration ( $\sim 3.03\text{E}4$  dpm/mL) measured in the September 2019 SHT samples was consistent with previous values observed when Modular Caustic-Side Solvent Extraction Unit (MCU) was idle (for example, between February and August 2017). Higher values were seen when MCU was processing liquid waste.

Statistical analysis of the different analytical methods detected a bias between the FT-HNMR and High-Performance Liquid Chromatography (HPLC) methods when measuring the MaxCalix and Modifier concentrations; the FT-HNMR gave a higher concentration possibly due to peak overlapping in the measured data.

The laboratory will continue to monitor the quality of the solvent for any new impurities or degradation of the solvent components.

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## LIST OF ABBREVIATIONS

BOBCalixC6	calix[4]arene-bis( <i>tert</i> -octylbenzo-crown-6)
CSSX	Caustic-Side Solvent Extraction
CVAA	Cold Vapor Atomic Absorption
DMA	Direct Mercury Analysis
FT-HNMR	Fourier Transform Hydrogen Nuclear Magnetic Resonance
HPLC	High Performance Liquid Chromatography
MCU	Modular Caustic-Side Solvent Extraction Unit
MaxCalix	1,3- <i>alt</i> -25,27-bis(3,7-dimethyloctyloxy)calix[4]arene-benzocrown-6
NGS	Next Generation Solvent
SHT	Solvent Hold Tank
SRNL	Savannah River National Laboratory
SVOA	Semi-Volatile Organic Analysis
TiDG	<i>N,N',N''</i> -tris(3,7-dimethyloctyl)guanidine
TOA	Trioctylamine
XRF	X-Ray Fluorescence

## 1.0 Introduction

In late FY13, MCU implemented the Next Generation Solvent (NGS) flow sheet. Facility personnel added a non-radioactive, NGS “cocktail” containing the new Extractant (MaxCalix) and a new Suppressor (TiDG) to the SHT heel to implement the NGS flow sheet. The resulting “blend” solvent (“NGS blend solvent”) is essentially NGS with residual amounts of calix[4]arene-bis(tert-octylbenzo-crown-6) (BOBCalixC6) and trioctylamine (TOA). For process monitoring, SHT samples are sent to Savannah River National Laboratory (SRNL) to examine solvent composition changes over time.<sup>1</sup> With the exception of Isopar™ L which is regularly added to the SHT due to its high vapor pressure, this report shows the cumulative chemical composition data, including impurities like mercury, of three SHT samples: MCU-19-557-558-559, MCU-19-560-561-562, and MCU-19-566-567-568. A summary report for each of the SHT monthly samples was issued previously.<sup>2,3,4</sup> This report examines the cumulative results from these and several past monthly reports.

These samples are intended to verify that the solvent is within the specified composition range. A baseline “scratch” solvent – a scratch solvent is a preparation of all 6 solvent components of the composition that approximates the blend of cocktail<sup>5</sup> and heel solvent – was prepared in the lab (September 2018) and used for comparison and evaluation. The results from the analyses are presented in this document.

## 2.0 Experimental Procedure

### 2.1 Experimental Procedure

Table 2-1 lists a summary of relevant and recent trims to the MCU solvent as well as the arrival date of the samples currently being studied.

**Table 2-1. Log of trims to MCU solvent for 2019 and SHT sampling dates.**

Event	Date
SHT special trim added	January 23, 2019
SHT sample MCU-19-2-3-4	January 26, 2019
9 gallons of Isopar <sup>1</sup> ™ L added to MCU	February 4, 2019
SHT sample MCU-19-83-84-85	February 17, 2019
11 gallons of Isopar <sup>1</sup> ™ L added to MCU	February 21, 2019
SHT sample MCU-19-138-139-140 special trim added	March 5, 2019
SHT sample MCU-19-208-209-210	March 19, 2019
9 gallons of Isopar <sup>1</sup> ™ L added to MCU	March 27, 2019
SHT sample MCU-19-366-367-368	April 13, 2019
SHT sample MCU-19-469-470-471	May 17, 2019
9 gallons Isopar <sup>1</sup> ™ L added to MCU	May 31, 2019
SHT sample MCU-19-524-525-526	June 23, 2019
SHT sample MCU-19-557-558-559	July 23, 2019
SHT sample MCU-19-560-561-562	August 13, 2019
SHT sample MCU-19-566-567-568	September 16, 2019

Samples shown in Table 2-1 were received in P-nut vials containing ~10 mL each (see Figure 3-1). Once taken into a radioactive hood, the samples were visually inspected and analyzed for pH. Contents of the P-nut vials for each monthly SHT sample were composited before use. Aliquots of the composited sample were removed to perform the following analyses: density, SVOA, HPLC, titration for TiDG, gamma counting, Direct Mercury Analysis (DMA), and FT-HNMR. Results from analytical measurements were compared with the theoretical values shown in Table 2-2. Note that the SVOA, HPLC, DMA, density, titration for TiDG, and FT-HNMR results for each SHT sample are shown in the respective monthly reports.

All reported values were checked against the values obtained from the scratch solvent made in September 2018. All error bars represent one-sigma (one standard deviation). In the case of the physical measurements (density, surface tension, and viscosity measurements), the one-sigma was obtained from three replicates (observations). Suppressor concentration derived from titration was performed twice for the as received sample. Except for the data from the HPLC, FT-HNMR, and gamma counting where one observation was made, the one-sigma from the DMA measurement was obtained from duplicate observations (replicates). Therefore, the error bars shown in this report are the variations within replicates (or fidelity of the analytical measurements).

**Table 2-2. Nominal concentrations of the relevant components in NGS Blend at 25 °C (Ref. 5)**

Component	mg/L	Molar
MaxCalix	~ 44,400* to 47,800*	~ 0.0465 to 0.050
BOBCalixC6*	< 4,030	< 0.0035
TOA*	< 530	< 0.0015
Modifier	~ 169,000	~ 0.50
TiDG	~1,440♥	~ 0.003
Isopar™ L	~ 607,000* to 613,000*	~ 73.05 to 73.69 wt. %

\*Values represent starting values when NGS blend was implemented. These components are no longer added to or refurbished in MCU.

\* Solvent composition is closer to a pure NGS formulation.

\* Solvent composition is closer to an NGS-CSSX blend formulation.

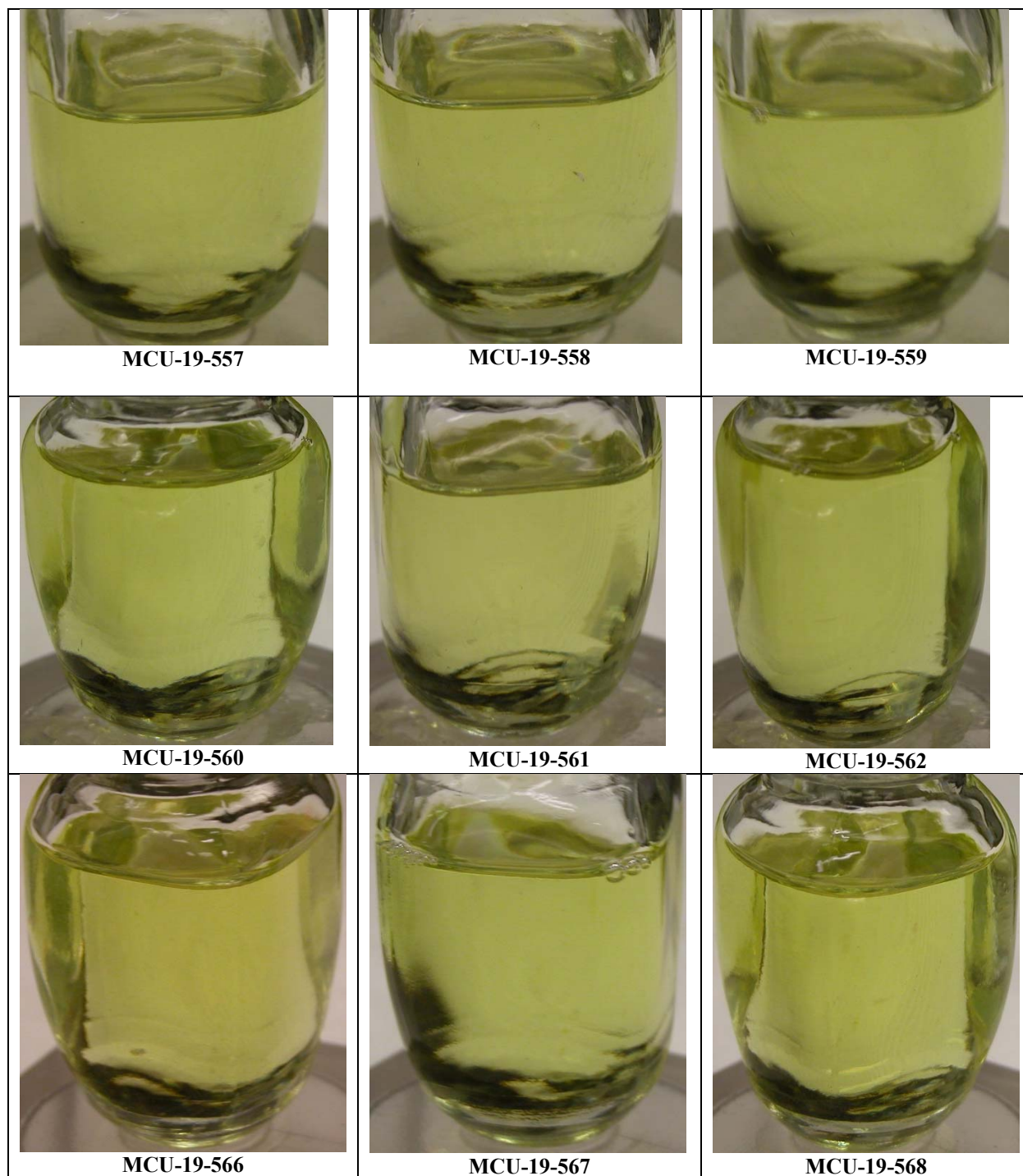
♥ Assuming a molecular weight for caustic-washed TiDG of 479 g/mol (516 g/mol for TiDG\*HCl).

## 2.2 Quality Assurance

This work was performed under Technical Task Request (TTR).<sup>6</sup> The recorded data, analysis, and conclusions satisfy the Production Support requirements in the Task Technical and Quality Assurance Plan (TTQAP) associated with this TTR.<sup>7</sup> Requirements for performing reviews of technical reports and the extent of review are established in Reference 8 (design check requirements). SRNL documents the extent and type of review using the SRNL Technical Report Design Checklist contained in Reference 9. The work performed, all analyses, and the review process for this report complies with those requirements.

## 3.0 Results and Discussion

Each sample (and its corresponding P-nut vial) was visually examined. No floating debris or foam were observed (see Figure 3-1). No droplets were found in the samples. All solvent samples had a pH value of 5.5. No unusual reactions, solids, foaming, or immiscible layers were observed after combining the samples into one Teflon container for each set of monthly SHT samples.



**Figure 3-1. A picture of samples MCU-19-557-559 (top), MCU-19-560-562 (middle), and MCU-19-566-568 (bottom).**

### 3.1 Modifier Concentrations and Density Measurements

MCU resumed operations in May 2018 (after suspending operations in January 2017) and since then, several Isopar<sup>™</sup>L additions and three trim additions were made to the solvent.<sup>10</sup> Based on the July, August, and September results, both the density measurements and the Modifier concentration were steady (flat) near their nominal values and the corresponding error intervals included the nominal (0.830 mg/L at 25 °C

in the case of the density measurement) or recommended value (in the case of the Modifier, the recommended concentration is 1.69E5 mg/L) [see Figure 3-2 and the tabulated data in Appendix A].<sup>2,4</sup> A bias was detected between the FT-HNMR and HPLC method for measuring the Modifier (see Figure A1 in Appendix A). Using the average of the two methods minimizes the bias effect. The reported density measurements were obtained from triplicate measurements of the sample (with the density measured by the vibrations of a specially calibrated tube filled with the organic liquid and corrected for temperature using the CSSX temperature correction formula).<sup>11</sup> The uncertainty (one sigma) by this method is 3%. Unlike the gravimetric measurement that uses calibrated 2 mL flasks (for limited samples) where manufacturing errors of the flask's geometry such as camber, concentricity, roundness, cylindricity, and thick marked lines for visual detection of the meniscus raised the measurement error to 9% (excluding human error). After comparing the density of several SHT samples by the two methods and determined no statistical difference between the two methods, the more precise density measuring method is reported.

The slightly fluctuating values observed in the density (and in the Modifier concentration) for July, August, and September samples are likely due to aliasing between the monthly samples and the monthly additions to the solvent. However, the observed density and Modifier values from the July, August, and September samples were consistent with previous measurements when MCU was operating continuously (for example in 2017). Both the density data and the Modifier concentration correlated strongly ( $r^2 = 0.99$ ) with each other as expected (see Figure 3-2).<sup>11</sup> The Isopar™ L concentration (not shown) in the September sample was similar to that of the baseline solvent (scratch made on September 2018). This finding is expected since the solvent density is a volume-weighted linear combination of the Modifier and Isopar™ L densities. Other physical measurements of the July, August, and September SHT samples such as viscosity and surface tension were similar to the baseline solvent measurements (see Figure A3). No bias was detected in either the viscosity or surface tension measurements of the monthly solvent samples relative to the scratch baseline solvent (Figure A2 in Appendix A).

All measurements indicate (based on the July, August, and September samples) that the Isopar™ L concentration was at its nominal value (100%). Isopar™ L is added to the solvent more frequently (compared to the Modifier) to compensate for its high evaporation rate.

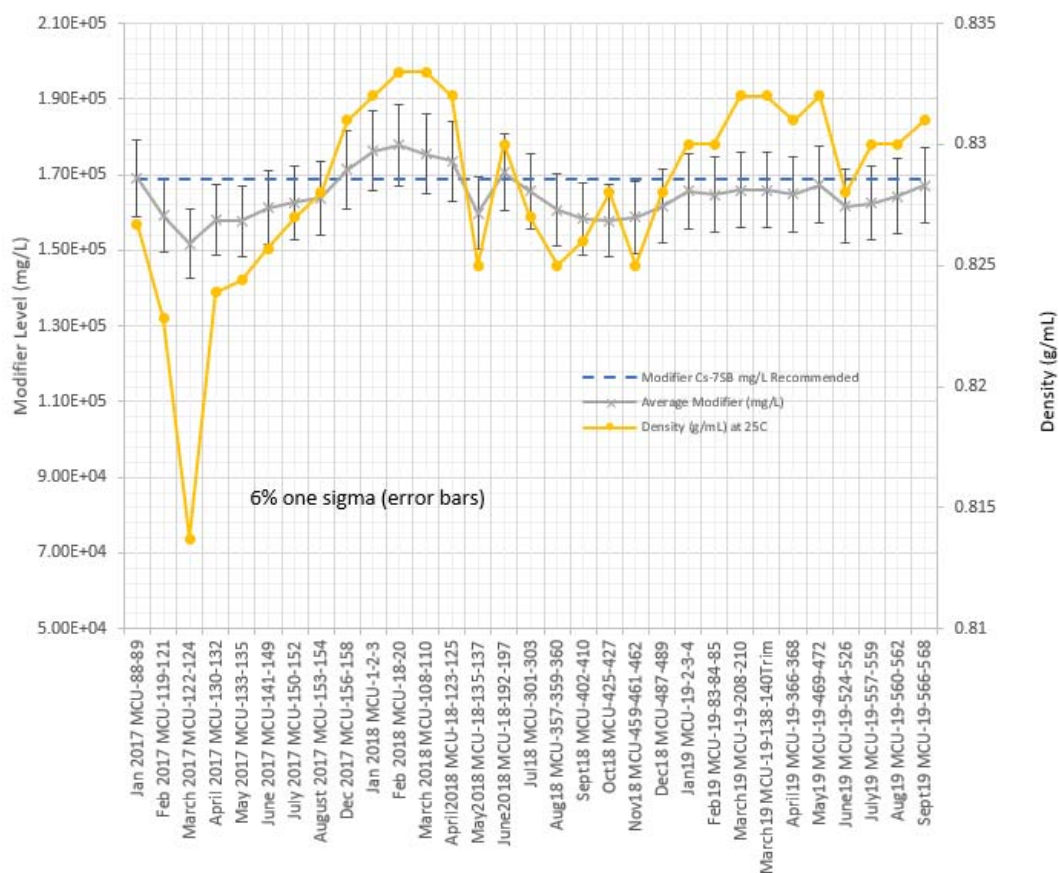
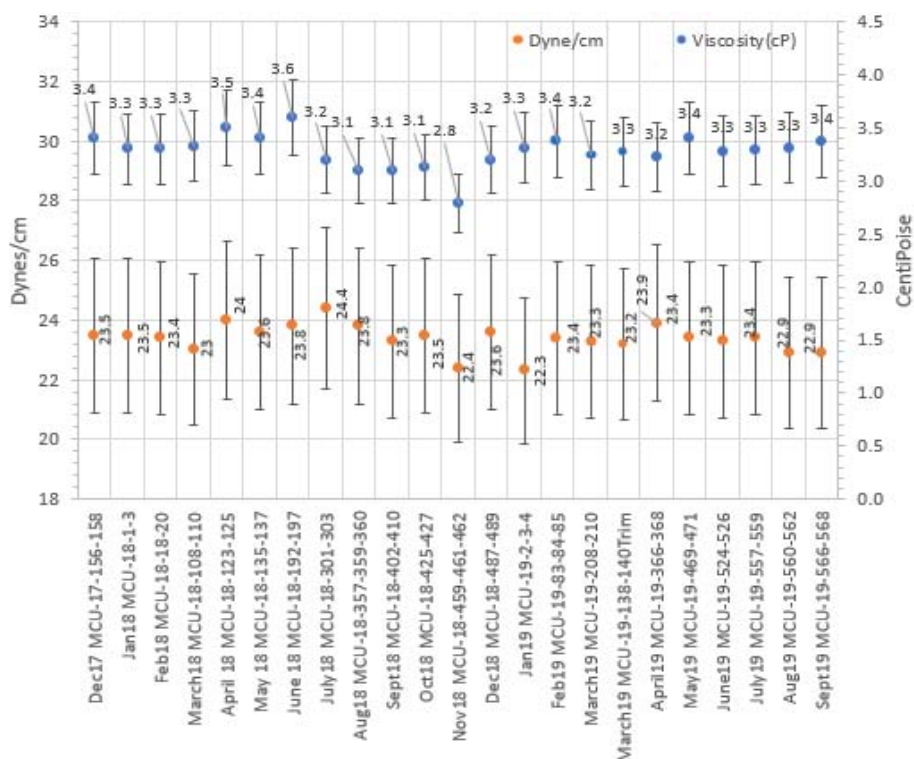


Figure 3-2. Modifier concentration in the solvent as measured by HPLC (one sigma is 6%).

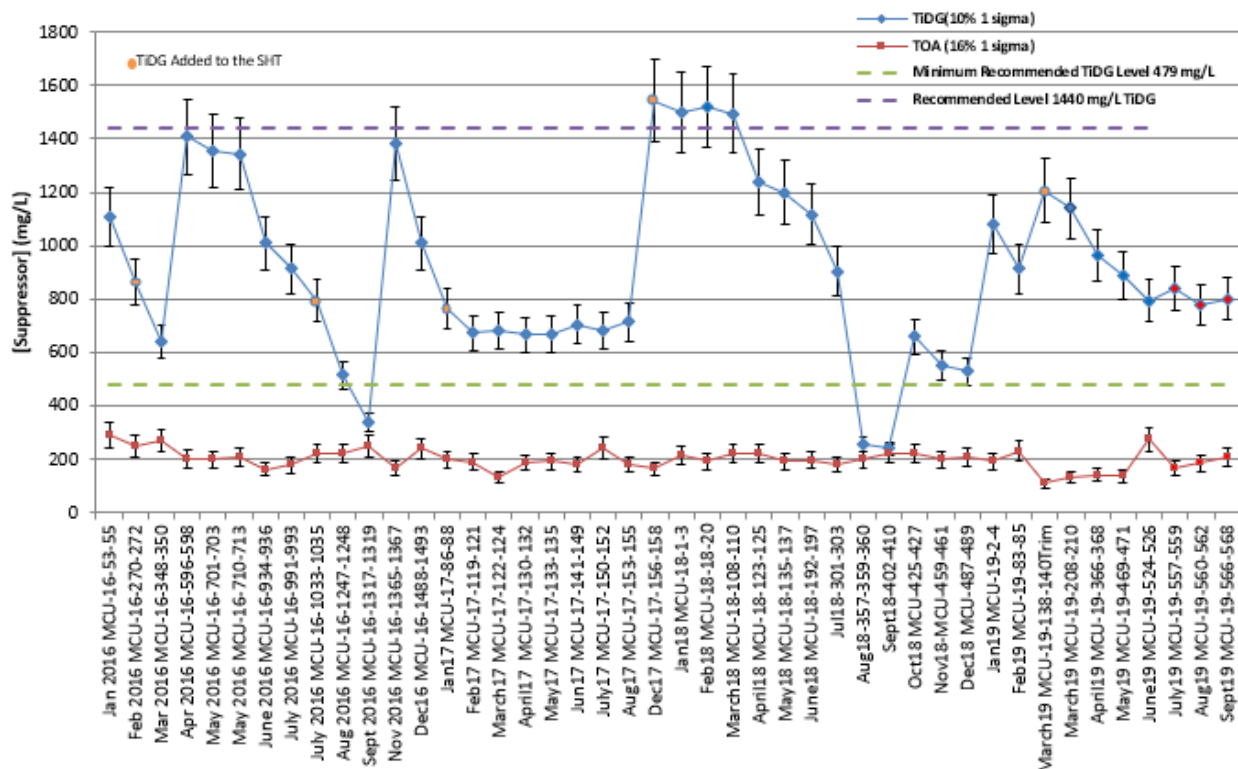


**Figure 3-3. Viscosity and surface tension measurements of the last 23 SHT samples. The scratch blend measured a viscosity of  $3 \pm 0.3$  cP and a surface tension of  $23 \pm 0.6$  dynes/cm (at 25°C).**

### 3.2 Suppressor Concentrations

The TiDG concentrations for MCU-19-557-558-559, MCU-19-560-561-562, and MCU-19-566-567-568 are shown in Figure 3-4. As can be seen in Figure 3-4, the TiDG concentration has remained steady (around 800 g/mL) since June 2019. Considering the July, August, and September samples, the steady trend has previously been observed before (for example from February to August 2017). The steady TiDG concentration is expected given that MCU did not process liquid waste during this time. Based on the September SHT sample, the Suppressor (TiDG) concentration ( $8.00 \pm 0.8E2$  mg/L) is above its minimum recommended operating concentration (479 mg/L for caustic washed TiDG: See the communication that set the minimum level in Appendix B). The TOA concentration appears to remain steady at  $208 \pm 33$  mg/L but is consistent with previous measurements. Since May 2016, the TOA level range can be estimated by  $195 \pm 36$  mg/L. Since MCU no longer adds TOA, a drop in TOA concentration is expected with time. However, a detectable and steady TOA concentration persists with time, perhaps due to a slower than expected degradation rate, a slower transfer rate to the aqueous streams during operation, or a bias from the degradation of TiDG into primary amines, which have previously been identified as degradation products of the Suppressor when heated (3 °C, 25 °C and 36 °C).<sup>12</sup> The primary amine degradation products would likely have a similar pKa to the TOA (tertiary amine) making the equivalent points coincide, and therefore difficult to distinguish.<sup>13</sup>





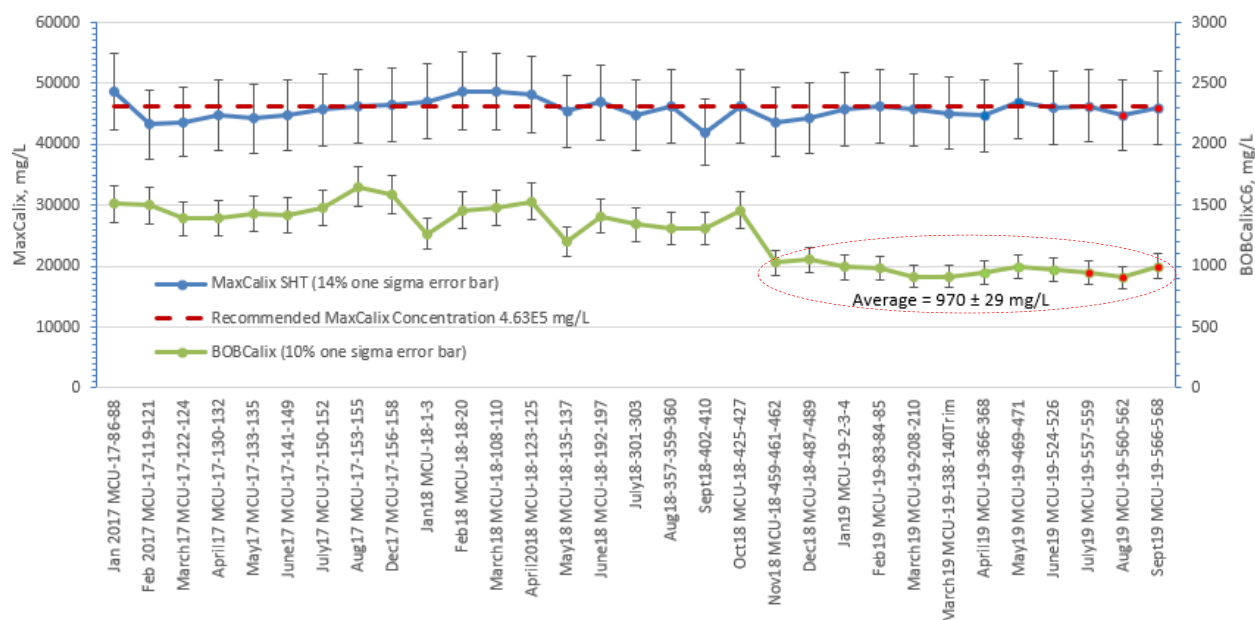
**Figure 3-4. Suppressor concentration as measured by titration in the SHT samples since NGS implementation. The minimum recommended concentration is 479 mg/L for TiDG**

### 3.3 Extractant Concentration

The calculated MaxCalix concentration statistically varied from 4.48E4 to 4.63E4 mg/L in the last 3 SHT samples (see Figure 3-5). Furthermore, this range and scatter have been previously observed (for example, February 2017 to February 2018) when MCU was in an extended outage due to the Defense Waste Processing Facility melter outage. Note the current recommended value of 46,800 mg/L is the difference between 47,800 mg/L (50 mM MaxCalix as referred to in Table 2.2) and the BOBCalixC6 concentration in the SHT (1000 mg/L in the September sample). Also note that a positive bias was detected in the FT-HNMR relative to the HPLC method (see Figure A3) that is minimized by using the average of the two methods. The recent variations in the MaxCalix concentration seen in Figure 3-5 (including a concentration minimum observed in the August 2019 SHT sample) is within the uncertainty range for this measurement. The pseudo-linear trends observed in Figure 3-5 correlate (correlation coefficient of 0.84) with the trends observed in the Modifier levels (see Figure A4 in Appendix A for residual plots of the Modifier and MaxCalix). This indicates that the MaxCalix is lost (similarly to the Modifier) through whole solvent carry-over into the aqueous phase.

The BOBCalixC6 concentration in the SHT since January 2017 is shown in Figure 3-5. The residual average concentration of BOBCalixC6 from November 2018 to September 2019 can be estimated as  $970 \pm 29$  mg/L (95% confidence interval). This concentration level is 24% of the concentration measured when the NGS was implemented in late FY13. The average BOBCalixC6 concentration before November 2018 was  $1423 \pm 53$  mg/L. The reason for the lower BOBCalixC6 concentration after November 2018 is probably due to dilution from trim (October 24, 2018) and an Isopar<sup>TM</sup> (October 31, 2018) addition. Since no BOBCalixC6 is added to the SHT, the level of BOBCalixC6 is expected to decrease with time (a correlation of 0.23 was measured between BOBCalixC6 and MaxCalix since January 2017).





**Figure 3-5. Average MaxCalix (average of HPLC and FT-HNMR) and BOBCalixC6 concentration of recent samples since NGS implementation (46,800 mg/L is the recommended nominal concentration).**

A closer look at the MaxCalix concentration data obtained from the HPLC and FT-HNMR methods from January 2018 to September 2019 is shown in Figure A3 Appendix A. In Figure A3, the ordinate axis presents the difference of the measurements from the two methods while the coordinate axis presents the average value. As can be seen from Figure A3, for several samples, the FT-HNMR method reported higher values than the HPLC. SRNL believes this is due to overlapping at the base of the peaks between the aromatic peak assigned to MaxCalix and the aromatic peaks assigned to the Modifier. The area of the aromatic peak assigned to MaxCalix is computed without conducting any effort to deconvolute it from neighboring peaks (the same arithmetic treatment is done to the spectrum of the scratch September 2018 standard). A significant number of data points lie outside the 95% confidence interval (as shown in Figure A3) that does not include the origin. The observed bias is not constant (not displayed through the whole domain in Figure A3), but it is noticeable at the lower magnitude of the average MaxCalix measurements and it is statistically significant (see insert table in Figure A3 in Appendix A).

### 3.4 Gamma Measurements

The gamma measurements for the July, August, and September samples are shown in Figure 3-6 (colored red) in relation to past measurements. The values of the July, August, and September samples are consistent with previous concentrations observed when MCU was idled (for example from February to August 2017). The variability in the gamma measurements is due to several factors that include the Isopar™ L addition (sometimes 12% dilution or 25 gallons of Isopar™ L to 200 gallons of solvent), processing start-up, and measurement imprecision.

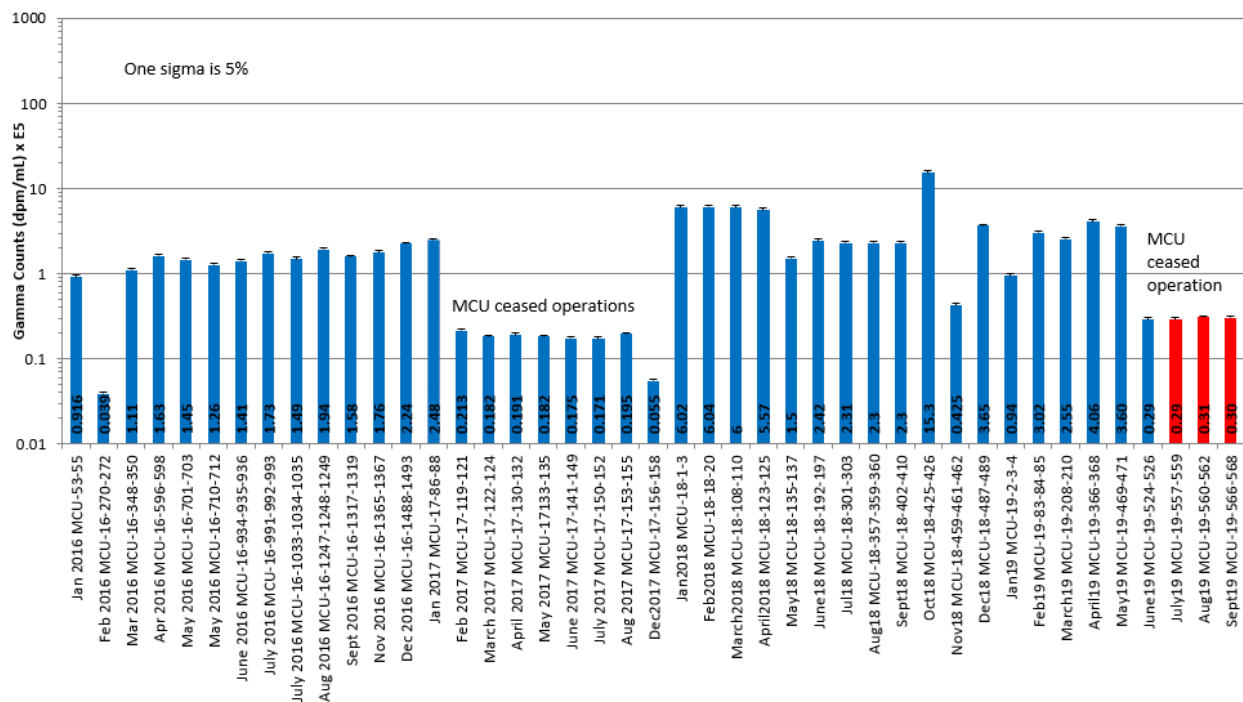


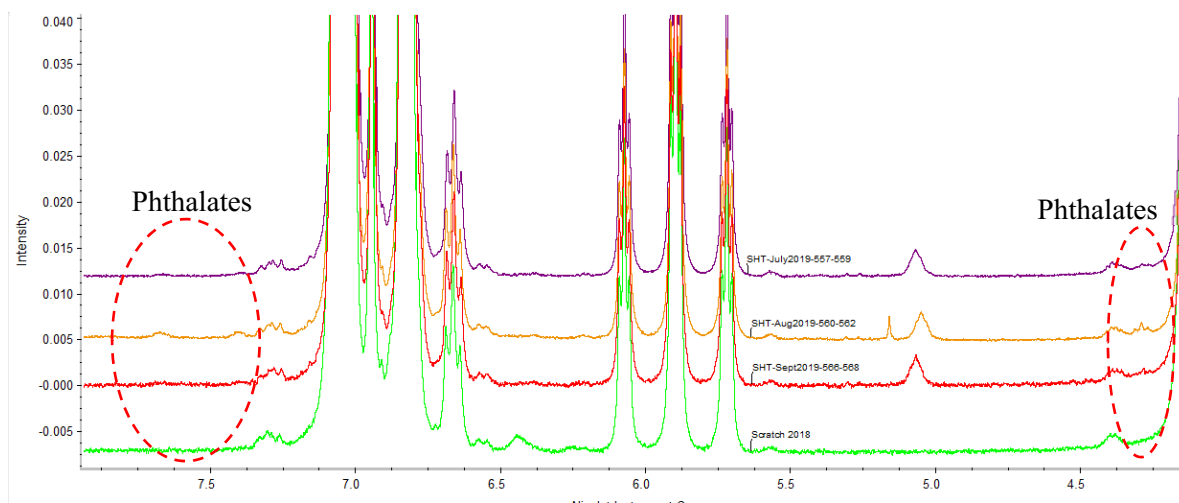
Figure 3-6. The gamma counts of selected SHT samples.

### 3.5 Impurities

No impurities were observed when performing the SVOA. However, the FT-HNMR analysis revealed the presence of three visible peaks (7.7, 7.4, 4.3, and 2.4 ppm) not observed in the spectrum of the baseline scratch solvent (see Figure 3-7). These peaks are believed to be due to phthalates (for example, diethyl heptyl phthalate or di-octylphthalate). The impurity concentration appeared to be less than 1 ppm as the signal is barely detectable. There is the potential that other new peaks may also be present, but if any are, they overlap with the solvent peaks and are indistinguishable.

Another impurity being tracked in the SHT solvent is the concentration of mercury. A few mL of each sample was digested and analyzed for total mercury by the DMA method. The average mercury concentrations in the July, August, and September SHT samples were  $27 \pm 5$  ug/g,  $29 \pm 6$  ug/g, and  $22 \pm 4$  ug/g, respectively (see Figure 3-8). Please note, the July, August, and September samples were measured by the DMA method alone. The calculated mercury concentration of the samples obtained after April 2018 and before May 2019 were averages of the XRF and DMA measurements (prior to April, averages of the XRF and Cold Vapor Atomic Adsorption (CVAA) were reported). SRNL used to measure total mercury by two different analytical techniques to eliminate single method bias in the reported results. But SRNL determined the DMA method had a better accuracy than the XRF method for soluble mercury and decided to use only the DMA (for samples after May 2019). Measurements of the July, August, and September SHT samples are consistent with the measurements obtained since August 2016 (during Salt Batch 9 and 10) possibly indicating variability that the mercury concentration in the SHT has reached a steady state value. The current mercury level is still higher than the level of mercury in the solvent when MCU was processing Salt Batch 8. This level of mercury still supports the noticeable jump in the mercury concentration of the SHT seen after July 2016. The average mercury before July 2016 was  $17 \pm 4$  ug/g and after was  $29 \pm 4$  ug/g (see the insert table in Figure 3-8). SRNL believes this jump is due to a feed stream with a higher mercury concentration (possibly Salt Batch 9) sent to MCU rather than an analytical measurement outlier.

The concentration of mercury observed in the July, August, and September samples are significantly higher than the solubility of metallic Hg in dodecane ( $\sim 3$  ppm),<sup>14</sup> implying that other solubility-enhancing mechanisms are at play (for example extraction by an Extractant or sorption on trapped solids; solids were not observed in these samples) or a more organic soluble form of mercury is present (organo-mercury like ethyl or dimethyl mercury). Organo-mercury compounds were recently detected in Tank 22H.<sup>15</sup> Based on the September SHT sample DMA mercury measurements, for 200 gallons of solvent (757.1 L), the solvent could contain up to  $14 \pm 3$  g of mercury. A comparison of these measurements with previous months (especially 2016 samples) confirms a higher mercury concentration in the solvent (data are shown in Figure 3-8). This finding may be consistent with the higher concentrations of total mercury ( $\sim 104$  ppm) observed in Tank 50H in the third quarter (8/2019) surveillance samples.<sup>16</sup> It appears that the solvent may hold on to the mercury it receives (as no statistically detected downward trend in the mercury data is observed).



**Figure 3-7. FT-HNMR of the July(top), August, and September SHT samples and the September 2018 scratch baseline solvent**

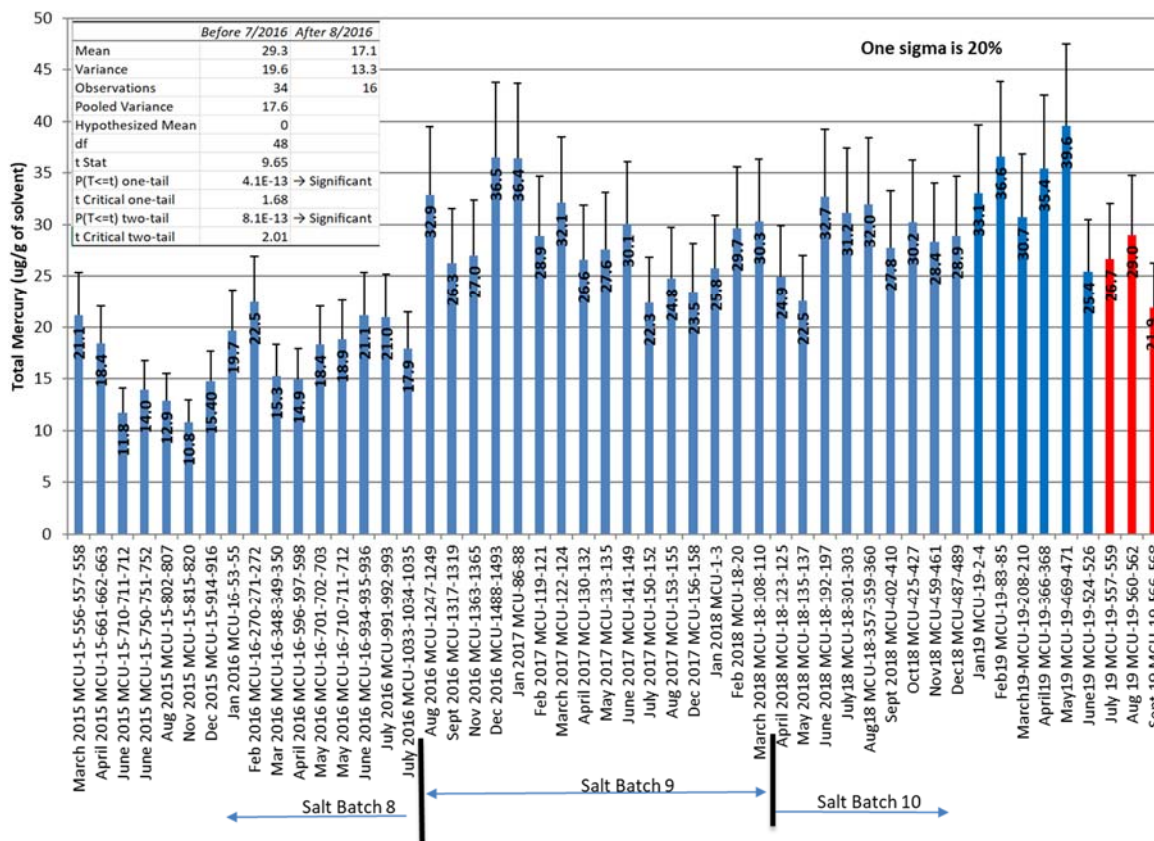


Figure 3-8. Total mercury in recent SHT samples.

#### 4.0 Conclusions

A trend summary of three sets of Solvent Hold Tank (SHT) monthly samples MCU-19-557-558-559(July), MCU-19-560-561-562 (August), and MCU-19-566-567-568 (September) are reported. Most of the conclusions are based on the September SHT sample (MCU-19-566-567-568). Analyses of the September SHT sample (MCU-19-566-567-568) indicated that the Modifier (Cs-7SB) and the Extractant (MaxCalix) concentrations were slightly below their nominal recommended concentrations (169,000 mg/L and 46,800 mg/L respectively) by 1% and 2% respectively but consistent with previously observed levels during normal operations. The Suppressor (*N,N,N'*-tris(3,7-dimethyloctyl)guanidine or TiDG) concentration has remained steady since the June 2019 measurement at 800 mg/L, which is above the minimum recommended concentration (479 mg/L).

The SemiVolatile Organic Analysis (SVOA) did not detect any impurities. However, the Fourier-Transformed Hydrogen Nuclear Magnetic Resonance (FT-HNMR) analysis detected presence of phthalates at a few ppm. The impurity concentration was highest in the August sample and consistently detected in the July and September samples (but always registered as a few ppm or less). Another impurity observed in the samples was mercury. Based on the September SHT sample, up to  $14 \pm 3$  microgram of mercury per mL of solvent was detected. The higher mercury concentration in the solvent (as determined in the last three-monthly samples) is possibly due to the higher mercury concentration in Salt Batches 9 and 10.

The gamma concentration ( $\sim 3.03E4$  dpm/mL) measured in the September 2019 SHT samples was consistent with previous values observed when MCU was idle (for example, between February and August 2017).

Higher values were seen when MCU was processing liquid waste.

Statistical analysis of the different analytical methods detected a bias between the FT-HNMR and High-Performance Liquid Chromatography (HPLC) methods when measuring the MaxCalix and Modifier concentrations; the FT-HNMR gave a higher concentration possibly due to peak overlapping in the measured data.

The laboratory will continue to monitor the quality of the solvent for any new impurities or degradation of the solvent components.

## 5.0 References

- <sup>1</sup> T. B. Peters, A. L. Washington, II, F. F. Fondeur, “Task Technical and Quality Assurance Plan for Routine Samples in Support of ARP and MCU”, SRNL-RP-2013-00536, Rev. 2, January 2019.
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### Appendix A. Average Modifier concentration in the SHT samples

Sample	Weighted Average (mg/L)	HPLC (mg/L)	FT-HNMR (mg/L)	Density (mg/L)
Jan 2017 MCU-88-89	1.70E+05	1.65E+05	1.70E+05	1.70E+05
Feb 2017 MCU-119-121	1.59E+05	1.55E+05	1.51E+05	1.60E+05
March 2017 MCU-122-124	1.52E+05	1.50E+05	1.51E+05	1.52E+05
April 2017 MCU-130-132	1.58E+05	1.58E+05	1.59E+05	1.58E+05
May 2017 MCU-133-135	1.58E+05	1.56E+05	1.57E+05	1.58E+05
June 2017 MCU-141-149	1.61E+05	1.57E+05	1.59E+05	1.62E+05
July 2017 MCU-150-152	1.63E+05	1.56E+05	1.57E+05	1.64E+05
August 2017 MCU-153-154	1.64E+05	1.58E+05	1.59E+05	1.65E+05
Dec 2017 MCU-156-158	1.72E+05	1.63E+05	1.69E+05	1.73E+05
Jan 2018 MCU-1-2-3	1.76E+05	1.72E+05	1.73E+05	1.77E+05
Feb 2018 MCU-18-20	1.77E+05	1.77E+05	1.72E+05	1.78E+05
March 2018 MCU-108-110	1.75E+05	1.78E+05	1.72E+05	1.75E+05
April 2018 MCU-18-123-125	1.74E+05	1.66E+05	1.68E+05	1.75E+05
May 2018 MCU-18-135-137	1.59E+05	1.59E+05	1.53E+05	1.60E+05
June 2018 MCU-18-192-197	1.70E+05	1.68E+05	1.64E+05	1.71E+05
Jul 18 MCU-301-303	1.65E+05	1.64E+05	1.61E+05	1.66E+05
Aug 18 MCU-357-359-360	1.60E+05	1.54E+05	1.49E+05	1.62E+05
Sept 18 MCU-402-410	1.58E+05	1.50E+05	1.49E+05	1.60E+05
Oct 18 MCU-425-427	1.60E+05	1.40E+05	1.61E+05	1.62E+05
Nov 18 MCU-459-461-462	1.59E+05	1.52E+05	1.58E+05	1.60E+05
Dec 18 MCU-487-489	1.63E+05	1.47E+05	1.64E+05	1.65E+05
Jan 19 MCU-19-2-3-4	1.67E+05	1.51E+05	1.67E+05	1.69E+05
Feb 19 MCU-19-83-84-85	1.66E+05	1.50E+05	1.69E+05	1.68E+05
March 19 MCU-19-208-210	1.67E+05	1.48E+05	1.59E+05	1.70E+05
March 19 MCU-19-138-140 Trim	1.67E+05	1.48E+05	1.55E+05	1.70E+05
April 19 MCU-19-366-368	1.66E+05	1.47E+05	1.57E+05	1.69E+05
May 19 MCU-19-469-471-472	1.68E+05	1.55E+05	1.59E+05	1.70E+05
June 19 MCU-19-524-526	1.62E+05	1.55E+05	1.61E+05	1.63E+05
July 19 MCU-19-557-559	1.63E+05	1.47E+05	1.57E+05	1.66E+05
Aug 19 MCU-19-560-562	1.65E+05	1.52E+05	1.63E+05	1.67E+05
Sept 19 MCU-19-566-568	1.67E+05	1.58E+05	1.61E+05	1.69E+05

### Viscosity and surface tension of the SHT samples

SHT sample (Rheology)	Viscosity (cP)	Surface Tension (Dyne/cm)	Control Viscosity (cP)	Control Surface Tension (dyne/cm)
Dec17 MCU-17-156-158	3.4	23.5	3.10	22.4
Jan18 MCU-18-1-3	3.3	23.5	3.08	22.9
Feb18 MCU-18-18-20	3.3	23.4	3.08	23.4
March18 MCU-18-108-110	3.3	23	3.28	22.6
April 18 MCU-18-123-125	3.5	24	3.47	22.9
May 18 MCU-18-135-137	3.4	23.6	3.60	23.7
June 18 MCU-18-192-197	3.6	23.8	3.60	23.6
July18 MCU-18-301-303	3.2	24.4	4.00	24.0
Aug18 MCU-18-357-359-360	3.1	23.8	3.16	24.0
Sept18 MCU-18-402-410	3.1	23.3	3.11	23.2
Oct18 MCU-18-425-427	3.1	23.5	3.15	23.0
Nov18 MCU-18-459-461-462	2.8	22.4	3.12	22.5
Dec18 MCU-18-487-489	3.2	23.6	3.17	23.8
Jan19 MCU-19-2-3-4	3.3	22.3	3.17	23.7
Feb19 MCU-19-83-84-85	3.4	23.4	3.20	23.2
March19 MCU-19-208-210	3.2	23.3	3.18	22.9
March19 MCU-19-138-140Trim	3.3	23.2	3.21	23.4
April19 MCU-19-366-368	3.2	23.9	3.17	23.3
May19 MCU-19-469-471-472	3.4	23.4	3.19	22.9
June19 MCU-19-524-526	3.3	23.3	3.21	23.4
July19 MCU-19-557-559	3.3	23.4	3.19	23.4
Aug19 MCU-19-560-562	3.3	22.9	3.19	23.4
Sept19 MCU-19-566-568	3.4	22.9	3.20	22.9



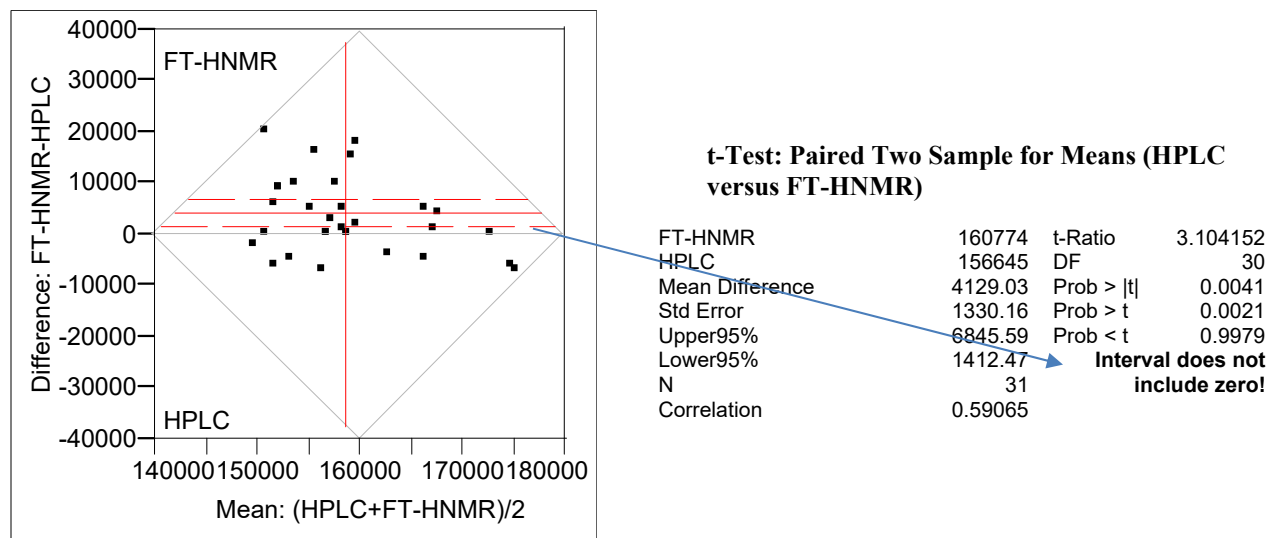
**Average MaxCalix concentration in the SHT samples**

SHT Sample (MaxCalix)	HPLC (mg/L)	HNMR (mg/L)	Average (mg/L)
Jan 2017 MCU-17-86-88	4.82E+04	49300	48597
Feb 2017 MCU-17-119-121	4.30E+04	43700	43255
March17 MCU-17-122-124	4.33E+04	44300	43661
April17 MCU-17-130-132	4.41E+04	46000	44769
May17 MCU-17-133-135	4.39E+04	44700	44191
June17 MCU-17-141-149	4.42E+04	45800	44768
July17 MCU-17-150-152	4.58E+04	45600	45725
Aug17 MCU-17-153-155	4.65E+04	46000	46312
Dec17 MCU-17-156-158	4.61E+04	46900	46391
Jan18 MCU-18-1-3	4.64E+04	48300	47071
Feb18 MCU-18-18-20	4.83E+04	49600	48767
March18 MCU-18-108-110	4.89E+04	48100	48596
April2018 MCU-18-123-125	4.84E+04	48100	48288
May18 MCU-18-135-137	4.63E+04	44200	45473
June18 MCU-18-192-197	4.67E+04	47100	46847
July18-301-303	4.50E+04	44400	44773
Aug18-357-359-360	4.52E+04	48400	46289
Sept18-402-410	4.28E+04	40700	41969
Oct18 MCU-18-425-427	4.52E+04	48400	46289
Nov18 MCU-18-459-461-462	4.18E+04	47600	43617
Dec18 MCU-18-487-489	4.24E+04	48500	44300
Jan19 MCU-19-2-3-4	4.48E+04	47600	45763
Feb19 MCU-19-83-84-85	4.49E+04	48800	46202
March19 MCU-19-208-210	4.42E+04	48800	45703
March19 MCU-19-138-140Trim	4.34E+04	48800	45122
April19 MCU-19-366-368	4.22E+04	50700	44671
May19 MCU-19-469-471-472	4.45E+04	53300	47070
June19 MCU-19-524-526	4.32E+04	53300	46027
July19 MCU-19-557-559	4.36E+04	53300	46351
Aug19 MCU-19-560-562	4.41E+04	46200	44836
Sept19 MCU-19-566-568	4.40E+04	50700	46065

**Mercury concentration measured by the DMA Method**

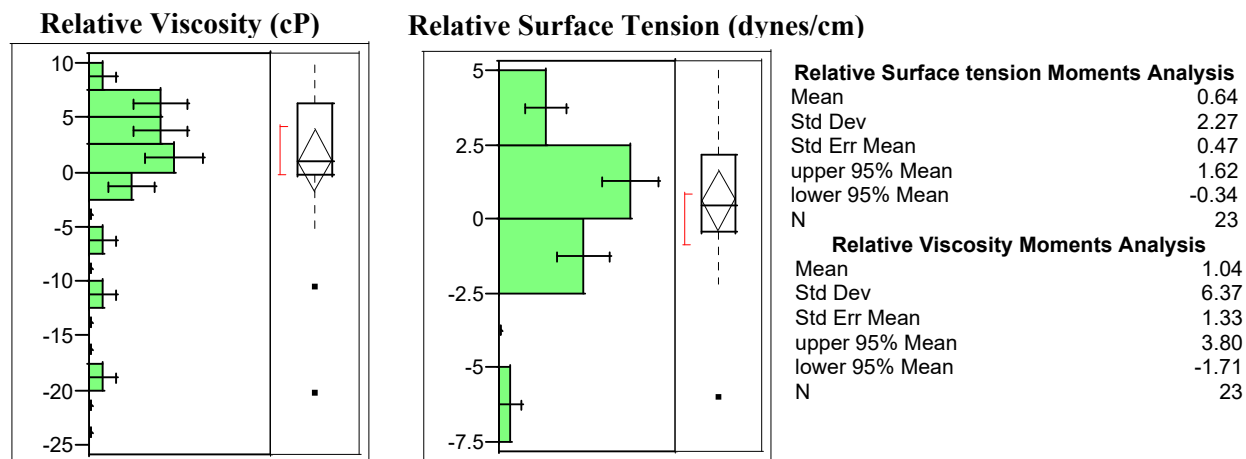
SHT Sample (mercury)	DMA (ug/g)
April 2018 MCU-18-123-125	24.40
May 2018 MCU-18-135-137	19.90
June 2018 MCU-18-192-197	33.20
July18 MCU-18-301-303	28.60
Aug18 MCU-18-357-359-360	26.20
Sept 2018 MCU-402-410	26.70
Oct18 MCU-425-427	28.00
Nov18 MCU-459-461	25.90
Dec18 MCU-487-489	25.80
Jan19 MCU-19-2-4	25.10
Feb19 MCU-19-83-85	38.50
March19-MCU-19-208-210	29.00
April19 MCU-19-366-368	33.70
May19 MCU-19-469-471-472	37.40
June19 MCU-19-524-526	25.40
July 19 MCU-19-557-559	26.70
Aug 19 MCU-19-560-562	29.00
Sept 19 MCU-19-566-568	21.90

Figure A-1 shows the difference between the HPLC and the FT-HNMR results for the Modifier as a function of their average results. The confidence interval does not contain the number zero. Therefore, there is a statistical difference between the methods



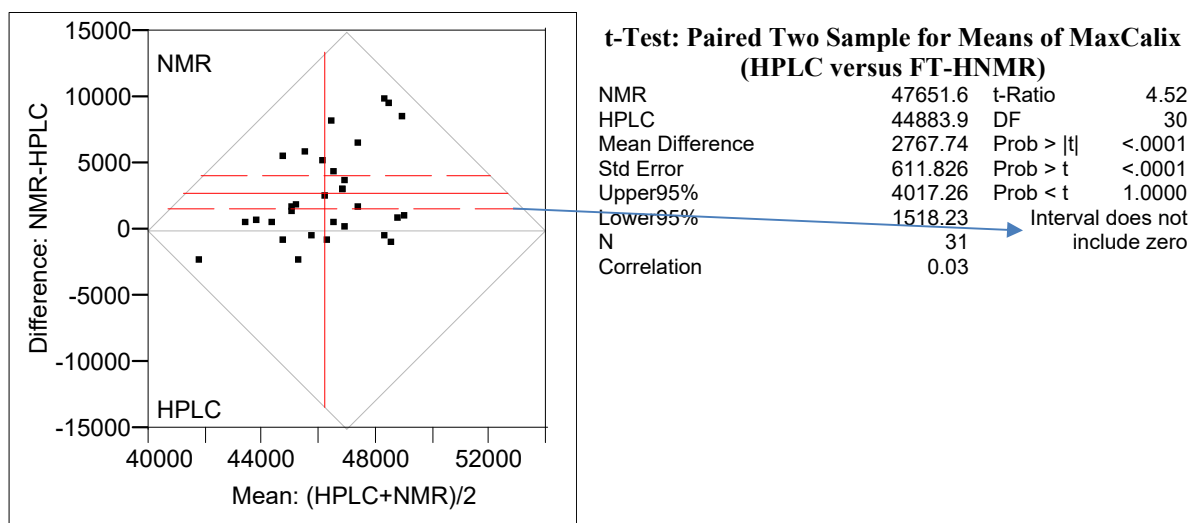
**Figure A-1. A comparison of the HPLC and FT-HNMR methods for measuring the Modifier**

Figure A-2 shows the 95% confidence interval (CI) of the viscosity and surface tension of the SHT samples relative to the control. The 95% CI of the relative viscosity measurements contain the zero number (indicating no difference with the control) similarly the 95% CI of the relative surface tension does contain the number zero indicating no bias.



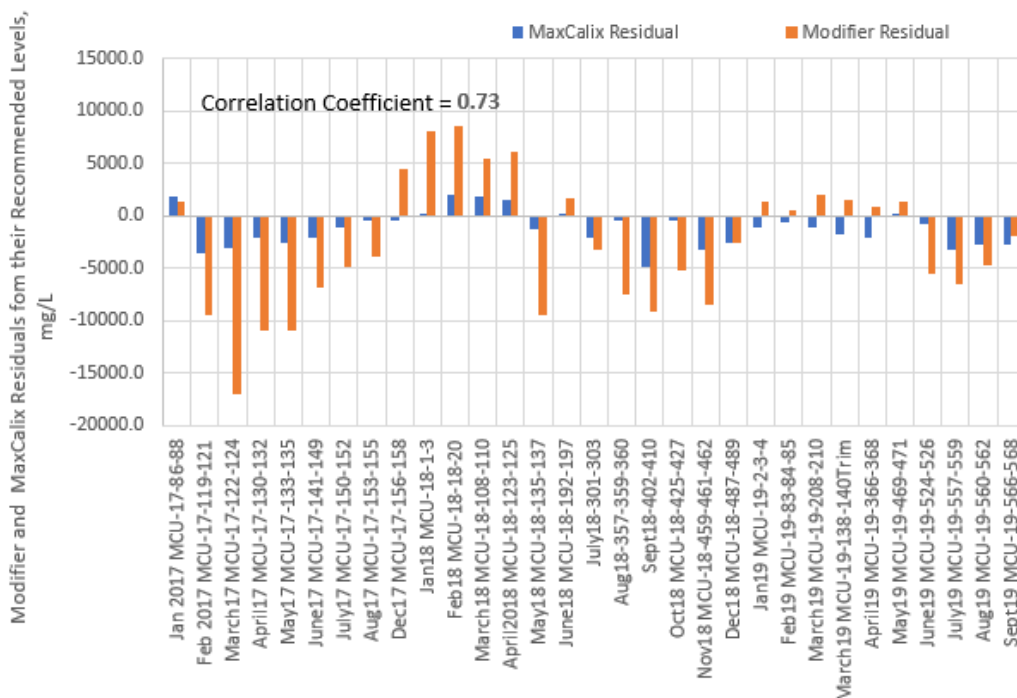
**Figure A-2. Descriptive analysis of the relative difference (left is viscosity and the right is surface tension) between the SHT samples and the September 2018 scratch control sample.**

Figure A-3 shows the 95% CI of the difference between the HPLC and FT-HNMR results for MaxCalix and its shows the 95% confidence interval of the method's difference does not include zero indicate a positive bias in the FT-HNMR method.



**Figure A-3. A comparison of the HPLC and HNMR analytical methods for measuring MaxCalix. The ordinate is the subtraction of the two methods and the coordinate is their average**

Figure A-4 shows the residuals (relative to their recommended levels) of the Modifier and MaxCalix and it shows a strong correlation between the two measurements of two solvent components.



**Figure A-4. MaxCalix and Modifier residuals from their recommended levels**

## Appendix B: Minimum recommended level for TiDG in NGS-CSSX solvent

Re: Dr. Moyer, if you have the time , we have a question for you .

Moyer, Bruce A. to: fernando.fondeur@srnl.doe.gov 06/24/2014 12:36 AM

Hi Fernando,

Our laboratory tests with simulants indicate that the solvent strips adequately even if the TiDG concentration falls to 10% of its nominal value of 3 mM. My recommendation is to trim when the TiDG gets to 1 mM. That should give some margin.

That said, our study of TiDG decomposition rate is making me rethink the nominal value of 3 mM TiDG. The rate data show that the decomposition slows down as the TiDG concentration decreases. The decomposition is rather fast at

3 mM. Since you want to minimize organics going to salt stone and DWPF, it might be advisable to trim only up to 2 mM and operate in the range 1-2 mM TiDG. With more experience in operating NGS in the MCU, that range might eventually be reduced even further.

Thanks for sharing your analytical data. It would be good to see the X-axis as time, though, but I suspect you are showing data back to December. That means the TiDG has not decomposed as fast as I would have thought based on our recent study. Perhaps the cold weather has been helpful in that regard. The TiDG concentration will bear careful watching in the warm summer months, as decomposition definitely speeds up with increasing temperature.

Bruce

From: "fernando.fondeur@srnl.doe.gov<mailto:fernando.fondeur@srnl.doe.gov>"  
<fernando.fondeur@srnl.doe.gov<mailto:fernando.fondeur@srnl.doe.gov>> Date: Monday, June 23, 2014 3:49 PM

To: Bruce Moyer <moyerba@ornl.gov<mailto:moyerba@ornl.gov>>

Subject: Dr. Moyer, if you have the time, we have a question for you. Dr. Moyer:

Please pardon my numerous e-mails on this topic. Thank you for your last reply on the effect of high [K] and low temperature on third phase formation. But we need your advice. The TiDG concentration, since the implementation of NGS-CSSX blend, is around 750 mg/L (as you may see below) which is well below the nominal concentration of 1,550 mg/L. If this condition continues (that is without trimming more TiDG), is the solvent susceptible to soaps affecting the stripping? From your extensive experience on this, do you happen to know what is the lowest level of TiDG the solvent can have without any deleterious effect on mass transfer and/or hydrodynamics in the stripping stages? Thanks.

Sincerely,

Fernando Fondeur

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