INTEROFFICE MEMORANDUM

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Recommended Modeling Inputs for Evaluating Cement Free Saltstone, Based on Down Selection Report and Other Literature

Purpose

The purpose of this memorandum is to provide a summary of recommended chemical and material properties to use as model inputs for evaluating cement-free saltstone.

Background

Decontaminated salt solution, processed from tank farm waste, is mixed with dry grout feeds to create a waste form called saltstone. After mixing, the wet saltstone grout slurry is pumped into saltstone disposal units (SDUs) at the Saltstone Disposal Facility (SDF). Once the slurry cures within the SDUs, saltstone becomes a solid, low permeability waste form designed to immobilize waste.

Disposal of saltstone within SDUs at the SDF is an ongoing activity and Saltstone Engineers are considering revising the formula for creating saltstone. The dry feeds in the current formula is comprised 45% blast furnace slag, 45% fly ash, and 10% cement, by weight. The proposed change excludes cement and instead uses 60% blast furnace slag and 40% fly ash, by weight. By eliminating cement from the mix, the Saltstone Production Facility (SPF) will be better able to support the increased rates for waste processing that are anticipated once the Salt Waste Processing Facility (SWPF) begins processing waste (SRR-CWDA-2020-00008).

Prior to employing the cement free formula for saltstone, an evaluation must be performed to ensure that the use of the material will not compromise the performance of the SDUs or invalidate conclusions of the SDF Performance Assessment (PA) (SRR-CWDA-2019-00001).

Summary of Analyses

Based on the analyses described within this document, no changes are recommended to any material properties except for those explicitly impacted by the changed batching quantities (see Table 17). Specifically, the particle density, dry bulk density, porosity, initial saturated hydraulic conductivity, effective diffusion coefficient, reducing capacity, Tc-99 solubility, and all Kd values shall remain unchanged relative to the values used in the 2019 SDF PA (SRR-CWDA-2019-00001). The following discussion provides the bases for these recommendations.

Analysis of Current Saltstone Mix

An analytical approach will be applied to the design mix specifications for the cement-free saltstone to develop values to use as recommended material properties for the cured waste form. Prior to doing this, the same analytical approach will be applied to the current saltstone mix in order to verify that the values developed through this analytical approach closely reflect the recommended material properties for saltstone (which were based on physical analyses of cured field-emplaced saltstone), as summarized in *Recommended Values for Cementitious Degradation Modeling to Support Future SDF Modeling* (SRR-CWDA-2018-00004).

The design specifications for the current saltstone mix are provided in Table 3.2-6 of the *Performance Assessment for the Saltstone Disposal Facility at the Savannah River Site* (SRR-CWDA-2019-00001), hereafter referred to as the SDF PA. The relevant specifications are provided here as Table 1. Specific gravity values for these material components have been added to this table. These values come from SDU construction specifications and analyses of the salt solution in the SPF Feed Tank (Tank 50).

Table 1: Current Saltstone Formulation

Material	Specific Gravity (Unitless) or Solid Phase Density (g/mL)	Dry Feed Weight Percent
Ordinary Portland Cement (Type II [a])	3.15 [c]	10
Blast Furnace Slag (Grade 100 or 120 [b])	2.89 [c]	45
Class F Fly Ash	2.25 [c]	45
Decontaminated Salt Solution (DSS)	1.234 [d]	N/A
Maximum Mass Water-to-Premix (WPM) Ratio = 0.6 [e]	N/A	N/A

Notes: Modified from SRR-CWDA-2019-00001, Table 3.2-6.

a) Type II Ordinary Portland Cement has moderate resistance to sulfate and slower strength gains than other types of cement.
b) Slag Grades are a measure of the “slag activity index” which roughly corresponds to a comparison of the average 28-day compressive strengths of slag-reference cement cubes versus slag-free reference cement cubes (SRR-CWDA-2015-00057).
c) Specific Gravity values for dry feeds are based on values from C-SPP-Z-00015, Rev. 3, Attachment 03300-B.
d) For the DSS, the specific gravity is based on the mean DSS density from 2Q14 to 2Q19 (see Table 2).
e) This this the designed maximum WPM ratio. Operationally, a limit of 0.59 is applied to the feed per Attachment 6 of the *Saltstone Production Facility Operating Manual* (SW24.6-SPF, Section 4.1). This ensures that the maximum design value of 0.6 will not be exceeded.

Assuming that the particle densities of the premix dry feeds are equivalent to the specific gravities in Table 1, the density of the combined dry feeds can be estimated as:

$$\rho_{DF} = \frac{1}{[(wt\%_{BFS\ in\ DF}/\rho_{BFS}) + (wt\%_{FA\ in\ DF}/\rho_{FA}) + (wt\%_{OPC\ in\ DF}/\rho_{OPC})]} \qquad \text{Eq. 1}$$

Where:

ρ_{DF} is the estimated density (g/mL) of the dry feeds,

ρ_{BFS} is the solid phase or particle density (g/mL) of the blast furnace slag (BFS),

ρ_{FA} is the solid phase or particle density (g/mL) of the fly ash (FA),

ρ_{OPC} is the solid phase or particle density (g/mL) of the Ordinary Portland Cement (OPC),

$wt\%_{BFS\ in\ DF}$ is the weight-percent of the premix dry feeds from BFS,

$wt\%_{FA\ in\ DF}$ is the weight-percent of the premix dry feeds from FA, and

$wt\%_{OPC\ in\ DF}$ is the weight-percent of the premix dry feeds from OPC.

The resulting estimated density of the combined dry feeds is 2.581 g/mL. Using this estimate, the quantity (in g) for each component per unit volume (in mL) of the dry feeds can be estimated. It is estimated (via Equations 2 through 4, below) that for each mL of dry feeds: 1.161 g is from blast furnace slag (2.581 g × 0.45 = 1.161 g), 1.161 g is from fly ash (2.581 g × 0.45 = 1.161 g), and 0.2581 g is from Ordinary Portland Cement (2.581 g × 0.10 = 0.2581 g). These values provide a combined total of 2.581 g/mL.

For blast furnace slag (BFS):

$$Q_{DF,BFS} = \rho_{DF} \times wt\%_{BFS\ in\ DF} \qquad \text{Eq. 2}$$

Where:

$Q_{DF,BFS}$ is the quantity (g) of BFS per unit volume (mL) of dry feeds,

ρ_{DF} is the estimated density (g/mL) of the dry feeds (from Eq. 1), and

$wt\%_{BFS\ in\ DF}$ is the weight-percent of the premix dry feeds from BFS (from Table 1).

For fly ash (FA):

$$Q_{DF,FA} = \rho_{DF} \times wt\%_{FA\ in\ DF} \quad \text{Eq. 3}$$

Where:

$Q_{DF,FA}$ is the quantity (g) of FA per unit volume (mL) of dry feeds,

ρ_{DF} is the estimated density (g/mL) of the dry feeds (from Eq. 1), and

$wt\%_{FA\ in\ DF}$ is the weight-percent of the premix dry feeds from FA (from Table 1).

For Ordinary Portland Cement (OPC):

$$Q_{DF,OPC} = \rho_{DF} \times wt\%_{OPC\ in\ DF} \quad \text{Eq. 4}$$

Where:

$Q_{DF,OPC}$ is the quantity (g) of OPC per unit volume (mL) of dry feeds,

ρ_{DF} is the estimated density (g/mL) of the dry feeds (from Eq. 1), and

$wt\%_{OPC\ in\ DF}$ is the weight-percent of the premix dry feeds from OPC (from Table 1).

Next, as indicated in the notes to Table 1, the DSS specific gravity is assumed based on the mean DSS density (1.234 g/mL) from 2Q14 to 2Q19. The values used to find this mean are provided in Table 2. Table 2 also shows the volume ratio of DSS-to-saltstone grout slurry, and the weight-percent (wt%) of solids in the DSS. These values are used as described below.

Table 2: Data from Quarterly Saltstone Processing Reports

Period	Volume Ratio: DSS-to-Grout	Wt % Solids in DSS	DSS Density (g/mL)	Reference
2Q19	0.626	23.66	1.2157	X-CLC-Z-00089, Rev. 0
1Q19	0.632	26.90	1.2339	X-CLC-Z-00088, Rev. 0
4Q18	0.632	26.75	1.2335	X-CLC-Z-00087, Rev. 1
3Q18	0.633	27.26	1.2354	X-CLC-Z-00086, Rev. 1
2Q18	0.632	27.22	1.2368	X-CLC-Z-00085, Rev. 1
1Q18	0.633	27.47	1.2369	X-CLC-Z-00084, Rev. 0
3Q17	0.6327	27.37	1.2369	X-CLC-Z-00083, Rev. 0
2Q17	0.6349	27.43	1.2333	X-CLC-Z-00082, Rev. 0
1Q17	0.6329	27.16	1.2347	X-CLC-Z-00081, Rev. 0
4Q16	0.6395	28.27	1.2322	X-CLC-Z-00080, Rev. 0
3Q16	0.6403	29.15	1.2390	X-CLC-Z-00078, Rev. 1
2Q16	0.634	27.39	1.2342	X-CLC-Z-00077, Rev. 0
1Q16	0.632	26.69	1.2319	X-CLC-Z-00076, Rev. 0
4Q15	0.638	28.25	1.2353	X-CLC-Z-00074, Rev. 0
3Q15	0.636	27.74	1.2334	X-CLC-Z-00073, Rev. 0
2Q15	0.637	27.87	1.2336	X-CLC-Z-00072, Rev. 0
1Q15	0.634	27.10	1.2320	X-CLC-Z-00071, Rev. 0
3Q14	0.628	27.86	1.2363	X-CLC-Z-00070, Rev. 0
2Q14	0.626	28.48	1.2462	X-CLC-Z-00069, Rev. 0
Mean	**0.633**	**27.37**	**1.234**	**This Document**

Table 1 indicated a maximum mass ratio of the water-to-premix components is 0.60. However, because the water is introduced into the saltstone slurry through DSS, and because the DSS has variable compositions (Table 2), the DSS quantities must be adjusted to ensure that this maximum mass water-to-premix ratio of 0.60 will not be exceeded. The *Saltstone Production Facility Operating Manual* (SW24.6-SPF, Section 4.1), Attachment 6, is used to develop the processing parameters for disposal operations. Specifically, the attachment provides instructions for converting the WPM ratio into a salt solution weight percent (functionally equivalent to a DSS-to-slurry ratio). The processing calculations from this procedure are shown here as Equations 5, 6, and 7. Note that the procedure assumes a WPM ratio of 0.59 instead of 0.60 to ensure that the maximum mass ratio will not be exceeded.

First, the weight percent of water from DSS in the saltstone grout slurry is determined:

$$wt\%_{DSS,H2O\ in\ slurry} = \frac{1}{[1+(wt\%_{solids\ in\ DSS}/(100\%-wt\%_{solids\ in\ DSS}))+(1/0.59)]} \times 100\% \qquad \text{Eq. 5}$$

Where:

$wt\%_{DSS,H2O\ in\ slurry}$ is the weight-percent of water from DSS in the saltstone grout slurry,

$wt\%_{solids\ in\ DSS}$ is the weight-percent of the solids in the DSS (from Table 2), and

0.59 is the assumed WPM ratio as applied in SW24.6-SPF.

Next, the weight-percent of the solids in the DSS are converted from weight-percent in the DSS into weight percent in the saltstone grout slurry:

$$wt\%_{DSS,solids\ in\ slurry} = \frac{wt\%_{solids\ in\ DSS}}{(100 - wt\%_{solids\ in\ DSS})} \times wt\%_{DSS,H2O\ in\ slurry} \qquad \text{Eq. 6}$$

Where:

$wt\%_{DSS,solids\ in\ slurry}$ is the weight-percent of solids from DSS in the saltstone grout slurry,

$wt\%_{solids\ in\ DSS}$ is the weight-percent of solids in the DSS (from Table 2), and

$wt\%_{DSS,H2O\ in\ slurry}$ is the weight-percent of water from DSS in the saltstone grout slurry (from Eq. 5).

Finally, the maximum operational weight-percent of DSS in the saltstone grout slurry is estimated:

$$wt\%_{DSS\ in\ slurry} = wt\%_{DSS,H2O\ in\ slurry} + wt\%_{DSS,solids\ in\ slurry} \qquad \text{Eq. 7}$$

Where:

$wt\%_{DSS\ in\ slurry}$ is the weight-percent of DSS (water and solids) in the saltstone grout slurry,

$wt\%_{DSS,H2O\ in\ slurry}$ is the weight-percent of water from DSS in the saltstone grout slurry (from Eq. 5), and

$wt\%_{DSS,solids\ in\ slurry}$ is the weight-percent of solids from DSS in the saltstone grout slurry (from Eq. 6).

From these procedure-based equations (Eq. 5, Eq. 6, and Eq. 7) the weight-percent of premix dry feeds in the saltstone grout slurry can also be determined:

$$wt\%_{DF\ in\ slurry} = 100\% - wt\%_{DSS\ in\ slurry} \qquad \text{Eq. 8}$$

Where:

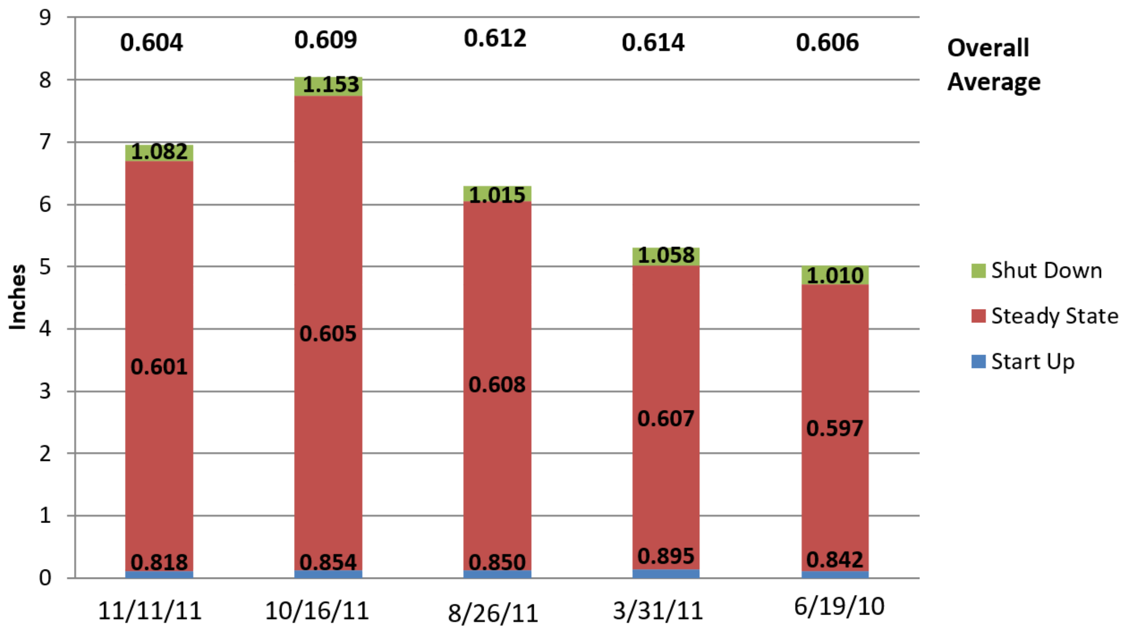
$wt\%_{DF\ in\ slurry}$ is the weight-percent of premix dry feeds in the saltstone grout slurry, and

$wt\%_{DSS\ in\ slurry}$ is the weight-percent of DSS (water and solids) in the saltstone grout slurry (from Eq. 7).

These values are based on processing feeds through the Saltstone Production Facility (SPF); however, they do not account for additional process water added before and after production runs. Specifically, throughout waste disposal operations at the SPF, the system components (mixer, grout hopper, grout pump, and piping) are all periodically flushed with water to mitigate process upsets. [SRNL-STI-2012-00558] The introduction of this extra flush water increases the total volume of the material being disposed of within the Saltstone Disposal Units, while decreasing the density of the final saltstone grout slurry. Therefore, it is appropriate to correct these values to account for the additional flush water.

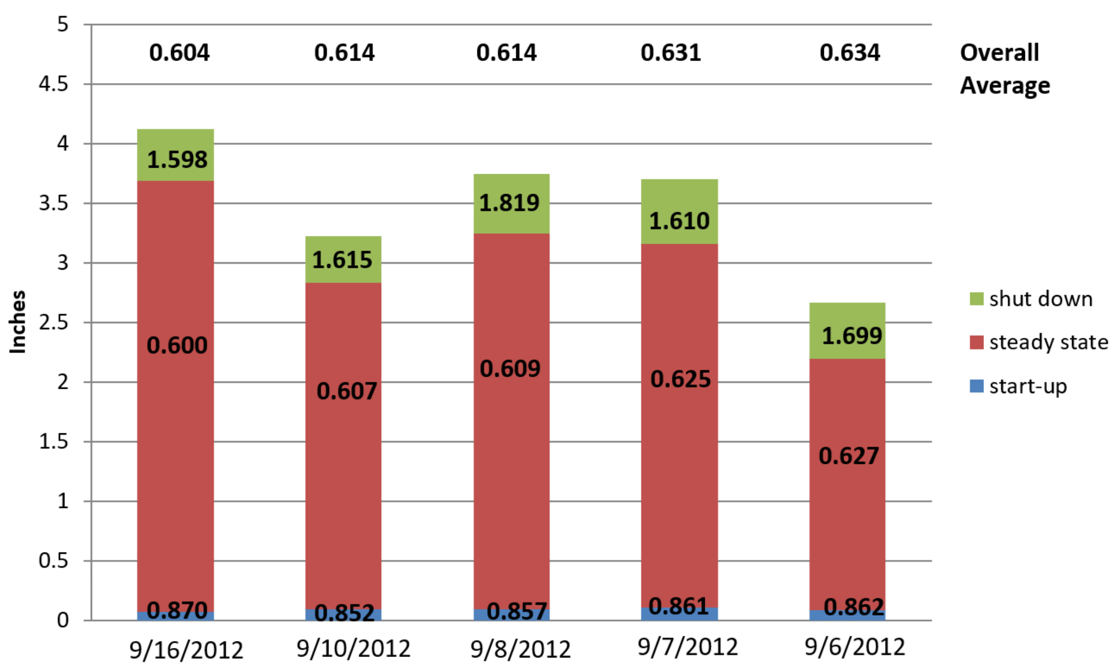
An analysis of the saltstone WPM ratios from actual processing data shows that the WPM ratios can vary between a range of 0.604 and 0.634 (see Figures 1 and 2, reproduced from X-CLC-Z-00050). Based on observation of these values, relative to the assumed value of 0.59 (from Attachment 6 of SW24.6-SPF, Section 4.1), a 4% increase in the WPM ratio shall be assumed (Eq. 9). This is effectively an increase from a WPM ratio of 0.59 to 0.614 to address the added process water. The results of Equations 5 through 9 are provided in Table 3.

Figure 1: Water-to-Premix Ratio for Production Runs to SDU 4



[Source: X-CLC-Z-00050, Fig. 2]

Figure 2: Water-to-Premix Ratio for Production Runs to SDU 2B



[Source: X-CLC-Z-00050, Fig. 3]

$$wt\%_{TOTAL,H2O\ in\ slurry} = wt\%_{DSS,H2O\ in\ slurry} + (wt\%_{DSS,H2O\ in\ slurry} \times 4\%) \qquad \text{Eq. 9}$$

Where:

$wt\%_{TOTAL,H2O\ in\ slurry}$ is the total weight-percent of water from both DSS and flush water in the saltstone grout slurry,

$wt\%_{DSS,H2O\ in\ slurry}$ is the weight-percent of water from DSS in the saltstone grout slurry (from Eq. 5) based on an assumed WPM ratio of 0.59, and

4% is an assumed correction factor for the WPM ratio based on interpretation of Figures 1 and 2.

Table 3: Estimated Weight-Percents in Saltstone Grout Slurry

Period	DSS Water Wt% per SW24.6-SPF-4.1, Att 6	DSS Solids Wt% per SW24.6-SPF-4.1, Att 6	Total DSS Wt% per SW24.6-SPF-4.1, Att 6	Wt% of Dry Feeds in Saltstone Grout Slurry	Increased Water Wt% to Account for process water
	(Eq. 5)	(Eq. 6)	(Eq. 7)	(Eq. 8)	(Eq. 9)
2Q19	33.28	10.31	43.59	56.41	34.61
1Q19	32.65	12.01	44.66	55.34	33.95
4Q18	32.68	11.93	44.61	55.39	33.99
3Q18	32.58	12.21	44.79	55.21	33.88
2Q18	32.58	12.19	44.77	55.23	33.89
1Q18	32.53	12.32	44.86	55.14	33.84
3Q17	32.55	12.27	44.82	55.18	33.86
2Q17	32.54	12.30	44.84	55.16	33.84
1Q17	32.60	12.15	44.75	55.25	33.90
4Q16	32.37	12.76	45.13	54.87	33.67
3Q16	32.19	13.24	45.44	54.56	33.48
2Q16	32.55	12.28	44.83	55.17	33.85
1Q16	32.69	11.90	44.59	55.41	34.00
4Q15	32.38	12.75	45.12	54.88	33.67
3Q15	32.48	12.47	44.95	55.05	33.78
2Q15	32.45	12.54	44.99	55.01	33.75
1Q15	32.61	12.12	44.73	55.27	33.91
3Q14	32.46	12.53	44.99	55.01	33.75
2Q14	32.33	12.87	45.20	54.80	33.62
Mean	**32.55**	**12.27**	**44.83**	**55.17**	**33.86**

The sum of the results for Eq. 5, Eq. 6, and Eq. 8 add up to 100% as this is the total planned batching estimate. However, because Eq. 9 increases the amount of water to account for additional flush water, the sum of the results of Eq. 9, Eq. 6, and Eq. 8 slightly exceed 100% because the total weight of the processed material is greater than the total planned batching estimate. Therefore, the weight-percent values in Table 3 need to be adjusted to account for this difference in the totals.

To perform this adjustment, the weight-percent overage is calculated:

$$wt\%_{Overage} = wt\%_{DSS,solids\ in\ slurry} + wt\%_{DF\ in\ slurry} + wt\%_{TOTAL,H2O\ in\ slurry} \qquad \text{Eq. 10}$$

Where:

$wt\%_{Overage}$ is the total unadjusted weight-percent from summing each of the following saltstone grout slurry components:

$wt\%_{DSS,solids\ in\ slurry}$ is the weight-percent of solids from DSS in the saltstone grout slurry (from Eq. 6),

$wt\%_{DF\ in\ slurry}$ is the weight-percent of premix dry feeds in the saltstone grout slurry (from Eq. 8), and

$wt\%_{TOTAL,H2O\ in\ slurry}$ is the total weight-percent of water from both DSS and flush water in the saltstone grout slurry (from Eq. 9).

Next, the weight-percents for each component are divided by the weight percent overage from Equation 10 as an adjustment such that the sum of each of the components equals 100%.

$$Adj\_wt\%_{DSS,solids\ in\ slurry} = \frac{wt\%_{DSS,solids\ in\ slurry}}{wt\%_{Overage}} \times 100\% \qquad \text{Eq. 11}$$

Where:

$Adj\_wt\%_{DSS,solids\ in\ slurry}$ is the adjusted weight-percent of solids from DSS in the saltstone grout slurry accounting for the total mass from saltstone processing,

$wt\%_{Overage}$ is the total unadjusted weight-percent from summing each of the saltstone grout slurry components (from Eq. 10), and

$wt\%_{DSS,solids\ in\ slurry}$ is the weight-percent of solids from DSS in the saltstone grout slurry (from Eq. 6).

And

$$Adj\_wt\%_{DF\ in\ slurry} = \frac{wt\%_{DF\ in\ slurry}}{wt\%_{Overage}} \times 100\% \qquad \text{Eq. 12}$$

Where:

$Adj\_wt\%_{DF\ in\ slurry}$ is the adjusted weight-percent of premix dry feeds in the saltstone grout slurry accounting for the total mass from saltstone processing,

$wt\%_{Overage}$ is the total unadjusted weight-percent from summing each of the saltstone grout slurry components (from Eq. 10), and

$wt\%_{DF\ in\ slurry}$ is the weight-percent of premix dry feeds in the saltstone grout slurry (from Eq. 8).

And

$$Adj\_wt\%_{TOTAL,H2O\ in\ slurry} = \frac{wt\%_{TOTAL,H2O\ in\ slurry}}{wt\%_{Overage}} \times 100\% \quad \text{Eq. 13}$$

Where:

$Adj\_wt\%_{TOTAL,H2O\ in\ slurry}$ is the adjusted total weight-percent of water from both DSS and flush water in the saltstone grout slurry accounting for the total mass from saltstone processing,

$wt\%_{Overage}$ is the total unadjusted weight-percent from summing each of the saltstone grout slurry components (from Eq. 10), and

$wt\%_{TOTAL,H2O\ in\ slurry}$ is the total weight-percent of water from both DSS and flush water in the saltstone grout slurry (from Eq. 9).

Now, the sum of weight-percents from the adjusted DSS solids, the adjusted premix dry feeds, and the adjusted total water is now 100%:

$$Adj\_wt\%_{TOTAL\ in\ slurry} = Adj\_wt\%_{DSS,solids\ in\ slurry} + Adj\_wt\%_{DF\ in\ slurry} + Adj\_wt\%_{TOTAL,H2O\ in\ slurry} \quad \text{Eq. 14}$$

Where:

$Adj\_wt\%_{TOTAL\ in\ slurry}$ is the total adjusted weight-percent from summing each of the following saltstone grout slurry components:

$Adj\_wt\%_{DSS,solids\ in\ slurry}$ is the adjusted weight-percent of solids from DSS in the saltstone grout slurry (from Eq. 11),

$Adj\_wt\%_{DF\ in\ slurry}$ is the adjusted weight-percent of premix dry feeds in the saltstone grout slurry (from Eq. 12), and

$Adj\_wt\%_{TOTAL,H2O\ in\ slurry}$ is the adjusted total weight-percent of water from both DSS and flush water in the saltstone grout slurry (from Eq. 13).

The resulting values from Equations 10 through 14 are provided in Table 4.

Table 4: Estimated Weight-Percents in Saltstone Grout Slurry

Period	Overage (Adjusted/ Unadjusted)	Final Adjusted DSS Solids Wt percent	Final Adjusted Dry Feeds Wt percent	Final Adjusted Total Water (DSS + Flush) Wt percent	Final Adjusted Total Wt percent
	(Eq. 10)	(Eq. 11)	(Eq. 12)	(Eq. 13)	(Eq. 14)
2Q19	101.33	10.18	55.67	34.16	100.0
1Q19	101.31	11.86	54.62	33.52	100.0
4Q18	101.31	11.78	54.67	33.55	100.0
3Q18	101.30	12.05	54.50	33.44	100.0
2Q18	101.30	12.03	54.52	33.45	100.0
1Q18	101.30	12.16	54.43	33.40	100.0
3Q17	101.30	12.11	54.47	33.42	100.0
2Q17	101.30	12.14	54.45	33.41	100.0
1Q17	101.30	12.00	54.54	33.46	100.0
4Q16	101.29	12.60	54.17	33.24	100.0
3Q16	101.29	13.08	53.87	33.05	100.0
2Q16	101.30	12.12	54.46	33.42	100.0
1Q16	101.31	11.75	54.69	33.56	100.0
4Q15	101.30	12.58	54.17	33.24	100.0
3Q15	101.30	12.31	54.34	33.35	100.0
2Q15	101.30	12.38	54.30	33.32	100.0
1Q15	101.30	11.97	54.56	33.48	100.0
3Q14	101.30	12.37	54.30	33.32	100.0
2Q14	101.29	12.71	54.10	33.19	100.0
Mean	**101.3**	**12.11**	**54.47**	**33.42**	**100**

It is also helpful to determine the adjusted weight-percents from each of the two water components: water from DSS (Eq. 15) and water from process flushing (Eq. 16). By splitting out these two water components, the adjusted weight-percent for combined DSS can be estimated (Eq. 17). These results are shown in Table 5.

$$Adj\_wt\%_{DSS,H2O\ in\ slurry} = \frac{wt\%_{DSS,H2O\ in\ slurry}}{wt\%_{Overage}} \times 100\% \qquad \text{Eq. 15}$$

Where:

$Adj\_wt\%_{DSS,H2O\ in\ slurry}$ is the adjusted total weight-percent of water from DSS in the saltstone grout slurry accounting for the total mass from saltstone processing,

$wt\%_{Overage}$ is the total unadjusted weight-percent from summing each of the saltstone grout slurry components (from Eq. 10), and

$wt\%_{DSS,H2O\ in\ slurry}$ is the total weight-percent of water from DSS in the saltstone grout slurry (from Eq. 5).

And

$$Adj\_wt\%_{Flush,H2O\ in\ slurry} = Adj\_wt\%_{TOTAL,H2O\ in\ slurry} - Adj\_wt\%_{DSS,H2O\ in\ slurry}$$ Eq. 16

Where:

$Adj\_wt\%_{Flush,H2O\ in\ slurry}$ is the adjusted total weight-percent of water from process flushes in the saltstone grout slurry accounting for the total mass from saltstone processing,

$Adj\_wt\%_{TOTAL,H2O\ in\ slurry}$ is the adjusted total weight-percent of water from both DSS and flush water in the saltstone grout slurry accounting for the total mass from saltstone processing (from Eq. 13), and

$Adj\_wt\%_{DSS,H2O\ in\ slurry}$ is the adjusted total weight-percent of water from DSS in the saltstone grout slurry accounting for the total mass from saltstone processing (from Eq. 15).

And

$$Adj\_wt\%_{DSS\ in\ slurry} = Adj\_wt\%_{DSS,solids\ in\ slurry} + Adj\_wt\%_{DSS,H2O\ in\ slurry}$$ Eq. 17

Where:

$Adj\_wt\%_{DSS\ in\ slurry}$ is the adjusted total weight-percent of DSS in the saltstone grout slurry accounting for the total mass from saltstone processing,

$Adj\_wt\%_{DSS,solids\ in\ slurry}$ is the adjusted weight-percent of solids from DSS in the saltstone grout slurry accounting for the total mass from saltstone processing (from Eq. 11), and

$Adj\_wt\%_{DSS,H2O\ in\ slurry}$ is the adjusted total weight-percent of water from DSS in the saltstone grout slurry accounting for the total mass from saltstone processing (from Eq. 15).

Table 5: Estimated Weight-Percents of Water and DSS in Saltstone Grout Slurry

Period	Final Adjusted DSS Water Wt percent	Final Adjusted Flush Water Wt percent	Final Adjusted DSS Wt percent
	(Eq. 15)	(Eq. 16)	(Eq. 17)
2Q19	32.84	1.314	43.02
1Q19	32.23	1.289	44.09
4Q18	32.26	1.290	44.04
3Q18	32.16	1.286	44.21
2Q18	32.17	1.287	44.20
1Q18	32.12	1.285	44.28
3Q17	32.14	1.285	44.25
2Q17	32.12	1.285	44.27
1Q17	32.18	1.287	44.18
4Q16	31.96	1.278	44.55
3Q16	31.78	1.271	44.86
2Q16	32.13	1.285	44.25
1Q16	32.27	1.291	44.02
4Q15	31.96	1.279	44.55
3Q15	32.06	1.283	44.37
2Q15	32.04	1.282	44.42
1Q15	32.19	1.288	44.15
3Q14	32.04	1.282	44.41
2Q14	31.92	1.277	44.63
Mean	**32.13**	**1.285**	**44.25**

Finally, the adjusted weight-percents from each of the premix dry feed components are also estimated (Eq. 18, Eq. 19, and Eq. 20), with results provided in Table 6.

$$Adj\_wt\%_{BFS\ in\ slurry} = Adj\_wt\%_{DF\ in\ slurry} \times wt\%_{BFS\ in\ DF} \quad \text{Eq. 18}$$

Where:

$Adj\_wt\%_{BFS\ in\ slurry}$ is the adjusted weight-percent of BFS in the saltstone grout slurry accounting for the total mass from saltstone processing,

$Adj\_wt\%_{DF\ in\ slurry}$ is the adjusted weight-percent of premix dry feeds in the saltstone grout slurry accounting for the total mass from saltstone processing (from Eq. 12), and

$wt\%_{BFS\ in\ DF}$ is the weight-percent of the premix dry feeds from blast furnace slag from Table 1.

And

	$$Adj\_wt\%_{FA\ in\ slurry} = Adj\_wt\%_{DF\ in\ slurry} \times wt\%_{FA\ in\ DF}$$	Eq. 19
Where:		
	$Adj\_wt\%_{FA\ in\ slurry}$ is the adjusted weight-percent of FA in the saltstone grout slurry accounting for the total mass from saltstone processing,	
	$Adj\_wt\%_{DF\ in\ slurry}$ is the adjusted weight-percent of premix dry feeds in the saltstone grout slurry accounting for the total mass from saltstone processing (from Eq. 12), and	
	$wt\%_{FA\ in\ DF}$ is the weight-percent of the premix dry feeds from fly ash (from Table 1).	

And

$$Adj\_wt\%_{OPC\ in\ slurry} = Adj\_wt\%_{DF\ in\ slurry} \times wt\%_{OPC\ in\ DF} \quad \text{Eq. 20}$$

Where:

$Adj\_wt\%_{OPC\ in\ slurry}$ is the adjusted weight-percent of OPC in the saltstone grout slurry accounting for the total mass from saltstone processing,

$Adj\_wt\%_{DF\ in\ slurry}$ is the adjusted weight-percent of premix dry feeds in the saltstone grout slurry accounting for the total mass from saltstone processing (from Eq. 12), and

$wt\%_{OPC\ in\ DF}$ is the weight-percent of the premix dry feeds from ordinary portland cement from Table 1.

Table 6: Estimated Weight-Percents of the Premix Dry Feeds in Saltstone Grout Slurry

Period	Final Adjusted BFS Wt percent	Final Adjusted FA Wt percent	Final Adjusted OPC Wt percent
	(Eq. 18)	(Eq. 19)	(Eq. 20)
2Q19	25.05	25.05	5.567
1Q19	24.58	24.58	5.462
4Q18	24.60	24.60	5.467
3Q18	24.53	24.53	5.450
2Q18	24.53	24.53	5.452
1Q18	24.50	24.50	5.443
3Q17	24.51	24.51	5.447
2Q17	24.50	24.50	5.445
1Q17	24.54	24.54	5.454
4Q16	24.38	24.38	5.417
3Q16	24.24	24.24	5.387
2Q16	24.51	24.51	5.446
1Q16	24.61	24.61	5.469
4Q15	24.38	24.38	5.417
3Q15	24.46	24.46	5.434
2Q15	24.44	24.44	5.430
1Q15	24.55	24.55	5.456
3Q14	24.44	24.44	5.430
2Q14	24.34	24.34	5.410
Mean	**24.51**	**24.51**	**5.447**

Using the adjusted weight percents and known densities, the volume per unit mass for selected components can be determined using Equation 21 (for DSS), Equation 22 (for flush water), and Equation 23 (for the premix dry feeds). Then, assuming that the volumes are additive, the total volume per unit mass is determined (Eq. 24). The inverse of this value (Eq. 25) gives the density of the saltstone grout slurry. The results for each of these equations are provided in Table 7.

$$UnitVol_{DSS\ in\ slurry} = \frac{Adj\_wt\%_{DSS\ in\ slurry}/100\%}{\rho_{DSS}} \qquad \text{Eq. 21}$$

Where:

$UnitVol_{DSS\ in\ slurry}$ is the volume (mL) per unit mass (g) of DSS in the saltstone grout slurry,

$Adj\_wt\%_{DSS\ in\ slurry}$ is the adjusted weight-percent of DSS in the saltstone grout slurry accounting for the total mass from saltstone processing (from Table 5), and

ρ_{DSS} is the density of DSS from Table 1.

And

$$UnitVol_{Flush,H2O\ in\ slurry} = \frac{Adj\_wt\%_{Flush,H2O\ in\ slurry}/100\%}{\rho_{H2O}} \quad \text{Eq. 22}$$

Where:

$UnitVol_{Flush,H2O\ in\ slurry}$ is the volume (mL) per unit mass (g) of flush water in the saltstone grout slurry,

$Adj\_wt\%_{Flush,H2O\ in\ slurry}$ is the adjusted total weight-percent of water from process flushes in the saltstone grout slurry (from Table 5), and

ρ_{H2O} is the density of water (1 g/mL).

And

$$UnitVol_{DF\ in\ slurry} = \frac{Adj\_wt\%_{DF\ in\ slurry}/100\%}{\rho_{DF}} \quad \text{Eq. 23}$$

Where:

$UnitVol_{DF\ in\ slurry}$ is the volume (mL) per unit mass (g) of the premix dry feeds in the saltstone grout slurry,

$Adj\_wt\%_{DF\ in\ slurry}$ is the adjusted weight-percent of the premix dry feeds in the saltstone grout slurry accounting for the total mass from saltstone processing (from Table 4), and

ρ_{DF} is the density of premix dry feeds (from Eq. 1).

And

$$UnitVol_{TOTAL,slurry} = UnitVol_{DSS\ in\ slurry} + UnitVol_{Flush,H2O\ in\ slurry} + UnitVol_{DF\ in\ slurry} \quad \text{Eq. 24}$$

Where:

$UnitVol_{TOTAL,slurry}$ is the volume (mL) per unit mass (g) of the saltstone grout slurry,

$UnitVol_{DSS\ in\ slurry}$ is the volume (mL) per unit mass (g) of DSS in the saltstone grout slurry (from Eq. 21),

$UnitVol_{Flush,H2O\ in\ slurry}$ is the volume (mL) per unit mass (g) of flush water in the saltstone grout slurry (from Eq. 22), and

$UnitVol_{DF\ in\ slurry}$ is the volume (mL) per unit mass (g) of the premix dry feeds in the saltstone grout slurry (from Eq. 23).

And

$$\rho_{slurry} = \frac{1}{UnitVol_{TOTAL,slurry}} \quad \text{Eq. 25}$$

Where:

ρ_{slurry} is the estimated density (g/mL) of the saltstone grout slurry, and

$UnitVol_{TOTAL,slurry}$ is the volume (mL) per unit mass (g) of the saltstone grout slurry (from Eq. 24).

Table 7: Estimated Volumes per Unit Mass and Density of Saltstone Grout Slurry

Period	Volume (mL) per Unit Mass (g) from DSS	Volume (mL) per Unit Mass (g) from Flush Water	Volume (mL) per Unit Mass (g) from Dry Feeds	Total Volume (mL) per Unit Mass (g)	Estimated Density of Saltstone Grout Slurry (g/mL)
	(Eq. 21)	(Eq. 22)	(Eq. 23)	(Eq. 24)	(Eq. 25)
2Q19	0.3539	0.0131	0.2157	0.5827	1.716
1Q19	0.3573	0.0129	0.2116	0.5818	1.719
4Q18	0.3570	0.0129	0.2118	0.5817	1.719
3Q18	0.3579	0.0129	0.2112	0.5819	1.719
2Q18	0.3573	0.0129	0.2112	0.5814	1.720
1Q18	0.3580	0.0128	0.2109	0.5818	1.719
3Q17	0.3577	0.0129	0.2110	0.5816	1.719
2Q17	0.3589	0.0128	0.2110	0.5827	1.716
1Q17	0.3578	0.0129	0.2113	0.5820	1.718
4Q16	0.3616	0.0128	0.2099	0.5842	1.712
3Q16	0.3621	0.0127	0.2087	0.5835	1.714
2Q16	0.3586	0.0129	0.2110	0.5824	1.717
1Q16	0.3573	0.0129	0.2119	0.5821	1.718
4Q15	0.3606	0.0128	0.2099	0.5833	1.714
3Q15	0.3598	0.0128	0.2106	0.5831	1.715
2Q15	0.3601	0.0128	0.2104	0.5833	1.714
1Q15	0.3584	0.0129	0.2114	0.5827	1.716
3Q14	0.3592	0.0128	0.2104	0.5825	1.717
2Q14	0.3581	0.0128	0.2096	0.5805	1.723
Mean	**0.3585**	**0.0129**	**0.2110**	**0.5824**	**1.717**

Historically, the average density of saltstone grout slurry has been reported as 1.71 g/cm^3 (for example, see X-CLC-Z-00070). Similarly, facility data provided in X-CLC-Z-00089 indicated that the "Nominal design/operational" range for the saltstone grout slurry densities is between 1.68 g/cm^3 and 1.73 g/cm^3. Therefore, the estimated densities of the saltstone grout slurry shown in Table 7 (mean of 1.717 g/mL or 1.717 g/cm^3) are consistent with process history.

We now have enough data to estimate the batch quantities for each of the component materials in the saltstone grout slurry. For convenience, each of the batch quantities are presented in units that are more typical for use in large-scale concrete batch preparations: lbs/yd^3. To show these units, the following conversion factors are used:

- 1 g = 2.2046E-03 lbs
- 1 mL = 1 cm^3 = 1.3080E-06 yd^3

From these, a conversion factor of 1685.6 lbs/yd^3 per g/mL is derived:

$$1\ \frac{g}{mL} = \frac{2.2046\text{E}\ 03\ \text{lbs}}{1.3080\text{E}\ 06\ \text{yd}^3} = 1685.6\ \frac{lbs}{yd^3} \qquad \text{Eq. 26}$$

The batch quantities for each of the premix dry feed components are provided in Table 8. The remaining components and the total batch quantity in lbs/yd^3 are provided in Table 9.

$$Qty_{BFS} = \left(1685.6\ \frac{lbs}{yd^3} / \frac{g}{mL}\right) \times \left(\frac{Adj\_wt\%_{BFS\ in\ slurry}}{100\%}\right) \times \rho_{slurry} \qquad \text{Eq. 27}$$

Where:

Qty_{BFS} is the quantity (lbs) per unit volume (yd^3) of BFS in the saltstone grout slurry,

$Adj\_wt\%_{BFS\ in\ slurry}$ is the adjusted weight-percent of BFS in the saltstone grout slurry (from Table 6),

ρ_{slurry} is the estimated density (g/mL) of the saltstone grout slurry (from Table 7).

And

$$Qty_{FA} = \left(1685.6\ \frac{lbs}{yd^3} / \frac{g}{mL}\right) \times \left(\frac{Adj\_wt\%_{FA\ in\ slurry}}{100\%}\right) \times \rho_{slurry} \qquad \text{Eq. 28}$$

Where:

Qty_{FA} is the quantity (lbs) per unit volume (yd^3) of FA in the saltstone grout slurry,

$Adj\_wt\%_{FA\ in\ slurry}$ is the adjusted weight-percent of FA in the saltstone grout slurry (from Table 6),

ρ_{slurry} is the estimated density (g/mL) of the saltstone grout slurry (from Table 7).

And

$$Qty_{OPC} = \left(1685.6\ \frac{lbs}{yd^3} / \frac{g}{mL}\right) \times \left(\frac{Adj\_wt\%_{OPC\ in\ slurry}}{100\%}\right) \times \rho_{slurry} \qquad \text{Eq. 29}$$

Where:

Qty_{OPC} is the quantity (lbs) per unit volume (yd^3) of OPC in the saltstone grout slurry,

$Adj\_wt\%_{OPC\ in\ slurry}$ is the adjusted weight-percent of OPC in the saltstone grout slurry (from Table 6),

ρ_{slurry} is the estimated density (g/mL) of the saltstone grout slurry (from Table 7).

And

$$Qty_{DSS,solids} = \left(1685.6\ \frac{lbs}{yd^3} / \frac{g}{mL}\right) \times \left(\frac{Adj\_wt\%_{DSS,solids\ in\ slurry}}{100\%}\right) \times \rho_{slurry} \qquad \text{Eq. 30}$$

Where:

$Qty_{DSS,solids}$ is the quantity (lbs) per unit volume (yd^3) of DSS solids in the saltstone grout slurry,

$Adj\_wt\%_{DSS,solids\ in\ slurry}$ is the adjusted weight-percent of DSS solids in the saltstone grout slurry (from Table 4),

ρ_{slurry} is the estimated density (g/mL) of the saltstone grout slurry (from Table 7).

And

$$Qty_{DSS,H2O} = \left(1685.6\ \frac{lbs}{yd^3} / \frac{g}{mL}\right) \times \left(\frac{Adj\_wt\%_{DSS,H2O\ in\ slurry}}{100\%}\right) \times \rho_{slurry} \qquad \text{Eq. 31}$$

Where:

$Qty_{DSS,H2O}$ is the quantity (lbs) per unit volume (yd^3) of DSS water in the saltstone grout slurry,

$Adj\_wt\%_{DSS,H2O\ in\ slurry}$ is the adjusted weight-percent of DSS water in the saltstone grout slurry (from Table 5),

ρ_{slurry} is the estimated density (g/mL) of the saltstone grout slurry (from Table 7).

And

$$Qty_{Flush,H2O} = \left(1685.6\ \frac{lbs}{yd^3} / \frac{g}{mL}\right) \times \left(\frac{Adj\_wt\%_{Flush,H2O\ in\ slurry}}{100\%}\right) \times \rho_{slurry} \qquad \text{Eq. 32}$$

Where:

$Qty_{Flush,H2O}$ is the quantity (lbs) per unit volume (yd^3) of flush water in the saltstone grout slurry,

$Adj\_wt\%_{Flush,H2O\ in\ slurry}$ is the adjusted weight-percent of flush water in the saltstone grout slurry (from Table 5),

ρ_{slurry} is the estimated density (g/mL) of the saltstone grout slurry (from Table 7).

And, finally

$$Qty_{TOTAL,slurry} = Qty_{BFS} + Qty_{FA} + Qty_{OPC} + Qty_{DSS,solids} + Qty_{DSS,H2O} + Qty_{Flush,H2O} \qquad \text{Eq. 33}$$

Where:

$Qty_{TOTAL,slurry}$ is the total batch quantity (lbs) per unit volume (yd^3) of the saltstone grout slurry,

Qty_{BFS} is the quantity (lbs) per unit volume (yd^3) of BFS in the saltstone grout slurry (from Eq. 27),

Qty_{FA} is the quantity (lbs) per unit volume (yd^3) of FA in the saltstone grout slurry (from Eq. 28),

Qty_{OPC} is the quantity (lbs) per unit volume (yd^3) of OPC in the saltstone grout slurry (from Eq. 29),

$Qty_{DSS,solids}$ is the quantity (lbs) per unit volume (yd^3) of DSS solids in the saltstone grout slurry (from Eq. 30),

$Qty_{DSS,H2O}$ is the quantity (lbs) per unit volume (yd^3) of DSS water in the saltstone grout slurry (from Eq. 31), and

$Qty_{Flush,H2O}$ is the quantity (lbs) per unit volume (yd^3) of flush water in the saltstone grout slurry (from Eq. 32).

Table 8: Estimated Batch Quantities for Premix Dry Feeds in Saltstone Grout Slurry

Period	**BFS Qty (lbs) per yd^3**	**FA Qty (lbs) per yd^3**	**OPC Qty (lbs) per yd^3**
	(Eq. 27)	(Eq. 28)	(Eq. 29)
2Q19	724.6	724.6	161.0
1Q19	712.1	712.1	158.2
4Q18	712.8	712.8	158.4
3Q18	710.5	710.5	157.9
2Q18	711.2	711.2	158.0
1Q18	709.7	709.7	157.7
3Q17	710.3	710.3	157.9
2Q17	708.7	708.7	157.5
1Q17	710.8	710.8	158.0
4Q16	703.2	703.2	156.3
3Q16	700.3	700.3	155.6
2Q16	709.3	709.3	157.6
1Q16	712.6	712.6	158.4
4Q15	704.5	704.5	156.5
3Q15	706.9	706.9	157.1
2Q15	706.2	706.2	156.9
1Q15	710.2	710.2	157.8
3Q14	707.2	707.2	157.1
2Q14	706.9	706.9	157.1
Mean	**709.4**	**709.4**	**157.6**

Table 9: Estimated Batch Quantities for Other Components in Saltstone Grout Slurry

Period	DSS Solids Qty (lbs) per yd^3	DSS Water Qty (lbs) per yd^3	Flush Water Qty (lbs) per yd^3	Total Qty (lbs) per yd^3
	(Eq. 30)	(Eq. 31)	(Eq. 32)	(Eq. 33)
2Q19	294.4	950.0	38.00	2892.7
1Q19	343.6	933.6	37.35	2897.0
4Q18	341.3	934.6	37.38	2897.4
3Q18	349.1	931.5	37.26	2896.7
2Q18	348.7	932.5	37.30	2899.0
1Q18	352.4	930.5	37.22	2897.4
3Q17	351.0	931.3	37.25	2898.1
2Q17	351.2	929.2	37.17	2892.5
1Q17	347.5	932.0	37.28	2896.3
4Q16	363.4	922.0	36.88	2885.0
3Q16	377.7	918.1	36.72	2888.7
2Q16	350.8	929.9	37.20	2894.0
1Q16	340.2	934.3	37.37	2895.5
4Q15	363.7	923.6	36.94	2889.7
3Q15	355.8	926.8	37.07	2890.5
2Q15	357.7	925.8	37.03	2889.8
1Q15	346.2	931.2	37.25	2892.9
3Q14	358.1	927.2	37.09	2893.8
2Q14	369.1	926.8	37.07	2903.8
Mean	**350.6**	**930.1**	**37.20**	**2894.2**

The weight-percent of the solids in the DSS and the density of the DSS (g/mL) are both given in Table 2. These values can be used to estimate an approximate density of the solids in the DSS.

First, the weight-percent of the water in the DSS is calculated:

$$wt\%_{H2O\ in\ DSS} = 100\% - wt\%_{solids\ in\ DSS} \qquad \text{Eq. 34}$$

Where:

$wt\%_{H2O\ in\ DSS}$ is the weight percent of water in DSS, and

$wt\%_{solids\ in\ DSS}$ is the weight percent of solids in DSS (from Table 2).

Next, this weight-percent of water is converted into actual mass of water (g) per unit volume (mL) of DSS:

$$Mass_{H2O\ in\ DSS} = \rho_{DSS} \times \frac{wt\%_{H2O\ in\ DSS}}{100\%} \qquad \text{Eq. 35}$$

Where:

$Mass_{H2O\ in\ DSS}$ is the mass (g) of water per unit volume (mL) of DSS,

$wt\%_{H2O\ in\ DSS}$ is the weight percent of water in DSS (from Eq. 34), and

ρ_{DSS} is the density (g/mL) of DSS (from Table 2).

Given that the density of water is assumed to be 1 g/mL, the volume of water (mL) per unit volume (mL) of DSS is:

$$Vol_{H2O\ in\ DSS} = \frac{Mass_{H2O\ in\ DSS}}{\rho_{H2O}} \qquad \text{Eq. 36}$$

Where:

$Vol_{H2O\ in\ DSS}$ is the volume (mL) of water per unit volume (mL) of DSS,

$Mass_{H2O\ in\ DSS}$ is the mass (g) of water per unit volume (mL) of DSS (from Eq. 35),

ρ_{H2O} is the density (g/mL) of water (assumed to be 1 g/mL).

Finally, the density of the DSS solids may be estimated:

$$\rho_{DSS,solids} = \frac{\left[\rho_{DSS} \times \left(\frac{wt\%_{solids\ in\ DSS}}{100\%}\right)\right]}{[1 - Vol_{H2O\ in\ DSS}]} \qquad \text{Eq. 37}$$

Where:

$\rho_{DSS,solids}$ is the density (g/mL) of the solids in the DSS,

ρ_{DSS} is the density (g/mL) of DSS (from Table 2),

$wt\%_{solids\ in\ DSS}$ is the weight percent of solids in DSS (from Table 2), and

$Vol_{H2O\ in\ DSS}$ is the volume (mL) of water per unit volume (mL) of DSS (from Eq. 36).

Table 10 presents the results from Eq. 34 through 37.

Table 10: Estimate of the Density of Solids in DSS

Period	Wt % Water in DSS	Mass (g) of Water per Unit Volume (mL) of DSS	Volume (mL) of Water per Unit Volume (mL) of DSS	Density (g/mL) of DSS Solids
	(Eq. 34)	(Eq. 35)	(Eq. 36)	(Eq. 37)
2Q19	76.34	0.9281	0.9281	3.999
1Q19	73.10	0.9020	0.9020	3.386
4Q18	73.25	0.9035	0.9035	3.421
3Q18	72.74	0.8986	0.8986	3.322
2Q18	72.78	0.9001	0.9001	3.371
1Q18	72.53	0.8971	0.8971	3.303
3Q17	72.63	0.8984	0.8984	3.331
2Q17	72.57	0.8950	0.8950	3.222
1Q17	72.84	0.8994	0.8994	3.332
4Q16	71.73	0.8839	0.8839	2.999
3Q16	70.85	0.8778	0.8778	2.956
2Q16	72.61	0.8962	0.8962	3.255
1Q16	73.31	0.9031	0.9031	3.393
4Q15	71.75	0.8863	0.8863	3.070
3Q15	72.26	0.8913	0.8913	3.146
2Q15	72.13	0.8898	0.8898	3.120
1Q15	72.90	0.8981	0.8981	3.277
3Q14	72.14	0.8919	0.8919	3.185
2Q14	71.52	0.8913	0.8913	3.265
Mean	**72.63**	**0.8964**	**0.8964**	**3.282**

Note that the estimated density of the DSS solids is only an approximate estimate. This approach assumes that the total volume of the DSS is equal to the volume of the DSS solids plus the volume of the DSS water.

Next, we can combine the solid components only (i.e., the premix dry feeds and the DSS solids) and determine the weight-percent for each of these components relative to the total solids in the saltstone grout slurry.

$$Qty_{solids} = Qty_{DSS,solids} + Qty_{BFS} + Qty_{FA} + Qty_{OPC} \qquad \text{Eq. 38}$$

Where:

Qty_{solids} is the total batch quantity (lbs) per unit volume (yd^3) of the solid components in the saltstone grout slurry,

Qty_{BFS} is the quantity (lbs) per unit volume (yd^3) of BFS in the saltstone grout slurry (from Table 8),

Qty_{FA} is the quantity (lbs) per unit volume (yd^3) of FA in the saltstone grout slurry (from Table 8),

Qty_{OPC} is the quantity (lbs) per unit volume (yd^3) of OPC in the saltstone grout slurry (from Table 8), and

$Qty_{DSS,solids}$ is the quantity (lbs) per unit volume (yd^3) of DSS solids in the saltstone grout slurry (from Table 9).

And

$$wt\%_{BFS\ in\ solids} = \frac{Qty_{BFS}}{Qty_{solids}} \times 100\% \qquad \text{Eq. 39}$$

Where:

$wt\%_{BFS\ in\ solids}$ is the weight-percent of BFS in the saltstone grout slurry solids,

Qty_{BFS} is the quantity (lbs) per unit volume (yd^3) of BFS in the saltstone grout slurry (from Table 8), and

Qty_{solids} is the total batch quantity (lbs) per unit volume (yd^3) of the solid components in the saltstone grout slurry (from Eq. 38).

And

$$wt\%_{FA\ in\ solids} = \frac{Qty_{FA}}{Qty_{solids}} \times 100\% \qquad \text{Eq. 40}$$

Where:

$wt\%_{FA\ in\ solids}$ is the weight-percent of FA in the saltstone grout slurry solids,

Qty_{FA} is the quantity (lbs) per unit volume (yd^3) of FA in the saltstone grout slurry (from Table 8), and

Qty_{solids} is the total batch quantity (lbs) per unit volume (yd^3) of the solid components in the saltstone grout slurry (from Eq. 38).

And

$$wt\%_{OPC\ in\ solids} = \frac{Qty_{OPC}}{Qty_{solids}} \times 100\% \qquad \text{Eq. 41}$$

Where:

$wt\%_{OPC\ in\ solids}$ is the weight-percent of OPC in the saltstone grout slurry solids,

Qty_{OPC} is the quantity (lbs) per unit volume (yd^3) of OPC in the saltstone grout slurry (from Table 8), and

Qty_{solids} is the total batch quantity (lbs) per unit volume (yd^3) of the solid components in the saltstone grout slurry (from Eq. 38).

And

$$wt\%_{DSS,solids\ in\ solids} = \frac{Qty_{DSS,solids}}{Qty_{solids}} \times 100\% \qquad \text{Eq. 42}$$

Where:

$wt\%_{DSS,solids\ in\ solids}$ is the weight-percent of DSS solids in the saltstone grout slurry solids,

$Qty_{DSS,solids}$ is the quantity (lbs) per unit volume (yd^3) of DSS solids in the saltstone grout slurry (from Table 9), and

Qty_{solids} is the total batch quantity (lbs) per unit volume (yd^3) of the solid components in the saltstone grout slurry (from Eq. 38).

The results from Equations 38 through 42 are provided in Table 11.

Table 11: Estimate of the Weight-Percent Solids in the Saltstone Grout Slurry

Period	Total Solids in Slurry lbs per cubic yard	Wt Percent of BFS in Slurry Solids	Wt Percent of FA in Slurry Solids	Wt Percent of OPC in Solids	Wt Percent of DSS Solids in Slurry Solids
	(Eq. 38)	(Eq. 39)	(Eq. 40)	(Eq. 41)	(Eq. 42)
2Q19	1904.7	38.04	38.04	8.454	15.46
1Q19	1926.0	36.97	36.97	8.216	17.84
4Q18	1925.4	37.02	37.02	8.227	17.73
3Q18	1927.9	36.85	36.85	8.189	18.11
2Q18	1929.2	36.87	36.87	8.192	18.08
1Q18	1929.6	36.78	36.78	8.174	18.26
3Q17	1929.5	36.81	36.81	8.181	18.19
2Q17	1926.1	36.79	36.79	8.177	18.23
1Q17	1927.1	36.89	36.89	8.197	18.03
4Q16	1926.1	36.51	36.51	8.113	18.87
3Q16	1933.9	36.21	36.21	8.047	19.53
2Q16	1926.9	36.81	36.81	8.180	18.20
1Q16	1923.8	37.04	37.04	8.232	17.68
4Q15	1929.1	36.52	36.52	8.115	18.85
3Q15	1926.6	36.69	36.69	8.153	18.47
2Q15	1927.0	36.65	36.65	8.144	18.56
1Q15	1924.4	36.91	36.91	8.201	17.99
3Q14	1929.6	36.65	36.65	8.144	18.56
2Q14	1939.9	36.44	36.44	8.098	19.02
Mean	**1927.0**	**36.81**	**36.81**	**8.181**	**18.19**

The information in Table 11 can then be used to generate an approximate estimate for the physical properties of cured saltstone, assuming that the DSS solids are completely incorporated into the matrix of the saltstone waste form (i.e., no DSS solids in the pore solution). Note that the following is only an approximate estimate because (1) the influence of hydration and curing processes are not accounted for and (2) entrapped air is not accounted for.

First, the particle density is estimated in a manner similar to Eq. 1, but excluding the water component:

$$\rho_{s,SS,all} = \frac{1}{\left[(wt\%_{BFS\ in\ solids}/\rho_{BFS}) + (wt\%_{FA\ in\ solids}/\rho_{FA}) + (wt\%_{OPC\ in\ solids}/\rho_{OPC}) + (wt\%_{DSS,solids\ in\ solids}/\rho_{DSS,solids})\right]} \times 100\%$$

Eq. 43

Where:

$\rho_{s,SS,all}$ is the estimated solid phase density (g/mL) (or particle density) of the cured saltstone, assuming that all solids are incorporated into the cementitious matrix,

ρ_{BFS} is the solid phase or particle density (g/mL) of the BFS (from Table 1),

ρ_{FA} is the solid phase or particle density (g/mL) of the FA (from Table 1),

ρ_{OPC} is the solid phase or particle density (g/mL) of the OPC (from Table 1),

$\rho_{DSS,solids}$ is the solid phase or particle density (g/mL) of the DSS solids (from Table 10),

$wt\%_{BFS\ in\ solids}$ is the weight-percent of the total solids from BFS (from Table 11),

$wt\%_{FA\ in\ solids}$ is the weight-percent of the total solids from FA (from Table 11),

$wt\%_{OPC\ in\ solids}$ is the weight-percent of the total solids from OPC (from Table 11), and

$wt\%_{DSS,solids\ in\ solids}$ is the weight-percent of the total solids from DSS solids (from Table 11).

Next, the associated bulk density is given as:

$$\rho_{b,SS,all} = \frac{\left(Qty_{BFS} + Qty_{FA} + Qty_{OPC} + Qty_{DSS,solids}\right)}{1685.6\,\frac{lbs}{yd^3}/\frac{g}{mL}} \qquad \text{Eq. 44}$$

Where:

$\rho_{b,SS,all}$ is the estimated bulk density (g/mL) of the cured saltstone, assuming that all solids are incorporated into the cementitious matrix,

Qty_{BFS} is the quantity (lbs) per unit volume (yd^3) of BFS in the saltstone grout slurry (from Table 8),

Qty_{FA} is the quantity (lbs) per unit volume (yd^3) of FA in the saltstone grout slurry (from Table 8),

Qty_{OPC} is the quantity (lbs) per unit volume (yd^3) of OPC in the saltstone grout slurry (from Table 8),

$Qty_{DSS,solids}$ is the quantity (lbs) per unit volume (yd^3) of DSS solids in the saltstone grout slurry (from Table 9), and

$1685.6\,\frac{lbs}{yd^3}/\frac{g}{mL}$ is the conversion factor from Eq. 26.

Then the associated porosity can be estimated:

$$\eta_{SS,all} = 1 - \left(\frac{\rho_{b,SS,all}}{\rho_{s,SS,all}}\right) \qquad \text{Eq. 45}$$

Where:

$\eta_{SS,all}$ is the porosity (mL/mL or unitless) of cured saltstone, assuming that all solids are incorporated into the cementitious matrix,

$\rho_{b,SS,all}$ is the estimated bulk density (g/mL) of the cured saltstone, assuming that all solids are incorporated into the cementitious matrix (from Eq. 44), and

$\rho_{s,SS,all}$ is the estimated solid phase density (g/mL) (or particle density) of the cured saltstone, assuming that all solids are incorporated into the cementitious matrix (from Eq. 43).

The results from Equations 43 through 45 are provided in Table 12.

Table 12: Estimated Material Properties of Cured Saltstone, Assuming DSS Solids Are Completely Incorporated into the Matrix

Period	Maximum Particle Density (g/mL) (Uses All Solids)*	Maximum Dry Bulk Density (g/mL) (Uses All Solids)*	Assumed Porosity After Curing Using All Solids*
	(Eq. 43)	(Eq. 44)	(Eq. 45)
2Q19	2.731	1.130	0.5862
1Q19	2.695	1.143	0.5761
4Q18	2.698	1.142	0.5767
3Q18	2.690	1.144	0.5747
2Q18	2.695	1.145	0.5753
1Q18	2.688	1.145	0.5741
3Q17	2.691	1.145	0.5746
2Q17	2.678	1.143	0.5733
1Q17	2.690	1.143	0.5750
4Q16	2.651	1.143	0.5689
3Q16	2.647	1.147	0.5665
2Q16	2.682	1.143	0.5738
1Q16	2.695	1.141	0.5765
4Q15	2.661	1.144	0.5699
3Q15	2.670	1.143	0.5718
2Q15	2.666	1.143	0.5713
1Q15	2.684	1.142	0.5745
3Q14	2.675	1.145	0.5721
2Q14	2.688	1.151	0.5718
Mean	**2.683**	**1.143**	**0.5739**

Note: * Values are approximate because they do not account for property changes resulting from hydration and curing processes or for the influences of entrapped air.

Where Equations 43, 44, and 45 assumes that the DSS solids are completely incorporated into the structure of the matrix of the saltstone waste form, Equations 46, 47, and 48, respectively, show equivalent estimates of the physical properties based on assuming that none of the DSS solids are incorporated into the matrix of the saltstone waste form (i.e., all DSS solids are in the pore solution). Note that the following is only an approximate estimate because (1) the influences of hydration and curing processes are not accounted for and (2) entrapped air is not accounted for.

First, the particle density is estimated in a manner similar to Eq. 43, but excluding the DSS solids component:

$$\rho_{s,SS,DF} = \frac{1}{[(wt\%_{BFS\ in\ solids}/\rho_{BFS})+(wt\%_{FA\ in\ solids}/\rho_{FA})+(wt\%_{OPC\ in\ solids}/\rho_{OPC})]} \times 100\%$$

Eq. 46

Where:

$\rho_{s,SS,DF}$ is the estimated solid phase density (g/mL) (or particle density) of the cured saltstone, assuming that only the premix dry feeds are incorporated into the cementitious matrix,

ρ_{BFS} is the solid phase or particle density (g/mL) of the BFS (from Table 1),

ρ_{FA} is the solid phase or particle density (g/mL) of the FA (from Table 1),

ρ_{OPC} is the solid phase or particle density (g/mL) of the OPC (from Table 1),

$wt\%_{BFS\ in\ solids}$ is the weight-percent of the total solids from BFS ($Qty_{BFS}/(Qty_{BFS}+Qty_{FA}+Qty_{OPC})$x100% = 45%),

$wt\%_{FA\ in\ solids}$ is the weight-percent of the total solids from FA ($Qty_{FA}/(Qty_{BFS}+Qty_{FA}+Qty_{OPC})$x100% = 45%), and

$wt\%_{OPC\ in\ solids}$ is the weight-percent of the total solids from OPC ($Qty_{BFS}/(Qty_{BFS}+Qty_{FA}+Qty_{OPC})$x100% = 10%).

Next, the associated bulk density is given as:

$$\rho_{b,SS,DF} = \frac{(Qty_{BFS} + Qty_{FA} + Qty_{OPC})}{1685.6\frac{lbs}{yd^3}/\frac{g}{mL}}$$

Eq. 47

Where:

$\rho_{b,SS,DF}$ is the estimated bulk density (g/mL) of the cured saltstone, assuming that only the premix dry feeds are incorporated into the cementitious matrix,

Qty_{BFS} is the quantity (lbs) per unit volume (yd^3) of BFS in the saltstone grout slurry (from Table 8),

Qty_{FA} is the quantity (lbs) per unit volume (yd^3) of FA in the saltstone grout slurry (from Table 8),

Qty_{OPC} is the quantity (lbs) per unit volume (yd^3) of OPC in the saltstone grout slurry (from Table 8), and

$1685.6\frac{lbs}{yd^3}/\frac{g}{mL}$ is the conversion factor from Eq. 26.

Then the associated porosity can be estimated:

$$\eta_{SS,DF} = 1 - \left(\frac{\rho_{b,SS,DF}}{\rho_{s,SS,DF}}\right) \quad \text{Eq. 48}$$

Where:

$\eta_{SS,DF}$ is the porosity (mL/mL or unitless) of cured saltstone, assuming that all solids are incorporated into the cementitious matrix,

$\rho_{b,SS,DF}$ is the estimated bulk density (g/mL) of the cured saltstone, assuming that only the premix dry feeds are incorporated into the cementitious matrix (from Eq. 47), and

$\rho_{s,SS,DF}$ is the estimated solid phase density (g/mL) (or particle density) of the cured saltstone, assuming that only the premix dry feeds are incorporated into the cementitious matrix (from Eq. 46).

The results from Equations 46 through 48 are provided in Table 13.

Table 13: Estimated Material Properties of Cured Saltstone, Assuming DSS Solids Are Completely Incorporated into the Matrix

Period	Minimum Particle Density (g/mL) (Uses Only Dry Feeds)*	Minimum Dry Bulk Density of Cementitious Solids (Uses Only Dry Feeds)*	Assumed Porosity After Curing Only Dry Feeds*
	(Eq. 38)	(Eq. 39)	(Eq. 40)
2Q19	2.581	0.955	0.6299
1Q19	2.581	0.939	0.6363
4Q18	2.581	0.940	0.6359
3Q18	2.581	0.937	0.6371
2Q18	2.581	0.938	0.6367
1Q18	2.581	0.936	0.6375
3Q17	2.581	0.936	0.6371
2Q17	2.581	0.934	0.6380
1Q17	2.581	0.937	0.6369
4Q16	2.581	0.927	0.6408
3Q16	2.581	0.923	0.6423
2Q16	2.581	0.935	0.6377
1Q16	2.581	0.940	0.6360
4Q15	2.581	0.929	0.6402
3Q15	2.581	0.932	0.6389
2Q15	2.581	0.931	0.6393
1Q15	2.581	0.936	0.6372
3Q14	2.581	0.932	0.6388
2Q14	2.581	0.932	0.6389
Mean	**2.581**	**0.935**	**0.6376**

Note: * Values are approximate because they do not account for property changes resulting from hydration and curing processes or for the influences of entrapped air.

Finally, by swapping the solid phase density values in Equations 45 and 48, the minimum and maximum porosity values can be estimated:

$$\eta_{SS,all/DF} = 1 - \left(\frac{\rho_{b,SS,all}}{\rho_{s,SS,DF}}\right) \quad \text{Eq. 49}$$

Where:

$\eta_{SS,all/DF}$ is the minimum estimated porosity (mL/mL or unitless) of cured saltstone,

$\rho_{b,SS,all}$ is the estimated bulk density (g/mL) of the cured saltstone, assuming that all solids are incorporated into the cementitious matrix (from Eq. 44), and

$\rho_{s,SS,DF}$ is the estimated solid phase density (g/mL) (or particle density) of the cured saltstone, assuming that only the premix dry feeds are incorporated into the cementitious matrix (from Eq. 46).

And

$$\eta_{SS,DF/all} = 1 - \left(\frac{\rho_{b,SS,DF}}{\rho_{s,SS,all}}\right) \quad \text{Eq. 50}$$

Where:

$\eta_{SS,DF/all}$ is the maximum estimated porosity (mL/mL or unitless) of cured saltstone,

$\rho_{b,SS,DF}$ is the estimated bulk density (g/mL) of the cured saltstone, assuming that only the premix dry feeds are incorporated into the cementitious matrix (from Eq. 47), and

$\rho_{s,SS,DF}$ is the estimated solid phase density (g/mL) (or particle density) of the cured saltstone, assuming that all solids are incorporated into the cementitious matrix (from Eq. 43).

These minimum and maximum estimated porosities are provided in Table 14.

Table 14: Estimated Minimum and Maximum Porosities of Cured Saltstone

Period	Minimum Porosity After Curing*	Maximum Porosity After Curing*
	(Eq. 49)	(Eq. 50)
2Q19	0.5622	0.6501
1Q19	0.5573	0.6517
4Q18	0.5574	0.6517
3Q18	0.5568	0.6517
2Q18	0.5565	0.6521
1Q18	0.5564	0.6519
3Q17	0.5565	0.6520
2Q17	0.5573	0.6511
1Q17	0.5570	0.6517
4Q16	0.5572	0.6502
3Q16	0.5555	0.6512
2Q16	0.5571	0.6514
1Q16	0.5578	0.6514
4Q15	0.5566	0.6510
3Q15	0.5571	0.6509
2Q15	0.5571	0.6508
1Q15	0.5576	0.6511
3Q14	0.5565	0.6515
2Q14	0.5541	0.6533
Mean	**0.5570**	**0.6514**

Note: * Values are approximate because they do not account for property changes resulting from hydration and curing processes or for the influences of entrapped air.

Compared to physical measurements for properties of cured, field-emplaced saltstone (SRR-CWDA-2018-00004), the analytically determined values in Tables 12, 13, and 14 generally have lower particle densities, higher bulk densities, and lower porosities. These differences may be due to property changes that occur during hydration and curing processes or, in the case of porosity, from the influences of entrapped air. As such, the estimated values from these tables are selected as follows:

- The highest mean particle density is assumed (mean of 2.683 g/mL),
- The lowest bulk density is assumed (mean of 0.935 g/mL), and
- The highest porosity is assumed (mean of 0.6514).

Despite the limitations of this approach, these values closely resemble the measured material properties from the analyses of cured, field-emplaced saltstone as discussed in SRR-CWDA-2018-00004. Therefore, these properties are selected as inputs for future modeling.

Table 15 provides a summary of the batch cementitious materials mix from this analysis based on the mean values from selected tables. Table 16 is similar, except it assumes the DSS solids are inert relative to the cementitious binding, so the DSS solids are excluded from the batch values.

Table 15: Analytically Determined Saltstone Batching Quantities for All Components

Material	Batch Qty of Slurry (lbs/yd3)	Wt% of Slurry (lbs/yd3)
Blast Furnace Slag (BFS)	709.4	24.5%
Fly Ash (FA)	709.4	24.5%
Ordinary Portland Cement (OPC)	157.6	5.4%
DSS	1280.7	44.2%
DSS Solids	350.6	12.1%
DSS Water	930.1	32.1%
Flush Water	37.2	1.3%
Water (DSS and Flush)	967.3	33.4%
Solids Total	1927.0	66.6%
Total	2894.2	100.0%

Table 16: Analytically Determined Saltstone Batching Quantities, Excluding DSS Solids

Material	Batch Qty of Slurry (lbs/yd3)	Wt% of Slurry (lbs/yd3)
Blast Furnace Slag (BFS)	709.4	27.9%
Fly Ash (FA)	709.4	27.9%
Ordinary Portland Cement (OPC)	157.6	6.2%
Water (DSS and Flush)	967.3	38.0%
Total	2543.6	100.0%

Table 17 provides a summary of the recommended material properties based on this analysis.

Table 17: Analytically Determined Saltstone Material Properties

Property	Mean	Notes
Particle Density (g/mL)	2.68	Very close to the recommended value (2.72 g/mL) based on analysis of SDU 2A material properties (SRR-CWDA-2018-00004 and SRNL-STI-2016-00106).
Dry Bulk Density (g/mL)	0.935	Very close to the recommended value (0.932 g/mL) based on analysis of SDU 2A material properties (SRR-CWDA-2018-00004 and SRNL-STI-2016-00106).
Porosity (mL/mL)	0.651	Very close to the recommended value (0.656) based on analysis of SDU 2A material properties (SRR-CWDA-2018-00004 and SRNL-STI-2016-00106).

Given the close agreement between these estimates and the values recommended in SRR-CWDA-2018-00004, there is confidence that this approach is appropriate for estimating these material property values.

Discussion of the Cement-Free Saltstone Mix

The previous discussion presented an analytical approach for estimating the material properties of saltstone based on the design mix and batch processing. This analytical approach shows a very favorable comparison to the recommended material properties based on laboratory analyses of field-emplaced saltstone. Therefore, applying this analytical approach to a modified design mix is expected to give an acceptable approximation of the resulting changes to the material properties.

By updating the design mix from Table 1 to the cement-free mix in Table 18, and then re-performing the analysis (Eq. 1 through Eq. 50) using this modified mix, the resulting batch quantities (Tables 19 and 20) and material properties (Table 21) can be determined.

Table 18: Cement-Free Saltstone Formulation

Material	Specific Gravity (Nominal)	Dry Feed Weight Percent
Ordinary Portland Cement (Type II [a])	3.15 [c]	0
Blast Furnace Slag (Grade 100 or 120 [b])	2.89 [c]	60
Class F Fly Ash	2.25 [c]	40
Decontaminated Salt Solution (DSS)	1.234 [d]	N/A

Notes:

a) Type II Ordinary Portland Cement has moderate resistance to sulfate and slower strength gains than other types of cement.
b) Slag Grades are a measure of the "slag activity index" which roughly corresponds to a comparison of the average 28-day compressive strengths of slag-reference cement cubes versus slag-free reference cement cubes (SRR-CWDA-2015-00057).
c) Specific Gravity values for dry feeds are based on values from C-SPP-Z-00015, Rev. 3, Attachment 03300-B.
d) For the DSS, the specific gravity is based on the mean DSS density from 2Q14 to 2Q19 (see Table 2).

Table 19 provides a summary of the batch cementitious materials mix from this analysis. Table 20 is similar, except it assumes the DSS solids are inert relative to the cementitious binding, so the DSS solids are excluded from the batch values.

Table 19: Analytically Determined Saltstone Batching Quantities for All Components

Material	Batch Qty of Slurry (lbs/yd3)	Wt% of Slurry (lbs/yd3)
Blast Furnace Slag (BFS)	947.6	32.7%
Fly Ash (FA)	631.8	21.8%
Ordinary Portland Cement (OPC)	0.0	0.0%
DSS	1283.2	44.2%
DSS Solids	351.3	12.1%
DSS Water	931.9	32.1%
Flush Water	37.3	1.3%
Water (DSS and Flush)	969.1	33.4%
Solids Total	1930.7	66.6%
Total	2899.8	100.0%

Table 20: Analytically Determined Saltstone Batching Quantities, Excluding DSS Solids

Material	Batch Qty of Slurry (lbs/yd3)	Wt% of Slurry (lbs/yd3)
Blast Furnace Slag (BFS)	947.6	37.2%
Fly Ash (FA)	631.8	24.8%
Ordinary Portland Cement (OPC)	0.0	0.0%
Water (DSS and Flush)	969.1	38.0%
Total	2548.5	100.0%

Table 21 provides a summary of the recommended material properties based on this analysis.

Table 21: Analytically Determined Saltstone Material Properties

Property	Mean	Notes
Particle Density (g/mL)	2.70	Very close to the recommended value (2.72 g/mL) based on analysis of SDU 2A material properties (SRR-CWDA-2018-00004 and SRNL-STI-2016-00106).
Dry Bulk Density (g/mL)	0.937	Very close to the recommended value (0.932 g/mL) based on analysis of SDU 2A material properties (SRR-CWDA-2018-00004 and SRNL-STI-2016-00106).
Porosity (mL/mL)	0.652	Very close to the recommended value (0.656) based on analysis of SDU 2A material properties (SRR-CWDA-2018-00004 and SRNL-STI-2016-00106).

Given that this analysis and the equivalent analysis for the typical (45-45-10) saltstone mix (see Table 17) both show nearly identical values, it is expected that both saltstone mixes will have nearly identical material properties and performance. Therefore, no changes are recommended to the particle density, dry bulk density, or porosity relative to the recommended values for saltstone described in SRR-CWDA-2018-00004.

Cement-Free Saltstone Initial Saturated Hydraulic Conductivity

When updating the quantities per cubic yard (equivalent to Tables 8 and 9) to determine the equivalent batching mix for cement-free saltstone, the resulting quantity values were also converted into quantities per 20 gallons of volume (Table 19). This gives batch quantities that are nearly equivalent to the quantities used to perform property testing on cement-free saltstone, as described in Section 2 of *Cement-Free Saltstone Down-Select Report Follow-Up* (SRR-CWDA-2020-00008) and detailed in *Cement-Free Saltstone: Instructions for Confirmation Testing* (SRR-CWDA-2019-00044). Because these values show very good agreement, the material properties described in SRR-CWDA-2020-00008 are expected to reflect the field-emplaced cement-free saltstone. Specifically, the saturated hydraulic conductivity, the effective diffusion coefficients (for I-129, Tc-99, and NO_3), and the reducing capacities were measured. The following provides modeling recommendations based on these measurements.

Table 19: Comparison of 20-Gallon Batch Quantities for Cement-Free Saltstone

Material	Batch Quantity (lbs) per 20-Gallons, from SRR-CWDA-2019-00044	Equivalent Batch Quantity (lbs) per 20-Gallons, Based on Analytical Approach Average
Blast Furnace Slag	93.6	93.8
Fly Ash	62.4	62.6
DSS or DSS Simulant	127.8	130.8 [a]

Notes: (a) This value also includes assumed flush water.

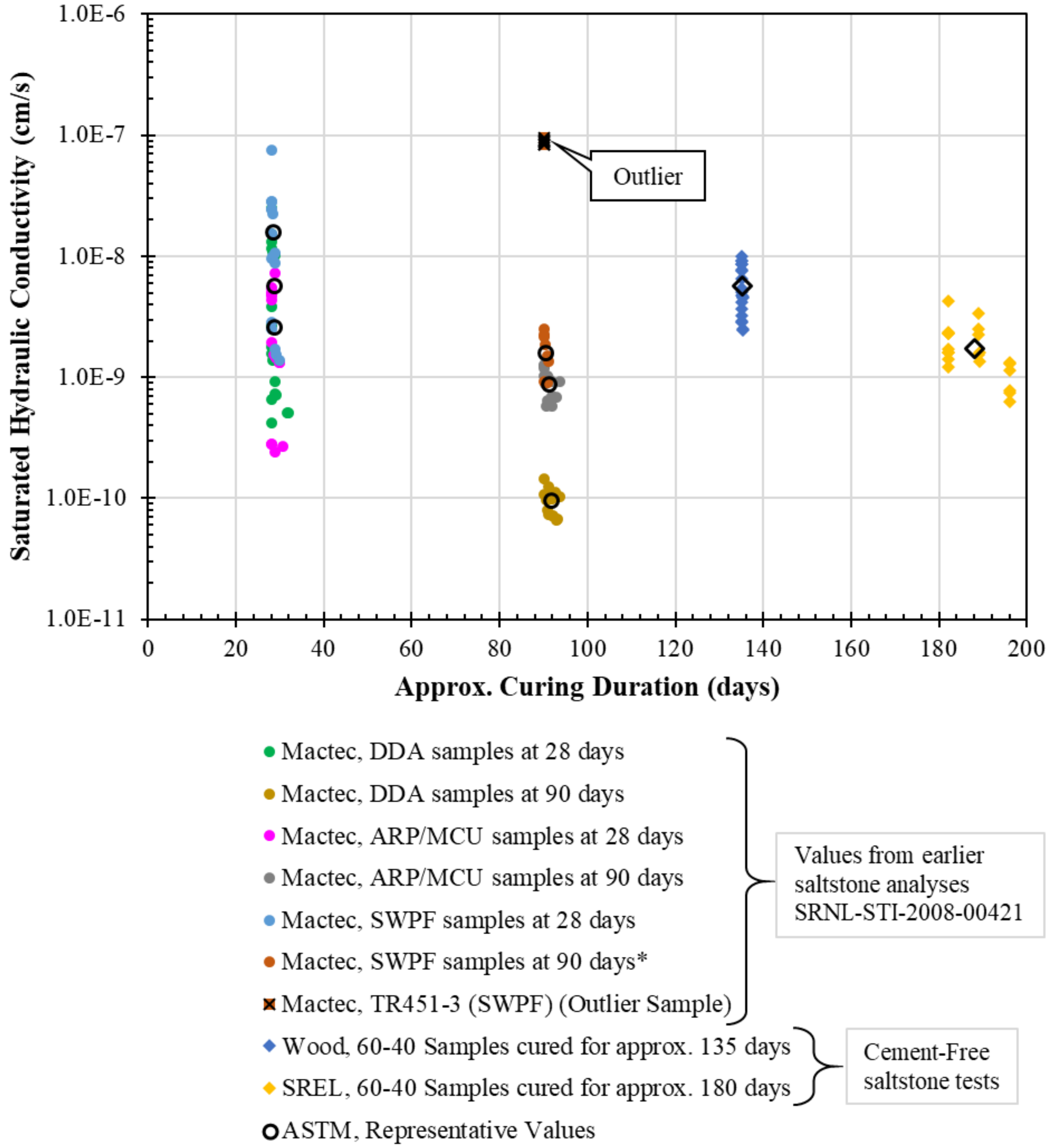
The Executive Summary of *Cement-Free Saltstone Down-Select Report Follow-Up* (SRR-CWDA-2020-00008) describes two saturated hydraulic conductivity (or K_{sat}) studies on cement-free samples, resulting in average values of 5.7E-09 cm/s for samples cured 135 days and 1.7E-09 cm/s for samples cured for 180 days. These values were measured according to American Society for Testing and Materials (ASTM) Standard D5084, *Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using A Flexible Wall Permeameter*. While these values are higher than the value used for the Compliance Case of the SDF PA (5.0E-10 cm/s per Section 4.3 of SRR-CWDA-2019-00001), it is noted that these K_{sat} measurements were based on samples that may not yet be cured sufficiently to be representative of initial PA conditions (i.e., conditions in the year 2037). Further ASTM D5084 specifies that there are limitations to the measurement approach for materials with low K_{sat} (i.e., values on the order of 1E-09 cm/s). While the measurements were above this lower limit, there may be additional uncertainty based on this approach. Figure 3 shows these cement-free measurements as a function of the approximate curing durations.

For context, Figure 3 also includes earlier saltstone measurements using the ASTM method. These values were measured by Mactec and documented in SRNL-STI-2008-00421. In this figure, circles indicate K_{sat} measurements of the 45-45-10 mix, diamonds indicate measurements of the cement-free 60-40 mix, and black-outlined shapes are included with each data set to show the representative (arithmetic average) values. This figure shows that individual saltstone samples can have K_{sat} values that show as much as an order of magnitude variability.

Alternatively, a dynamic leaching method (DLM) approach to measuring K_{sat} has no lower limit to the measurement values. The DLM analysis of the cement-free samples is described in Section 6 of SRR-CWDA-2020-00008, wherein the cement-free saltstone samples had cured considerably longer than the samples measured using the ASTM approach. These DLM tests were initiated on cement-free saltstone samples that had cured for more than 300 days and continued to measure the saturated hydraulic conductivities of these samples over a period of more than 100 days.

While the measured saturated hydraulic conductivity values from the DLM analysis were originally presented in SRR-CWDA-2020-00008 as a function of pore volume exchanges, Figures 4 and 5 present K_{sat} values as a function of days since the samples were prepared (i.e., the curing duration). In these figures, circles indicate DLM measurements for 45-45-10 mix and diamonds indicate DLM measurements for the cement-free 60-40 mix. These figures also include the average values from the ASTM tests discussed previously (Figure 3).

Figure 3: ASTM-Measured Saturated Hydraulic Conductivities as a Function of Curing Duration

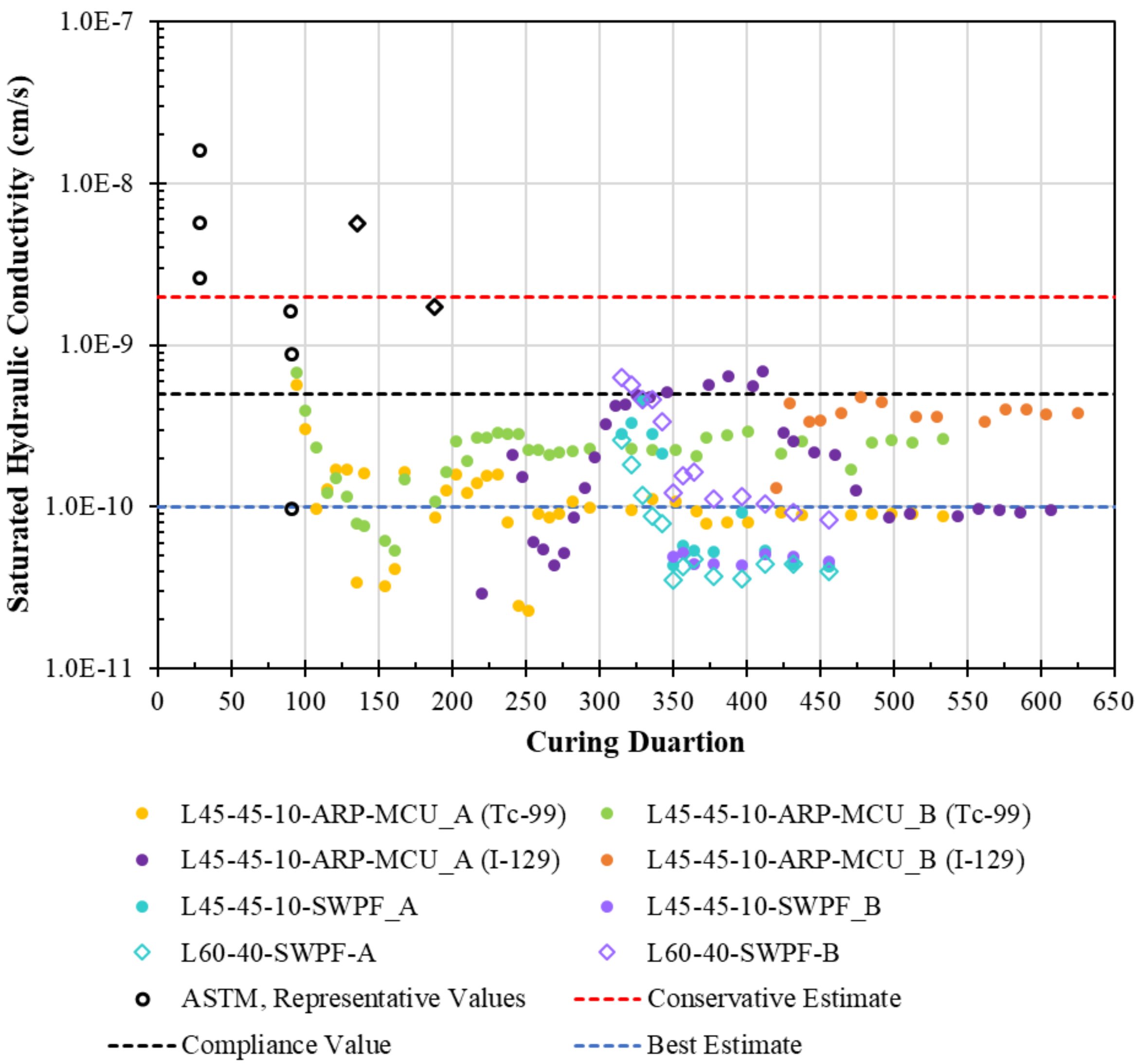


Notes: Circles represent 45-45-10 mix and diamonds represent the 60-40 mix.
The asterisk (*) indicates where the data set excludes the outlier sample (TR451-3), as this sample was suspect.
DDA, MCU, and SWPF each refer to the three different simulant solutions used for sample preparation, based on three different decontaminated salt solutions, where:
DDA = Deliquification, Dissolution, and Adjustment,
MCU = Actinide Removal Process /Modular Caustic Side Solvent Extraction Unit, and
SWPF = Salt Waste Processing Facility (SWPF).

The dashed lines in Figures 4 and 5 show the initial K_{sat} values that were used for modeling in the SDF PA (SRR-CWDA-2019-00001). The black dashed line at 5.0E-10 cm/s is the Compliance Value that was used in the "Compliance Case," the blue dashed line at 1.0E-10 cm/s is a Best Estimate that was used in the "Realistic Case," and the red dashed line at 2.0E-9 cm/s is a Conservative Estimate that was used in the "Pessimistic Case." As the DLM K_{sat} measurements show, most of the samples had values that were at or below the assumed Compliance Value. For the DLM-measured cement-free samples, the values start near the Compliance Value, then decline over time (likely due to continued curing) until the values are at or below the Best Estimate.

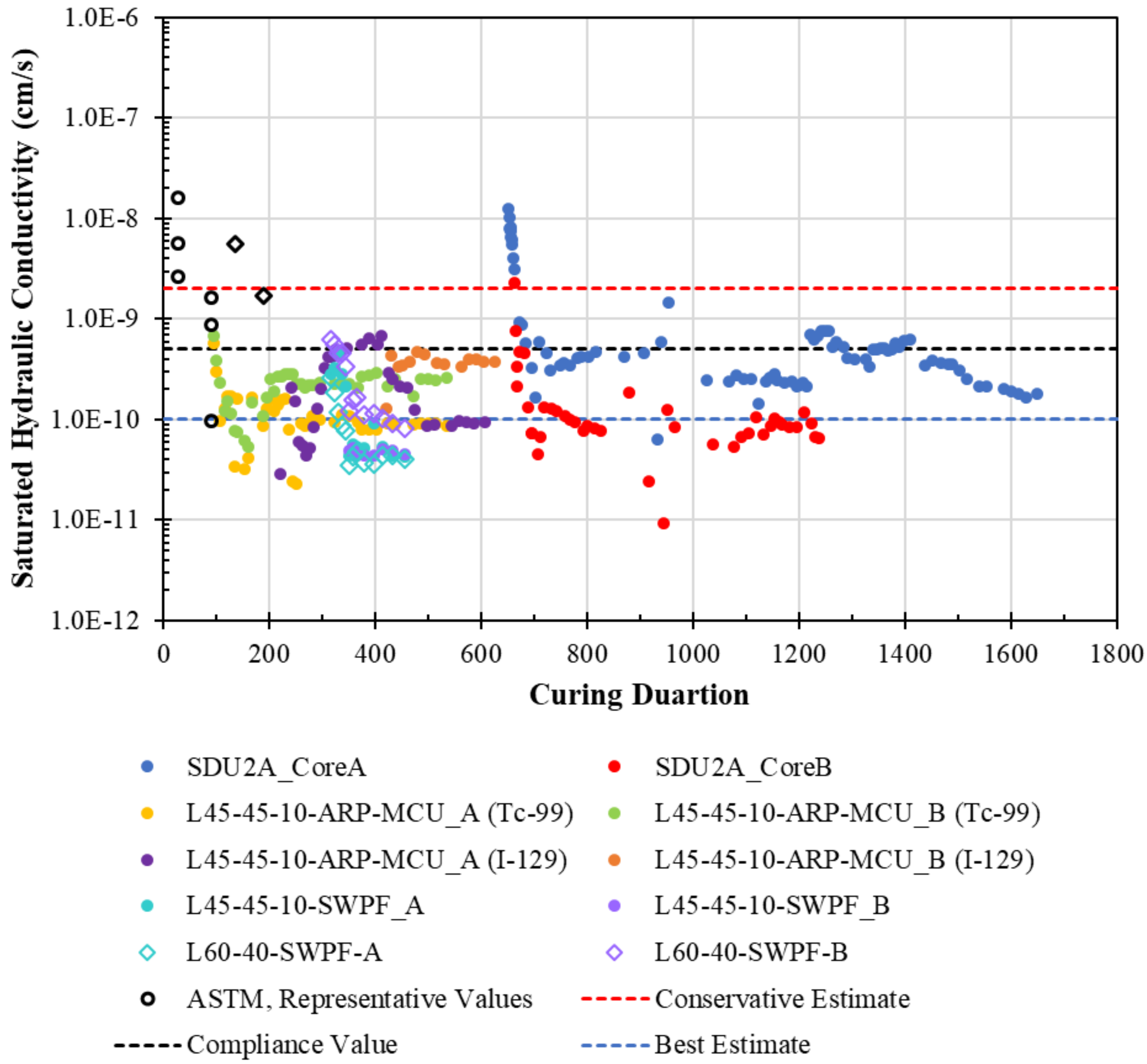
Given the comparisons between the typical 45-45-10 saltstone K_{sat} values and the 60-40 cement-free saltstone K_{sat} values, it is recommended that the same initial K_{sat} values be applied to both mixes for modeling saltstone performance.

Figure 4: ASTM- and DLM- Measured Saturated Hydraulic Conductivities as a Function of Curing Duration (1 of 2)



Note: Circles represent ASTM samples of 45-45-10 mix and diamonds represent the 60-40 mix.

Figure 5: ASTM- and DLM- Measured Saturated Hydraulic Conductivities as a Function of Curing Duration (2 of 2)



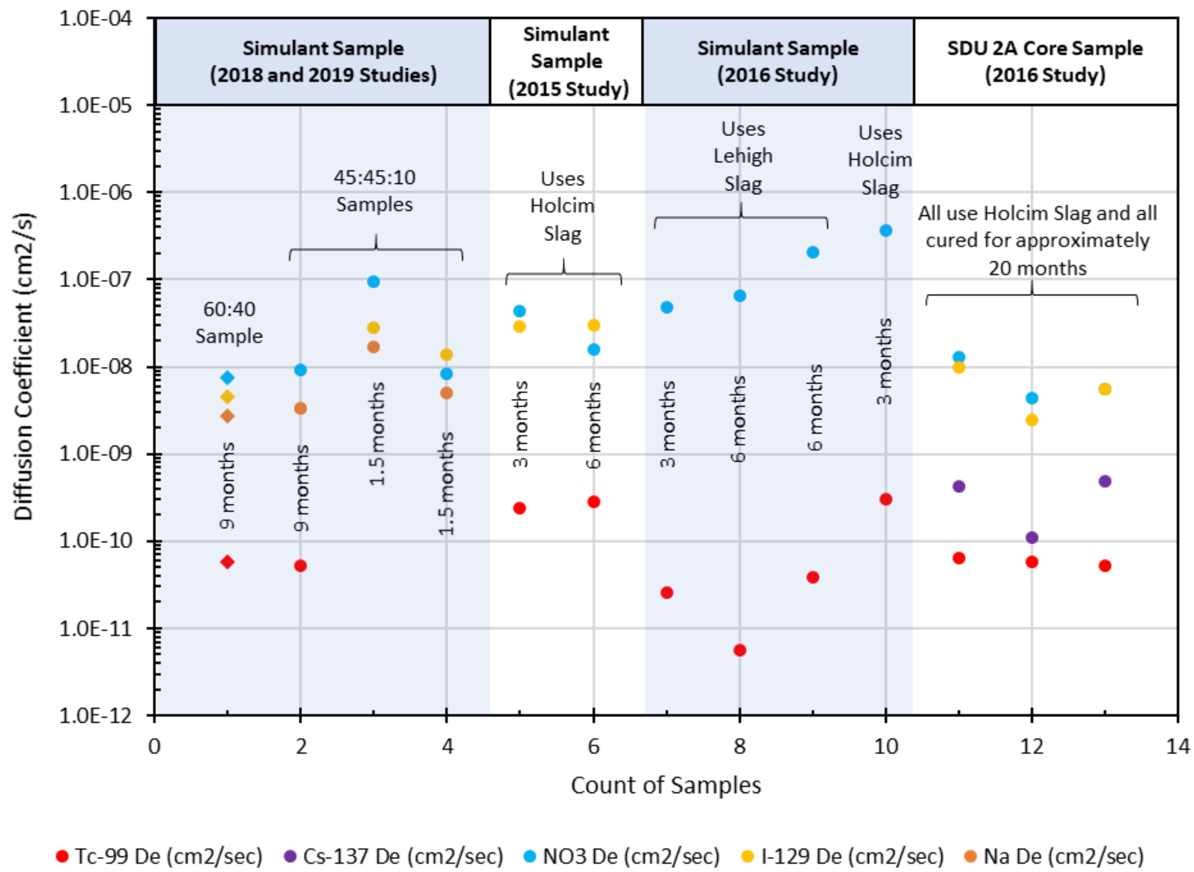
Note: Circles represent ASTM samples of 45-45-10 mix and diamonds represent the 60-40 mix.

Cement-Free Saltstone Initial Effective Diffusion Coefficients

The cement-free samples were also analyzed by SREL to determine the initial effective diffusion coefficients (D_e) (SREL DOC No. R-20-0002, Rev. 1.0 [SRRA099188-000010]). These values were determined using an approach described as Method 16.1 by the American National Standards Institute, Inc./American Nuclear Society (ANSI/ANS16.1) and in accordance with EPA Method 1315. The resulting values for cement-free saltstone are shown in Figure 6 along with the values from previous studies (previously shown in SRR-CWDA-2018-00004). As with Figures 3, 4, and 5, the circles in Figure 6 denote values based on the 45-45-10 mix and the diamonds denote values for the 60-40 cement-free mix.

The cement-free values for D_e are consistent with those measured for the 45:45:10 samples. Therefore, it is recommended that the same initial D_e values be applied to both mixes for modeling saltstone performance.

Figure 6: Summary of Saltstone Effective Diffusivities Measured by SREL



Note: For Count #2, the Na value is obscuring a similar value for I-129 and for Count #13, the I-129 value is obscuring a similar value for NO_3.

Cement-Free Saltstone Initial Reducing Capacity

Finally, SREL provided a comparison of the 45-45-10 saltstone reducing capacities versus cement-free (60-40) saltstone reducing capacities in Table 5 of *Contaminant Leaching from Saltstone Simulants: Summary of EPA 1315 and Dynamic Leaching Method Results for FY2019* (SREL DOC No. R-20-0002, Rev. 1.0 [SRRA099188-000010]). These values were measured using the Ce(IV) method. Based on the SREL estimates, the 45-45-10 mix has a reducing capacity of 0.640 milliequivalents of electrons per gram (meq e^-/g) while cement-free has a slightly lower reducing capacity of 0.625 meq e^-/g. Table 4.3-9 of the 2019 SDF PA indicated that three different sets of reducing capacities were considered for simulating saltstone (SRR-CWDA-2019-00001). The basis for these values was documented in *Recommended Reducing Capacity for Saltstone for the SDF PA* (SRR-CWDA-2018-00048). Table 20 shows how the SREL-measured reducing capacities compare to recommended values used for modeling.

While the SREL-measured values of 0.640 meq e^-/g and 0.625 meq e^-/g are both lower than the Best Estimate in Table 20 (i.e., the values used for the Realistic Case), the reducing capacities are relatively close. Regardless, they are both considerably higher than the recommended compliance value of 0.500 meq e^-/g, indicating that the Compliance Case of the SDF PA is still defensible with respect to the reducing capacity. Therefore, the recommended values in Table 20 are reasonable to apply to both mixes.

Table 20: Summary of Measured and Recommended Reducing Capacities for Saltstone

	Measured or Recommended Reducing Capacities for Saltstone (meq e^-/g)
Measured 45-45-10 Saltstone	0.640
Measured 60-40 Cement-Free Saltstone	0.625
Recommended Best Estimate (Realistic)	0.650
Recommended Compliance Value (Most Probable and Defensible)	0.500
Recommended Conservative Estimate (Pessimistic)	0.350

Summary of Recommended Material Properties for Cement-Free Saltstone

Table 21 provides a summary of the recommendations for cement-free saltstone material properties based on preceding discussions.

Table 21. Comparison of Recommended Material Properties

Parameter	Unit	Current Saltstone	Cement Free Saltstone	Justification for Cement-Free Recommendation
Global Values - For All Modeling				
Dry Bulk Density	g/mL	0.932	0.932	Based on an analytical analysis of the cement-free design mix and a comparison to the results of an equivalent analysis using the design mix for typical 45-45-10 saltstone.
Solid Phase (Particle) Density	g/mL	2.72	2.72	
Porosity	unitless	0.656	0.656	
Compliance Value - For Compliance Case				
Initial Saturated Hydraulic Conductivity (K_{sat})	cm/sec	5.0E-10	5.0E-10	Based on DLM-based measurements of cement-free saltstone and comparison to the results of equivalent measurements using typical 45-45-10 saltstone.
Initial Effective Diffusion Coefficient (D_e)	cm^2/sec	1.3E-08	1.3E-08	Values based on EPA Method 1315 for cement-free saltstone and comparison to the results of equivalent values using typical 45-45-10 saltstone.
Reducing Capacity	meq e^-/g	0.500	0.500	Based on Ce(IV) measurements for cement-free saltstone and comparison to the results of equivalent measurements using typical 45-45-10 saltstone.
Best Estimate - For Realistic Case				
Initial Saturated Hydraulic Conductivity (K_{sat})	cm/sec	1.0E-10	1.0E-10	Based on DLM-based measurements of cement-free saltstone and comparison to the results of equivalent measurements using typical 45-45-10 saltstone.
Initial Effective Diffusion Coefficient (D_e)	cm^2/sec	6.8E-09	6.8E-09	Values based on EPA Method 1315 for cement-free saltstone and comparison to the results of equivalent values using typical 45-45-10 saltstone.
Reducing Capacity	meq e^-/g	0.650	0.650	Based on Ce(IV) measurements for cement-free saltstone and comparison to the results of equivalent measurements using typical 45-45-10 saltstone.
Conservative Estimate - For Pessimistic Case				
Initial Saturated Hydraulic Conductivity (K_{sat})	cm/sec	2.0E-09	2.0E-09	Based on DLM-based measurements of cement-free saltstone and comparison to the results of equivalent measurements using typical 45-45-10 saltstone.
Initial Effective Diffusion Coefficient (D_e)	cm^2/sec	3.4E-08	3.4E-08	Values based on EPA Method 1315 for cement-free saltstone and comparison to the results of equivalent values using typical 45-45-10 saltstone.
Reducing Capacity	meq e^-/g	0.350	0.350	Based on Ce(IV) measurements for cement-free saltstone and comparison to the results of equivalent measurements using typical 45-45-10 saltstone.

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