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# M-Star® Modeling of SME Mixing with Three Impeller Blades

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December 2022

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# EXECUTIVE SUMMARY

Before a sample of the Slurry Mix Evaporator (SME) can be taken, the SME product sampling procedure requires that the agitator power be stable between 20 and 30 kW for at least one hour. The SME transfer to Melter Feed Tank (MFT) procedure also requires the SME agitator power be stabilized between 20 and 30 kW prior to transfer. These requirements are specified to ensure samples are homogeneous, as discussed in the Waste Form Qualification Report. During SME Batch 804, the agitator power dropped to 19 kW and struggled to achieve and maintain 20 kW. It was later discovered that the cause of the power drop was due to one of the bottom blades of the agitator breaking off. Both the sample and the transfer occurred without the power stabilizing between 20 and 30 kW. Therefore, the quality of SME Batch 804 is indeterminate, and homogeneity was questionable.

To evaluate mixing in the SME with a broken agitator containing only three blades (90 degrees apart with space for a missing blade) on the bottom impeller, the Savannah River National Laboratory (SRNL) was requested to perform computer simulations of impeller mixing in the SME using M-Star® software. The simulations will be used to determine if SME Batch 804 was well mixed and satisfies homogeneity requirements.

The M-Star® software is currently classified as Level C waste form affecting (WFA) in Software Classification Document X-SWCD-A-00011, Rev. 1 in accordance with the latest revision of Manual 1Q Procedure 20-1.

The conclusions from the work follow.

- The reduction in impeller power number after losing one or two blades observed in the M-Star® simulations is consistent with the reduction in the applied power to the agitation observed in the DWPF data.
- The dispersion of tracer particles observed in the M-Star® simulations shows the SME to be well mixed with three blades on the bottom impeller.
- The concentration of the miscible scalar observed in the M-Star® simulations shows the SME to be well mixed with three blades on the bottom impeller. The concentration of the scalar at the sample pump inlet, the transfer pump inlet, and the bulk tank concentration are within 2% of each other after simulation runtime of 1500 seconds.
- Based on the 95% mixing criterion, the vessel is homogeneous after 1500 seconds with an impeller speed of 106 rpm or 130 rpm.

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| CFD | Computational Fluid Dynamics |
| DWPF | Defense Waste Processing Facility |
| EN | Elson – Nienow |
| HB | Herschel Bulkley |
| LES | Large Eddy Simulation |
| MFT | Melter Feed Tank |
| PBT | Pitch Blade Turbine |
| QA | Quality Assurance |
| RANS | Reynolds Averaged Navier-Stokes |
| Re | Reynolds number |
| RPM | Revolutions per minute |
| SB | Sludge Batch |
| SME | Slurry Mix Evaporator |
| SRAT | Sludge Receipt and Adjustment Tank |
| SRMC | Savannah River Mission Completion |
| SRNL | Savannah River National Laboratory |
| SWCD | Software Classification Document |
| TTR | Technical Task Request |
| WFA | Waste Form Affecting |

## 1.0 Introduction

Before a sample of the Slurry Mix Evaporator (SME) can be taken, the SME product sampling procedure requires that the agitator power be stable between 20 and 30 kW for at least one hour.[1] The SME transfer to Melter Feed Tank (MFT) procedure also requires the SME agitator power be stabilized between 20 and 30 kW prior to transfer.[2] These requirements are specified to ensure samples are homogeneous, as discussed in the Waste Form Qualification Report.[3, 4] During SME Batch 804, the agitator power dropped to 19 kW and struggled to achieve and maintain 20 kW. It was later discovered that the cause of the power drop was one of the bottom blades of the agitator breaking off. Both the sample and the transfer occurred without the power stabilizing between 20 and 30 kW. Therefore, the quality of SME Batch 804 is indeterminate, and homogeneity was questionable.[5, 6]

To evaluate mixing in the SME with a broken agitator containing only three blades (90 degrees apart with space for a missing blade) on the bottom impeller, the Savannah River National Laboratory (SRNL) was requested to perform computer simulations of impeller mixing in the SME using M-Star® software, per Technical Task Request (TTR) X-TTR-S-00089 issued by Savannah River Mission Completion (SRMC).[5] The simulations will be used to determine if SME Batch 804 was well mixed and satisfies homogeneity requirements. The simulation results will be used to support the disposition of 2021-NCR-05-0033.[6]

The M-Star® software is currently classified as Level C WFA in Software Classification Document X-SWCD-A-00011, Rev. 1 in accordance with the latest revision of Manual 1Q Procedure 20-1.

M-Star® software is a computational fluid dynamics (CFD) program that utilizes the lattice-Boltzmann method rather than the traditional Reynolds-averaged Navier–Stokes (RANS) approach. This allows for simulations to be run quickly while delivering results accurately. The user interface allows the user to focus on the system and the process instead of the small nuances like other CFD software.

M-Star® software was used previously to develop and qualify a model that accurately calculated the release rate of retained hydrogen from benchtop vessels during Sludge Batch (SB) 3 and SB5 qualification testing. This model was then used to simulate hydrogen release from DWPF process vessels.[7]

## 2.0 Approach

SRNL performed simulations to determine homogeneity in SME Batch 804 when mixing the SME with three blades on the bottom impeller of the agitator (90 degrees apart with space for a missing blade). The simulations emulated SME Batch 804, utilizing both qualitative and quantitative modeling methods. The qualitative modeling used tracer particles to create a visualization of the mixing in the SME. These tracer particles have no impact on the mixing or the capability of the mixer. The quantitative modeling used a miscible scalar to measure the scalar concentration at the sampling and transfer pump inlets. These concentrations were compared with each other, as well as with the bulk concentration in the vessel. The miscible scalar quantified the homogeneity in the SME. The frit particles were included in some of the simulations. These particles affect the mixing and fluid motion in the SME as well as the mixing and fluid motion in the simulations. Both methods were used to assess homogeneity. An additional comparison with a four-blade bottom impeller, which is known to produce mixing homogeneity, was performed.

### 2.1 Modeling SME Mixing

Figure 1 shows the model of the SME used to perform the simulations. The vessel is a flat bottom cylinder with a diameter of 12 feet, height of 10.5 feet, and slurry level of 9.75 feet. The vessel contains three sets of heating/cooling coil assemblies, each assembly containing 18 coils and the centerline distance between two adjacent coils in an assembly is 3.5 inches.[a] The coils surround the agitator and the coil assemblies have centerline diameters of 46.5, 52.5, and 58.5 inches and are ~67 inches tall.[8] The coils have a 2-inch outside diameter. The agitator includes a top three blade 45-degree axial flow impeller (the top blade is a hydrofoil in the SME) and a bottom flat blade impeller containing three blades 90 degrees apart. The impellers have a diameter of 36 inches. The axial flow impeller was the standard M-Star® axial flow impeller. The radial flow impeller blades were 9.75 inches high. Internals such as the pump/shaft casings, bubblers, supply and return heating/cooling water lines and supports, were excluded from the simulation. Tracer particles and miscible scalars were added above and on the inside radius of the cooling coils. The locations of the inlet to the transfer pump and the sample pump are shown near the bottom of the vessel. The sample pump has coordinates of x = -1.55 m, y = 0.337 m, and z = 0 m. The transfer pump has coordinates of x = 1.49 m, y = 0.32 m, and z = 0 m. If the tank is "well mixed", the location of the sample pump and transfer pump should have minimal effect on the results.

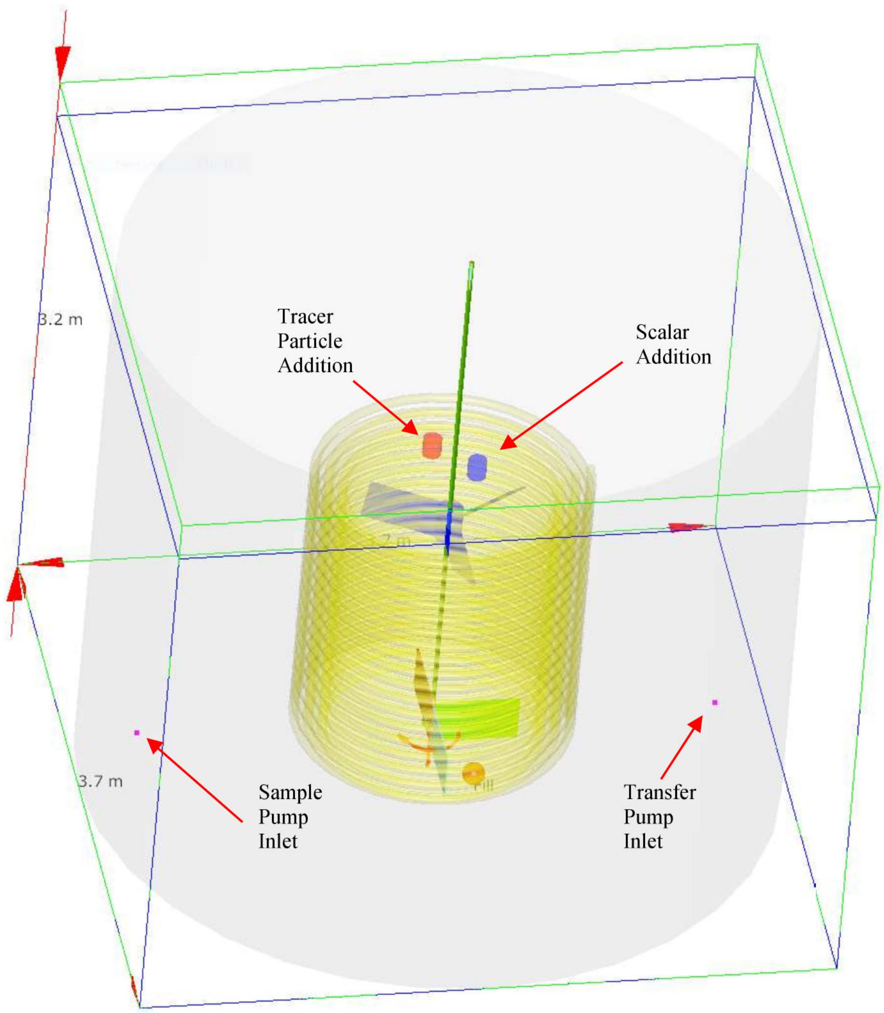


**Figure 1. M-Star® Model of SME with 3 Blades on the Bottom Impeller**

[a] The SME vessel has a sloped bottom. The initial model developed for previous work had a flat bottom, and it was used for this work. The SME has a height of 18 ft, but since only the height of the slurry is important for these simulations, a vessel height of 10.5 ft was selected to reduce the memory needed for the simulations.

2.2 Quality Assurance

The requested work is described in TTR X-TTR-S-00089 and directed by TTQAP SRNL-RP-2021-05004.[5,9] The Functional Classification of this task is Production Support. SME homogeneity is waste form affecting and needs to follow the quality assurance requirements of RW-0333P.[10] Requirements for performing reviews of technical reports and the extent of review are established in Manual E7 2.60. This document, including calculations, was reviewed by Design Verification. SRNL documents the Design Verification using the SRNL Technical Report Design Checklist contained in WSRC-IM-2002-00011, Rev. 2. The Design Checklists for this report are stored in electronic laboratory notebook experiment Y5714-00412.

## 3.0 Results and Discussion

### 3.1 SME Mixing

#### *3.1.1 M-Star® SME Model*

The authors performed M-Star® CFD simulations of impeller mixing in the DWPF SME. They used the model of the DWPF SRAT developed previously to investigate retained hydrogen release (see Figure 1).[7] The model vessel was a cylindrical tank with a flat bottom and cooling coils. The SME vessel is mixed with an impeller containing a 3-blade axial flow impeller on top and a 4-blade flat impeller on the bottom. In the simulations, one or two of the blades from the flat blade impeller were removed. Internal components such as the sample and transfer pump volute and casing, bubbler, and supply and return cooling/steam lines were not included. While these internal components would provide some resistance to flow, the effect is believed to be small. In addition, these components would affect flow with four blades on the bottom impeller. The results discussed later show a small difference in mixing effectiveness when the bottom impeller contains three blades rather than four blades. The volume of slurry in the tank is 8,000 gallons.[a]

The following slurry properties were used for the simulations:

- Slurry yield stress = 43 Pa
- Slurry consistency = 93 cP
- Slurry density = 1.47 g/mL

The slurry properties were determined from sludge batch 9 data.[11] The cavern model described in equation [4] in the software test plan shows that the cavern diameter is proportional to fluid density to the 1/3 power and inversely proportional to fluid yield stress to the 1/3 power.[12] A 10% decrease in the fluid density would decrease the cavern diameter by 3%, and a 10% increase in yield stress would decrease the cavern diameter by 3.5%. Given a power number of 4.4 (from subsequent simulations), an impeller speed of 130 rpm, an impeller diameter of 3 feet, a yield stress of 43 Pa, and a density of 1.47 g/mL, the calculated cavern diameter is ~13 feet, which is larger than the SME diameter (12 feet).

Mixing effectiveness was assessed by the following approaches:

- 100,000 tracer particles were added above the cooling coils, and their location in the vessel was determined after 60 or 300 seconds.
- A miscible scalar was added above the cooling coils, and its concentration throughout the vessel was determined.
- The miscible scalar concentration was measured at the inlet to the transfer pump and the sample pump as a function of time.
- In some simulations, glass frit was added to assess its impact on mixing the SME and to assess how well it was distributed throughout the vessel.

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[a] This volume was used in the previous simulations of SRAT mixer, and it is larger than the volume in the SME (7,400 gallons). This difference provides some conservatism to these simulations.

### *3.1.2 DWPF Data*

Figure 2 shows the power draw of the impellers. When the first impeller blade was lost, the power draw decreases by approximately 15%. When the second impeller blade was lost, the power draw decreases by approximately an additional 20%.

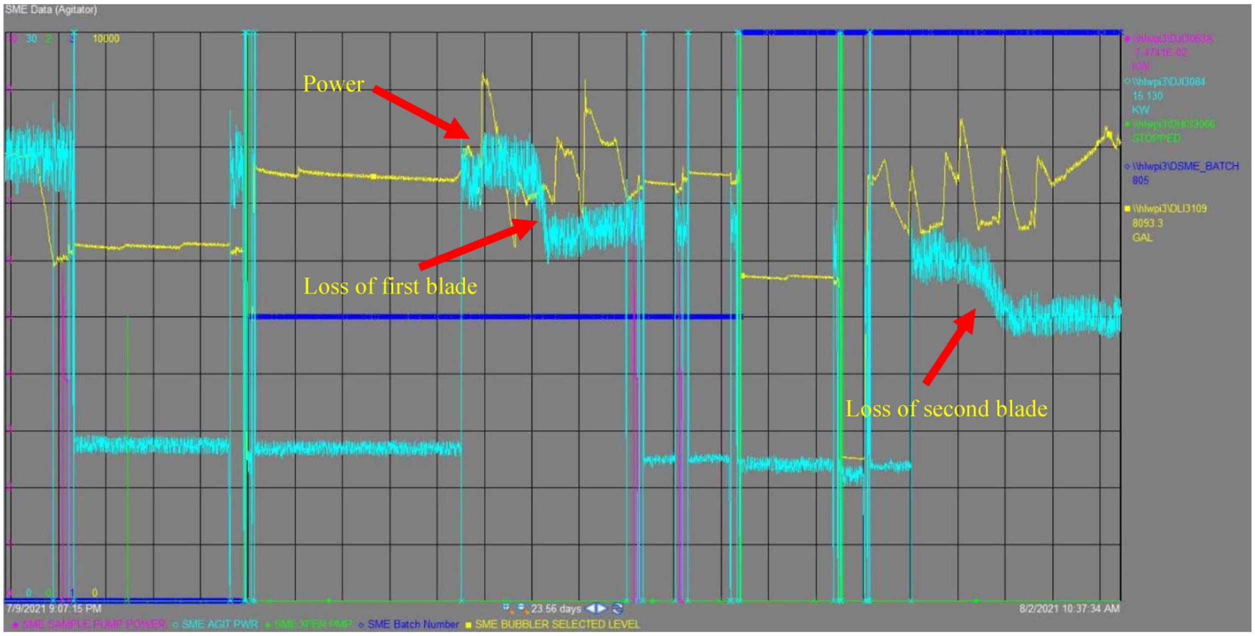



**Figure 2. SME Agitator Impeller Power Draw**

### *3.1.3 Simulations to Determine Power Number*

Figure 3 shows the calculated power number from the M-Star® simulations using 4 blades, 3 blades, and 2 blades on the bottom impeller.[a] The power number with 3 blades is ~ 15% less than the power number with 4 blades, and the power number with 2 blades is ~20% less than the power number with 3 blades. These results are consistent with the power draw found in PI when blades were lost from the bottom impeller (see Figure 2) and provide confidence in the ability of M-Star® to simulate impeller mixing of a Bingham plastic fluid.

[a] In the case with two blades on the bottom impeller, the blades were adjacent.

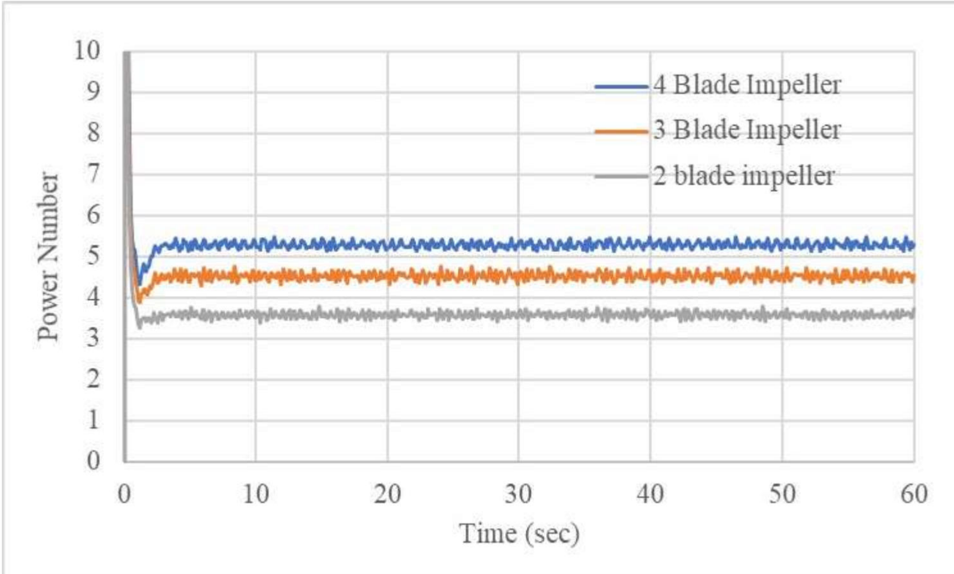



**Figure 3. Impeller Power Number from M-Star® Simulations**

Figure 4 shows the calculated flow number from the M-Star® simulations using 4 blades, 3 blades, and 2 blades on the bottom impeller.[a] The flow number is used to determine the pumping capacity of the impeller. The flow number to the side was selected for comparison, because it will best represent the radial flow generated by the flat blade impeller. The flow number with 3 blades is ~ 20% less than the flow number with 4 blades, and the flow number with 2 blades is ~15% less than the flow number with 3 blades. The loss of a blade on the bottom impeller will lead to a decrease in fluid motion in the vessel, but the reduction in fluid motion may not be enough to lead to incomplete mixing in the vessel.

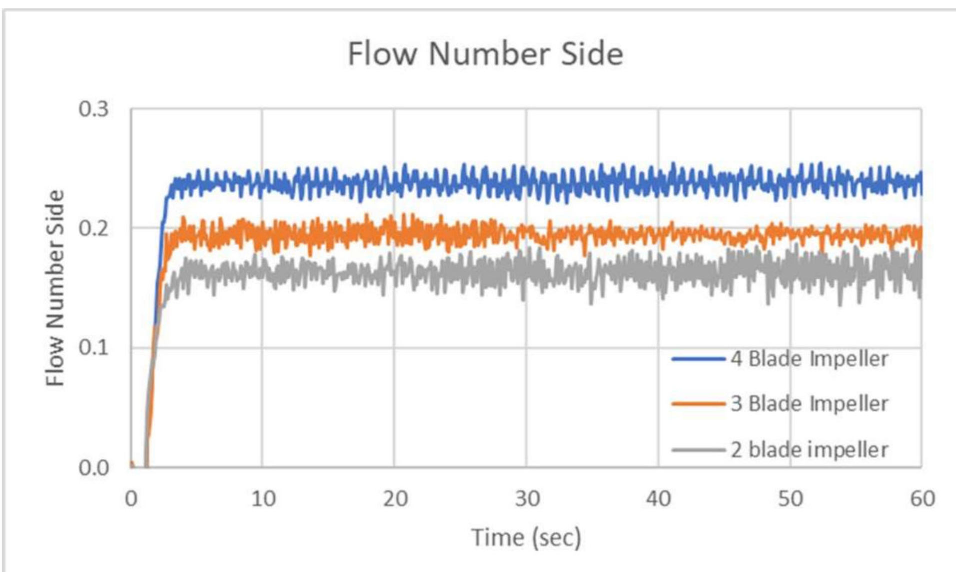



**Figure 4. Impeller Side Flow Number from M-Star® Simulations**

[a] The M-Star® software provides flow numbers for the top, bottom, and side of the impeller region. Given that the bottom impeller is a radial flow impeller, the flow number for the side was selected to best represent the effects of losing blades from this impeller.

### *3.1.4 Simulations using Tracer Particles*

Figure 5 shows the location of the tracer particles in the SME after mixing for 60 seconds with 4 blades on the bottom impeller. The figure shows the particles to be well dispersed in the vessel. However, there are some regions near the upper corners of the vessel that where the particle concentration appears to be lower than in the remainder of the vessel. This lower concentration of particles could be from the high yield stress, that the simulation was only run for 60 seconds, or a transient because the picture is a snapshot in time. The vessel is symmetric. Given equal radius and height, there should not be differences in mixing effectiveness or particle dispersion.

| Side | Top |
|---|---|

**Figure 5. Dispersion of particles after Mixing for 60 seconds in the SME with 4 Blades on the Bottom Impeller**

Figure 6 shows the location of the tracer particles in the SME after mixing for 60 seconds with 3 blades on the bottom impeller. In Figure 6, the particles are well dispersed in the vessel, although the dispersion appears to be less as compared to the bottom impeller with 4 blades. Areas where the dispersion is observed to be lower are near the regions where the fluid makes contact with the vessel. With the exception of the missing impeller blade, the dispersion in the vessel is symmetric. Given equal radius and height, there are no differences in mixing effectiveness or particle dispersion when comparing the 3 blades on the bottom impeller to 4 blades on the bottom impeller.

| Side | Top |
|---|---|

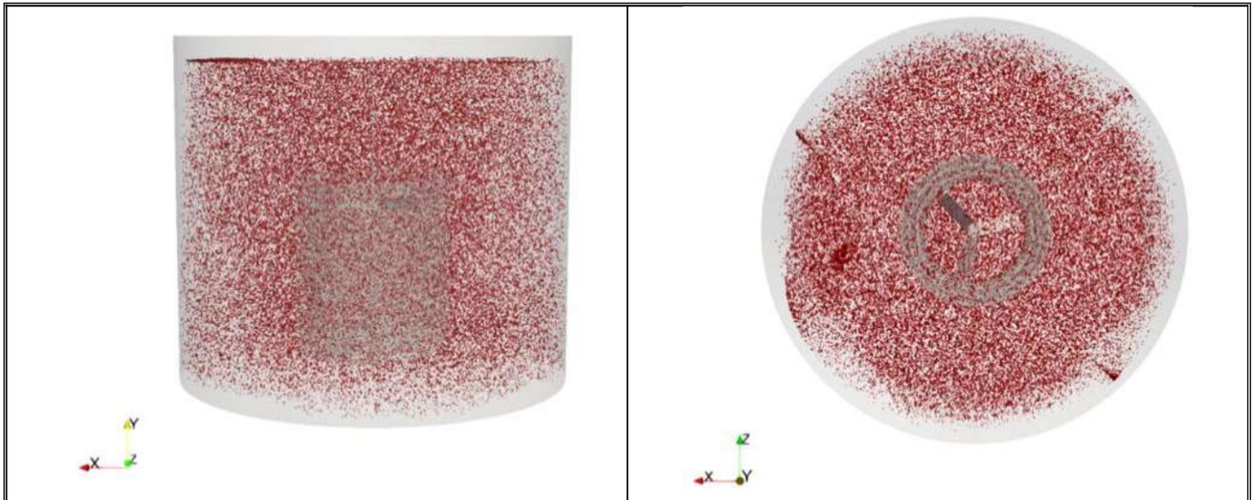
**Figure 6. Dispersion of particles after Mixing for 60 seconds in the SME with 3 Blades on the Bottom Impeller**

Figure 7 shows a comparison of the mixing in the SME with 4 blades on the bottom impeller and 3 blades on the bottom impeller. There is an area in the upper left of the vessels where there appears to be less tracer particles when the bottom impeller contained 3 blades. This difference could be from less effective mixing in the vessel or because the vessel was only mixed for 60 seconds. Additional simulations were performed with a longer mixing time, and the results will be discussed later. While the mixing appears to be better with 4 blades, the difference does not appear to be significant.

| 4-Blade | 3-Blade |
|---|---|

**Figure 7. Dispersion of Particles after Mixing for 60 seconds in the SME**

Figure 8 shows the location of the tracer particles in the SME after mixing for 300 seconds with 3 blades on the bottom impeller. The figure shows the particles to be more homogeneously dispersed in the vessel than after 60 seconds of mixing. There do not appear to be any unmixed regions in the vessel.

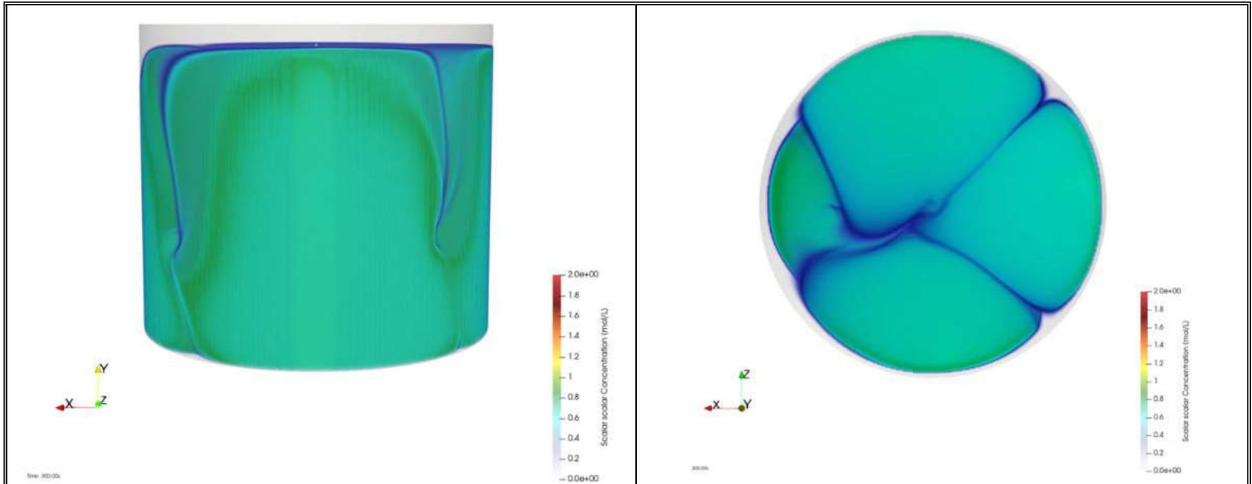


| Side | Top |
|---|---|

**Figure 8. Dispersion of Particles after Mixing for 300 seconds in the SME with 3 Blades on the Bottom Impeller**

*3.1.5 Simulations using Miscible Scalars*

Figure 9 shows the concentration of the miscible scalar in the vessel after 300 seconds of mixing using 3 blades. The figure shows the scalar to be well dispersed in the vessel, though there are regions near the diameter of the vessel where there are no scalars. There is variation in the scalar concentration in the vessel after mixing for 300 seconds, but in most of the vessel, the scalar concentration is much larger than zero, indicating that fluid mixing occurs throughout the vessel. Longer mixing times should reduce this variation. Figure 10 shows the scalar concentration at the inlet to the transfer pump and the inlet to the sample pump relative to the bulk scalar concentration in the vessel. The figure shows that after 300 seconds, the concentration at both inlets is within 10% of the bulk concentration in the vessel.



| Side | Top |
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**Figure 9. Scalar Concentration in the SME after Mixing for 300 seconds with 3 Blades on the Bottom Impeller**

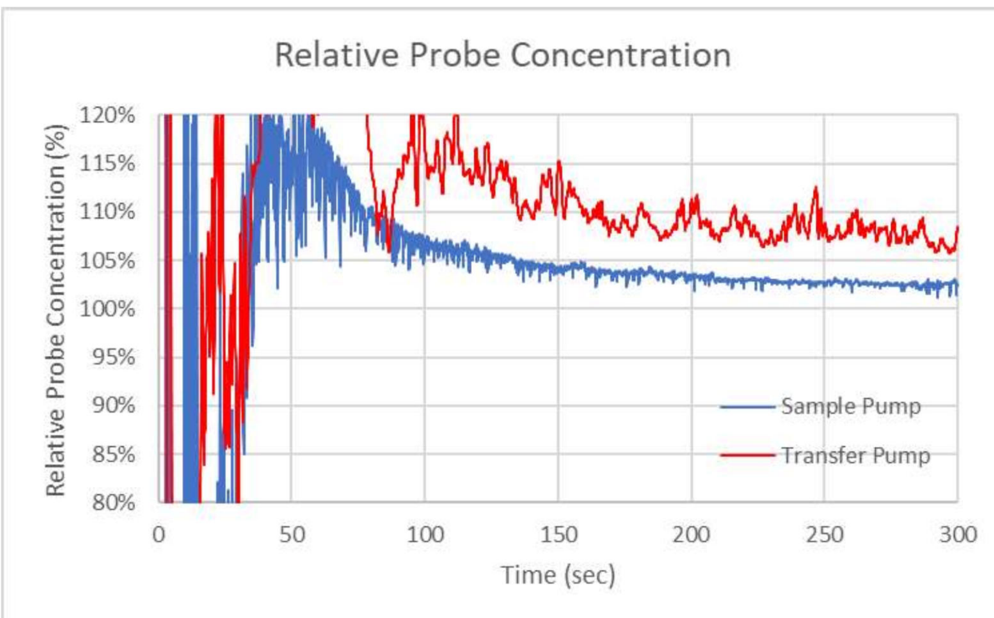



**Figure 10. Scalar Concentration at Sample Pump Inlet and Transfer Pump Inlet Compared with Bulk Concentration in the SME**

### *3.1.6 Simulations Including Free Surface*

Additional simulations were performed using the "free surface" feature of the software, which allows the liquid surface to form vortices. Figure 11 shows the tracer particles after 300 seconds when mixing with 3 blades on the bottom impeller. The figure shows the tracer particles to be well dispersed, and no vortex is observed at the liquid surface. The distribution of tracer particles is similar to that shown in Figure 8.


**Figure 11. Dispersion of Particles after Mixing for 300 seconds in the SME with 3 Blades on the Bottom Impeller with a Free Surface**

Figure 12 shows the miscible scale concentration throughout the vessel after 300 seconds. Again, the scalar is well dispersed in the vessel. While the vessel is not homogeneous after 300 seconds, the scalar concentration throughout the vessel is much larger than zero, and the scalar is being transported throughout the vessel.

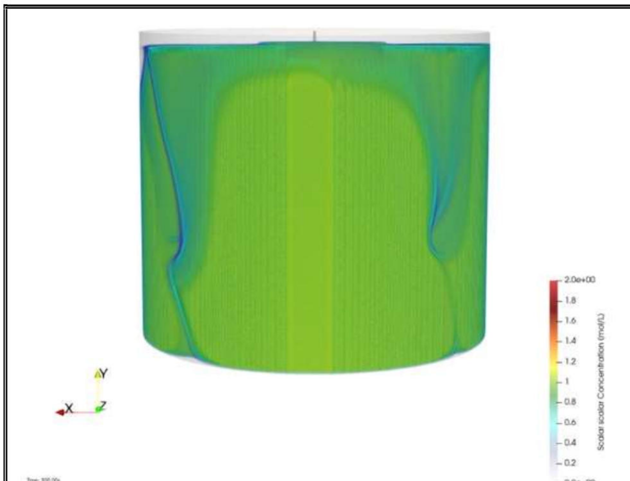
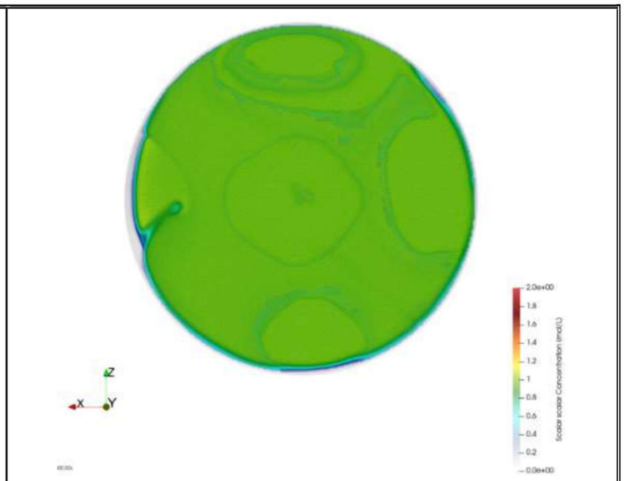
|  |  |
| --- | --- |
| Side | Top |

**Figure 12. Miscible Scalar Concentration after Mixing for 300 seconds in the SME with 3 Blades on the Bottom Impeller with a Free Surface**

Figure 13 shows the scalar concentration at the inlet to the transfer pump and the inlet to the sample pump relative to the bulk scalar concentration in the vessel. The scalar concentration at the sample pump inlet, the transfer pump inlet, and the bulk vessel concentration are approximately the same after 300 seconds. The concentration for the transfer pump approaches that of the sample pump, unlike that shown in Figure 10, hence the free surface assumption seems to increase the rate of mixing with respect to where the pumps are located.

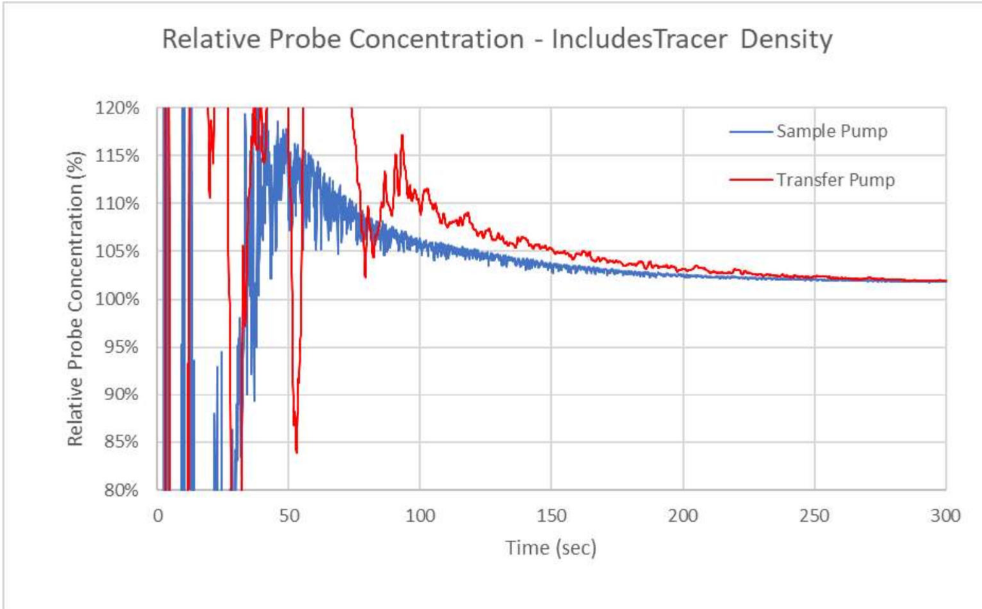



**Figure 13. Scalar Concentration at Sample Pump Inlet and Transfer Pump Inlet Compared with Bulk Concentration in the SME Including Scalar Density and a Free Surface**

Fluid mixing appears to be better with the free surface. Likely reasons for this difference are the free surface removes the stationary, no slip boundary that exists without the free surface. This boundary would provide a resistance to fluid motion and reduce the mixing effectiveness. In addition, the free surface allows vortexing to occur. While no significant vortexing was observed, the free surface may have allowed better fluid motion toward the top impeller.

*3.1.7 Simulations Including Glass Frit*

Simulations were performed in which 100,000 glass frit particles were added to the SME, and their movement through the vessel was tracked as a function of time. The particles had a density of 2.6 g/mL and a diameter of 126 micron.[13] Figure 14 shows the location of the glass frit particles in the vessel at the start of mixing and after mixing for 300 seconds. The figure shows the glass frit particles to be well dispersed in the SME.


**Figure 14. Dispersion of Added Glass Frit Particles after Mixing the SME for 300 Seconds**

*3.1.8 Simulations with an Impeller Speed of 106 RPM*

Following completion of the work described above, the authors were informed that during sludge batch 9 processing the impeller speed was 106 rpm rather than 130 rpm. Because of this change two additional simulations were performed with an impeller speed of 106 rpm. One of these simulations used three blades on the bottom impeller, and the other simulation used four blades on the bottom impeller.

In addition, the rheology of the sludge was adjusted to better represent the rheology of the material in the SME. The qualification sample had a calculated yield stress of 43 Pa and fluid consistency of 93 cP using the flow curve, and a measured density of 1.47 g/mL. The maximum density of this sludge during processing was 1.35 g/mL. This lower density would correspond to a lower insoluble solids concentration, a lower yield stress, and a lower fluid consistency.

The authors used the following approach to estimate the slurry rheology for the subsequent calculations. Water, which has no insoluble solids, no yield stress and a consistency of 1 cP, has a density of 1 g/mL. Yield stress and consistency increase exponentially with insoluble solids concentration.[14] For conservatism, the yield stress and consistency were assumed to be a linear function of slurry density with water as the zero point. The yield stress was calculated using equation [1], and the consistency using equation [2].

$$\tau_y = 43 \text{ Pa } [(1.35 - 1) \text{ g/mL}/((1.47 - 1) \text{ g/mL})] = 32 \text{ Pa} \qquad [1]$$

$$\eta = (93 - 1) \text{ cP } [(1.35 - 1 \text{ g/mL})/(1.47 - 1 \text{ g/mL})] + 1 \text{ cP} = 69 \text{ cP} \qquad [2]$$

The free surface boundary condition was also used in these simulations. Figure 15 shows the scalar concentration after 1500 seconds as a function of position in the SME for mixing with three blades on the bottom impeller and four blades on the bottom impeller. The colored portions of the figure show regions where the scalar concentration is within 5% of the bulk concentration. Less than 95% mixed regions are observed at the top corners of the vessels. The unmixed regions are slightly larger in the vessel with three blades on the bottom impeller. Both vessels are well mixed.

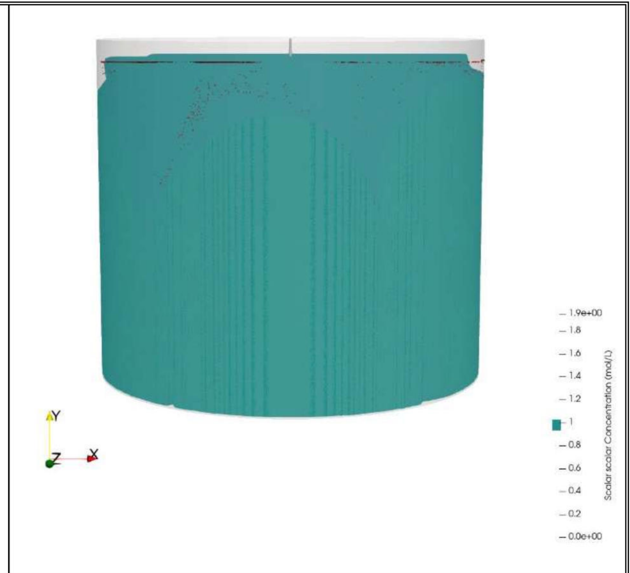
| | |
|---|---|
|  |  |
| 3-Blade | 4-Blade |

**Figure 15. Scalar Concentration in SME**

Figure 16 shows the relative standard deviation of the scalar in the SME as a function of time. The relative standard deviation is less than 5% (i.e., the vessel is 95% mixed) after ~1480 seconds. Since the DWPF is required to mix the SME for at least one hour prior to transfer to the melter feed tank, the simulation shows the vessel to be well mixed with three blades on the bottom impeller. The time to 95% mixed is ~ 1380 seconds with four blades on the bottom impeller.

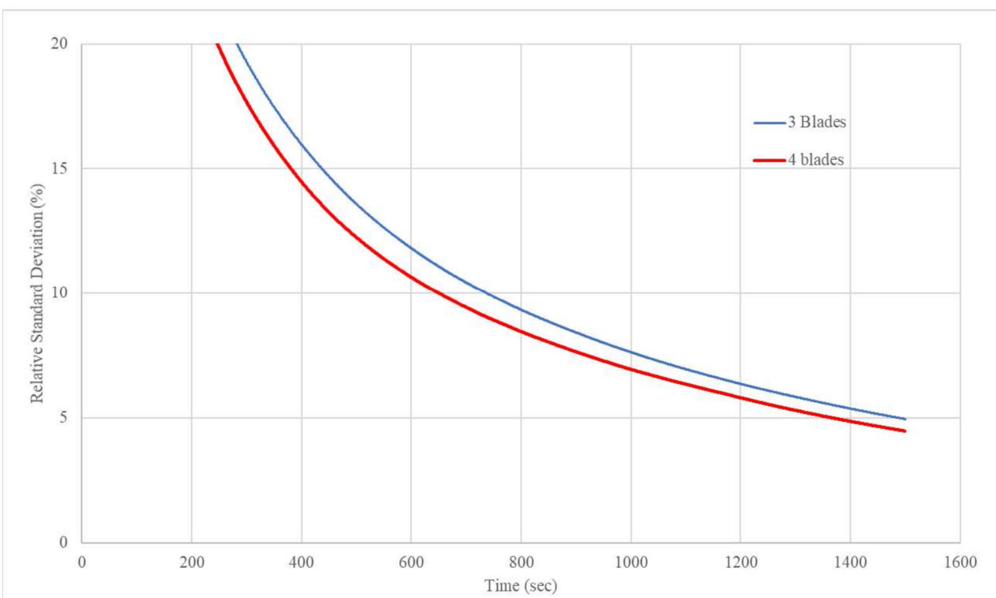



**Figure 16. Relative Standard Deviation of Scalar During SME Mixing**

Figure 17 shows the scalar concentration at the inlets to the sample pump and the transfer pump, as well as the bulk scalar concentration in the SME when mixing with three blades on the bottom impeller. The figure shows the concentration at the sample pump inlet is the same as the concentration at the transfer pump inlet after 200 seconds. Based on this result, the composition of the sludge in the collected sample would be the same as the composition of the sludge transferred to the melter. After ~1400 seconds, the scalar concentration at the inlets to the sample pump and the transfer pump is within 2% of the bulk concentration in the SME.

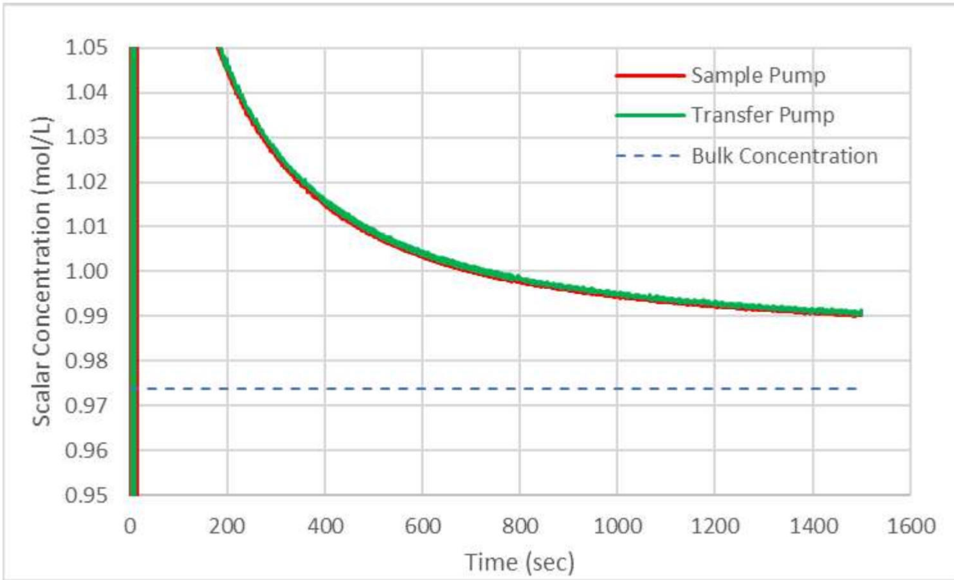



**Figure 17. Scalar Concentration at Inlets to Sample Pump and Transfer Pump with Three Blades on Bottom Impeller**

Figure 18 show the ratios of the scalar concentration at the sample pump inlet, the transfer pump inlet, and the bulk slurry in the SME. The concentrations at the sample pump inlet and the transfer pump inlet are the same, and they are within 2% of the bulk concentration in the slurry.

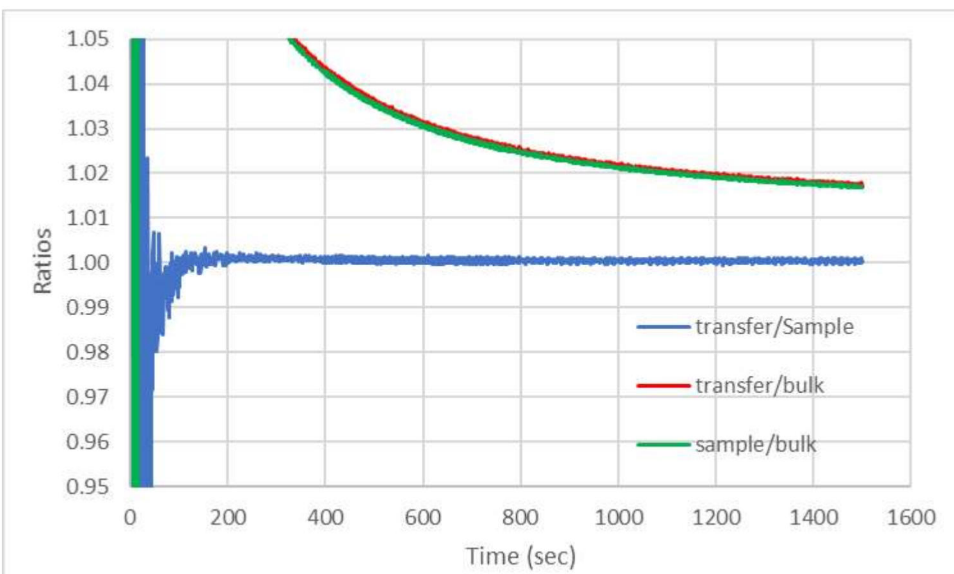



**Figure 18. Ratio of Scalar Concentrations at Sample Pump, Transfer Pump, and Bulk Slurry with Three Blades on Bottom Impeller**

Based on the results in Figures 15 – 18, the SME was well mixed after losing one of the blades on the bottom impeller, and the concentrations measured in the sample collected are representative of the concentrations of soluble species in the material transferred to the DWPF melter.

## 4.0 Discussion of Results

The SME is currently run at a maximum mixing speed of 106 rpm instead of the design maximum of 130 rpm. Therefore, a comparison test was performed to evaluate the difference between mixing speeds at 106 compared to 130 with three and four blades after mixing for 300 seconds. The velocity flow field, miscible scalar concentration field, and frit particle distribution were compared for each configuration and mixing speed. The physical properties are those identified in section 3.1.8.

- Slurry yield stress = 32 Pa
- Fluid consistency = 69 cP
- Fluid density = 1.35 g/mL

The fluid velocity fields are shown in Figure 19. For the cases where the impeller speeds are the same, the 4-blade generated fluid velocity field was greater at distances further from the impeller compared to the 3-blade generated fluid velocity field. This can be seen by the greenish yellow color extending further in the 4 blade cases when looking at the bottom of the vessel where the fluid is flowing away from the flat blade impeller. This contributes to faster mixing with 4 blades over 3 blades. The velocity field leaving the impeller at the 130 rpm conditions are greater than that for the 106 rpm conditions, indicating a faster mixing time for the 130 rpm conditions. In all cases the lowest velocity can be seen in the top corners of the vessel along the walls near the surface of the fluid.

There is not a significant difference in the mixing of the SME vessel with 3 or 4 blades. This can be seen by the scalar field images in Figure 20. The 3 and 4 blade simulations at the same mixing speeds show very similar scalar fields after 300 seconds of mixing, though there are differences. The regions of blue and green near the top part of the vessel where the fluid is not well mixed for the 106 rpm simulation is larger than that of the 130 rpm simulations. Moreover, the top right corners of the 106 rpm tests signify that there is little to no mixing in that region. Overall, the 130 rpm simulations show better mixing than the 106 rpm mixed simulations. This is further supported in Figure 21 where the degree of mixing (% of tank mixed) increases more quickly and the % mixed is greater in the 130 rpm simulations than the 106 rpm simulations. Furthermore the 3 blade 130 rpm simulation mixes more quickly than the 4 blade 106 rpm simulation showing that mixing speed is a larger factor than the number of blades in this situation.

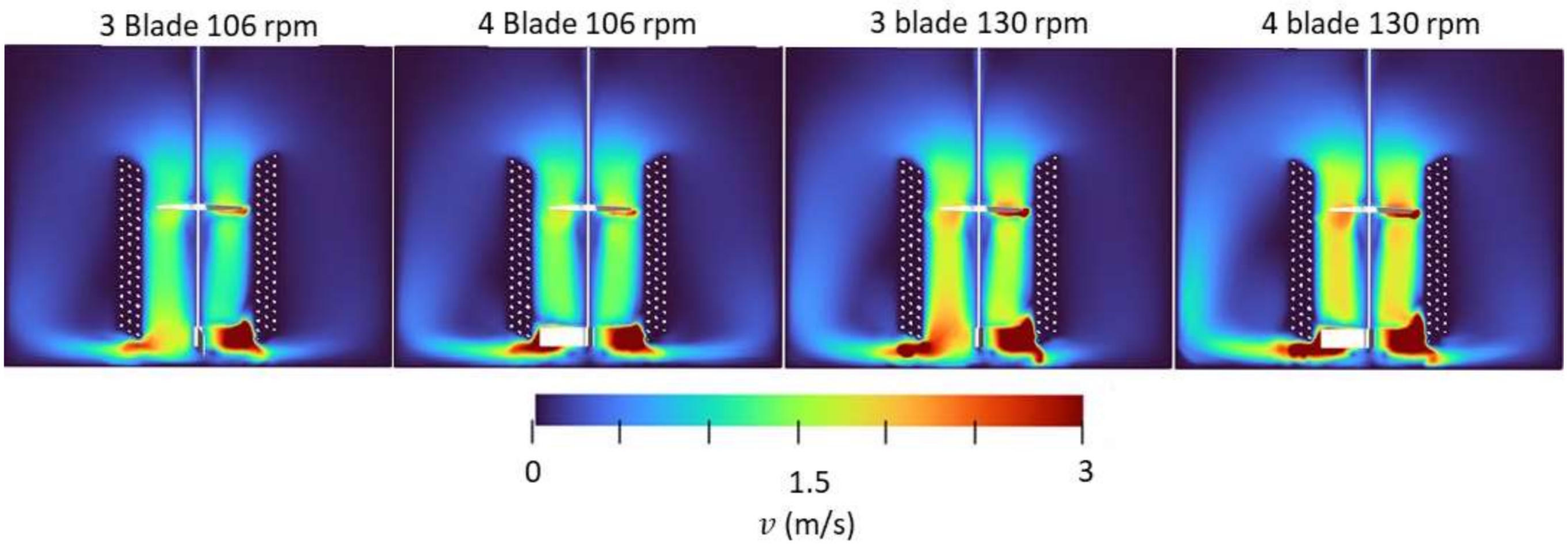



**Figure 19. Velocity Field at 300 seconds of simulated Time in the SME with 3 and 4 Blades at 106 and 130 rpm**

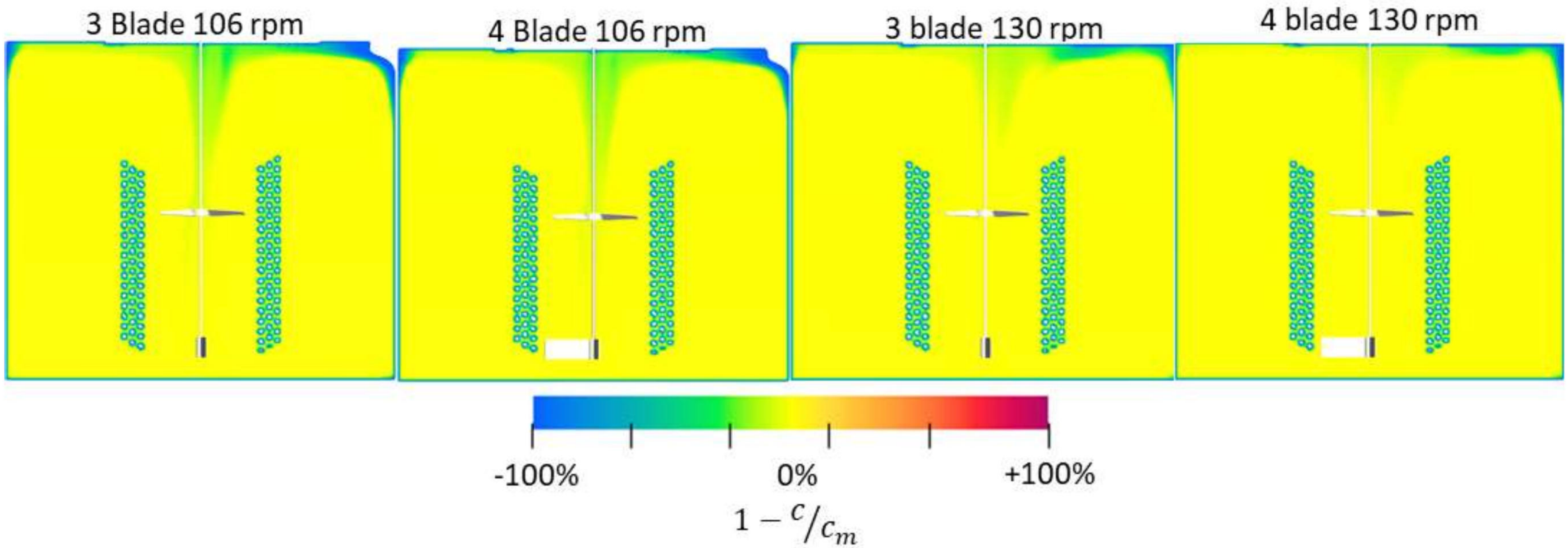



**Figure 20. Scalar Concentration at 300 seconds of simulated Time in the SME with 3 and 4 Blades at 106 and 130 rpm**

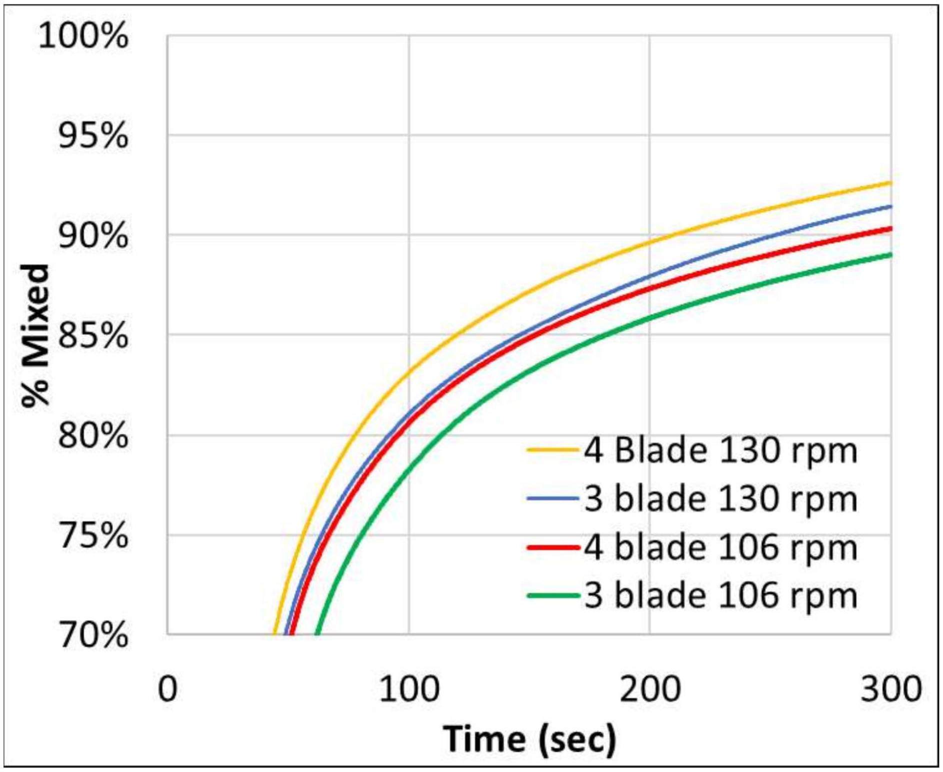



**Figure 21. Comparison of Degree of Mixing of Scalar as a Function of Time in the SME with 3 and 4 Blades at 106 and 130 rpm**

Frit particles were injected into the simulations to represent the frit added to the SME and illustrate how well the frit is mixed throughout the vessel. Figure 22 shows the dispersion of the particles after mixing for 300 seconds of simulated time. The vessel is shown at 3 different angles to properly show the dispersion of the particles. The results show that the mixing of the particles is similar for the 3 and 4 bottom bladed simulations at the same mixing speed. The dispersion is greater at higher mixing speeds. This is illustrated best by the top view of the vessel where at 106 rpm you can see areas along the vessel wall where the particles are not well mixed compared to the 130 rpm simulations where the particles are well mixed all around the perimeter of the vessel. However, the SME can be mixed to 95% homogeneity with three or four blades on the bottom impeller (see Figure 16) given a mixing time of at least 1500 seconds (25 minutes) and an impeller speed of at least 106 rpm.

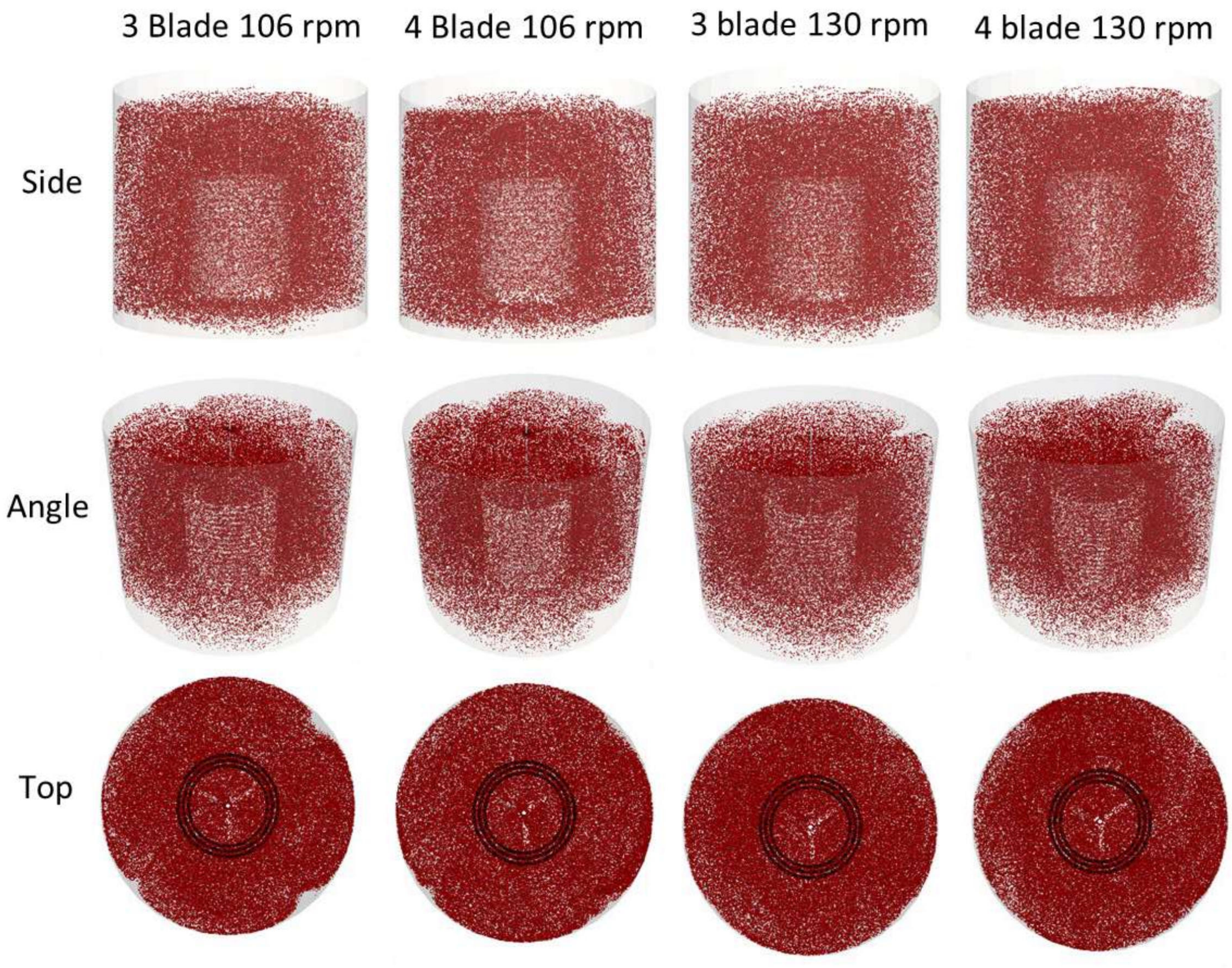



**Figure 22. Particle Dispersion at 300 seconds of simulated Time in the SME with 3 and 4 Blades at 106 and 130 rpm**

## 5.0 Conclusions

The conclusions from the work follow.

- The reduction in impeller power number after losing one or two blades observed in the M-Star® simulations is consistent with the reduction in the applied power to the agitation observed in the DWPF data.
- The dispersion of tracer particles observed in the M-Star® simulations shows the SME to be well mixed with three blades on the bottom impeller.
- The concentration of the miscible scalar observed in the M-Star® simulations shows the SME to be well mixed with three blades on the bottom impeller. The concentration of the scalar at the sample pump inlet, the transfer pump inlet, and the bulk tank concentration are within 2% of each other after simulation runtime of 1500 seconds.
- Based on the 95% mixing criterion, the vessel is homogeneous after 1500 seconds with an impeller speed of 106 rpm or 130 rpm.

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