Contract No:

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-08SR22470 with the U.S. Department of Energy (DOE) Office of Environmental Management (EM).

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Tank 50H Mixing Pump Run Time Reassessment

M. R. Poirier

JUNE 2020

SRNL-STI-2020-00122, Revision 0

SRNL.DOE.GOV

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Prepared for
U.S. Department of Energy

Keywords: *Mixing, Tank 50*

Retention: *Permanent*

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EXECUTIVE SUMMARY

Tank 50H is required to operate a single rotating standard slurry pump for 4.5 hours prior to transfers to the Salt Solution Receipt Tanks (SSRTs) in the Saltstone Production Facility (SPF). This mixing time is required to adequately mix miscible and immiscible liquids within Tank 50H and meet the Saltstone Waste Acceptance Criteria (WAC). The miscible liquids are aqueous solutions of dissolved salts, while the immiscible liquids include organic droplets such as Isopar® L. To support the accelerated salt processing rates from the Salt Waste Processing Facility (SWPF), a desire to reduce the transfer time of Decontaminated Salt Solution (DSS) downstream of SWPF was identified. This document describes the analysis performed to reassess the technical basis for the 4.5 hour mixing requirement for Tank 50H.

The analysis employed the following approaches to assess the required mixing time in Tank 50H.

- Assessing the impact of the required blending efficiency on the liquid blend time.
- Reassessing the conservatism within the previous Savannah River National Laboratory (SRNL) blend time calculation (SRNL-STI-2011-00362, Rev 0).
- Utilizing the Salt Disposition and Integration Project (SDIP) data to estimate the required mixing time.
- Determining if transfers into Tank 50H provide adequate mixing of the material.
- Assessing the blending occurring in the suction of the transfer pump.

Assessing the impact of differences between the pilot-scale miscible liquid blending tests and Tank 50H, shows that the 4X factor used in SRNL-STI-2011-00362 is overly conservative, and that the required blend time in Tank 50H can be reduced. At the current minimum liquid level in Tank 50H (76 inches), the calculated blend time is 60 minutes. The blend time would be longer at higher liquid levels in the tank. The analysis showed that reducing the required blending efficiency from 95% to 80% could reduce the required blending time to as low as 30 minutes (at a liquid level of 76 inches), provided the contents of Tank 50H are still acceptable for Saltstone.

An alternative to using the slurry pump to mix the tank contents is to use the “plunging jet” created by the added liquid and blending that occurs as fluid is drawn into the transfer pump suction. Adding liquid to Tank 50H through the downcomer in riser C1 creates a “plunging jet” that will blend the added material with the current contents of Tank 50H. The dilution factor could be as much as 250X. If the plunging jet is used to provide mixing in Tank 50H, the mixer pump should be indexed toward the downcomer through which the material is added to the tank to prevent accumulation of added material under the downcomer. As the liquid in Tank 50H enters the transfer pump suction to be transferred to Saltstone, the recently added material will blend with the other contents of Tank 50H, and the dilution factor could be as much as 600X. These two effects are multiplicative and can be combined. Mixing during the transfer into Tank 50H, combined with the mixing that occurs at the pump suction during the transfer from Tank 50H to Saltstone, would mix Tank 50H contents and would eliminate the slurry pump mixing required before transferring to Saltstone.

While unlikely, stratification could occur when liquid is added to Tank 50H. If the density difference between the added fluid and the existing fluid in Tank 50H is more than 5%, the potential for stratification exists. If the contents of Tank 50H have a density of 1.26 g/mL, the liquid added to Tank 50H should have a density between 1.20 and 1.32 g/mL to avoid stratification. If the density of the added liquid is outside this range, the potential for stratification should be evaluated.

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D	Nozzle diameter
D_j	Plunging jet diameter at liquid surface
D_z	Plunging jet diameter as a function of depth
DSS	Decontaminated Salt Solution
ETP	Effluent Treatment Plant
f	Fanning friction factor
Fr	Froude number
g	Gravitational acceleration
g_c	Constant
H	Height
H_p	Plunging jet penetration depth
L	Distance
m	Mixing efficiency
P	Pressure
Q	Flow rate
r	Radius of converging channel
Re	Reynolds number
SDIP	Salt Disposition and Integration Project
SPF	Saltstone Production Facility
SRNL	Savannah River National Laboratory
SRR	Savannah River Remediation
SSRT	Salt Solution Receipt Tank
SWPF	Salt Waste Processing Facility
TCCR	Tank Closure Cesium Removal
TTR	Technical Task Request
TTQAP	Task Technical and Quality Assurance Plan
U	Velocity
U_0	Nozzle discharge velocity
U_x	Velocity at distance x from pump
V_j	Velocity at liquid surface
WAC	Waste Acceptance Criteria
z	Change in elevation
V_0	Downcomer discharge velocity
θ_m	Mixing time at specified mixing efficiency
θ_{95}	Mixing time at 95% mixing efficiency

ν	Kinematic viscosity
ρ	Density

1.0 Introduction

Tank 50H is required to operate a single rotating standard slurry pump for 4.5 hours prior to transfers to the Salt Solution Receipt Tanks (SSRTs) in the Saltstone Production Facility (SPF).[1] This mixing time is required to adequately mix miscible and immiscible liquids within Tank 50H and meet the Saltstone Waste Acceptance Criteria (WAC).[2] The miscible liquids are aqueous solutions of dissolved salts, while the immiscible liquids include organic droplets such as Isopar® L. To support the accelerated salt processing rates from the Salt Waste Processing Facility (SWPF), the desire to reduce the transfer time of Decontaminated Salt Solution (DSS) downstream of SWPF was identified.[3] This document describes the analysis performed to reassess the technical basis for the 4.5 hour mixing requirement for Tank 50H.[4]

The following approaches were employed by Savannah River National Laboratory (SRNL) to reassess the required liquid blend time in Tank 50H.

- Assessing the impact of the required blending efficiency on the liquid blend time.
- Reassessing the conservatism within the previous SRNL blend time calculation (SRNL-STI-2011-00362, Rev 0).[5]
- Utilizing the Salt Disposition and Integration Project (SDIP) data to estimate the required mixing time.[6,7]
- Determining if transfers into Tank 50H provide adequate mixing of the material.
- Assessing the blending occurring in the suction of the transfer pump.

These approaches reassessed the duration and necessity of the slurry pump operation, as well as examined other Tank 50H operations to ensure adequate mixing.

The analysis looked at the reduction in blend time from reducing the required blending efficiency from 95% to 90%, 85%, and 80%.[8]

SRNL reviewed the original assessment document[5], as well as the data used to perform the analysis and the uncertainty analysis. Following the review, they determined a technical basis exists for reducing the blend time in Tank 50H.

In 2019, SRNL performed an analysis for Savannah River Remediation (SRR) that evaluated the impact of changing tank conditions (e.g., liquid level and pump elevation) on the miscible liquid blend time.[9] Those results and approach were applied to Tank 50H to account for differences between Tank 50H and the tanks investigated in the 2010-2011 work.

In 2010-2011, SRNL conducted pilot-scale miscible liquid blending tests to size pumps for blending the feed to the SWPF.[6,7] The testing measured the miscible liquid blend time as a function of tank geometry and pump operating parameters. That data was reviewed and applied to Tank 50H to estimate the required blend time for the tank.

A previous SRNL analysis subsequent of the original Tank 50H assessment showed that when liquid is added to a waste tank, a “plunging jet” can form when the liquid enters the tank.[10] This “plunging jet” entrains surrounding fluid, which is mixed with the fluid added to the tank. That approach was used, with the geometry and operating parameters of Tank 50H, to estimate the amount of mixing that occurs when additional material is added to Tank 50H.

Prior to being transferred to the SPF, the salt solution added to Tank 50H must enter the transfer pump suction. As the added salt solution moves from the addition point to the transfer pump suction, it will contact and blend with other material that is in Tank 50H.

1.1 <u>Quality Assurance</u>

This work was performed under a Technical Task Request (TTR).[3] The recorded data, analysis, and conclusions satisfy the Safety Significant requirements in the Task Technical and Quality Assurance Plan (TTQAP) associated with this TTR.[4]

Requirements for performing reviews of technical reports and the extent of review are established in manual E7 2.60.[11] SRNL documents the extent and type of review using the SRNL Technical Report Design Checklist contained in WSRC-IM-2002-00011, Rev. 2.[12]

2.0 Analysis

The analysis employed the following approaches to assess the required mixing time in Tank 50H.

- Assessing the impact of the required blending efficiency on the liquid blend time.
- Reassessing the conservatism within the previous SRNL blend time calculation (SRNL-STI-2011-00362, Rev 0).
- Utilizing the SDIP data to estimate the required mixing time.
- Determining if transfers into Tank 50H provide adequate mixing of the material.
- Assessing the blending occurring in the suction of the transfer pump.

A blending efficiency of 95% is often used in industry and was the target blending efficiency in the previous pilot-scale blending tests. A 95% blending efficiency means that the concentration of the selected species everywhere in the tank is within 5% of its bulk concentration in the tank. With a lower blending efficiency, the contents of Tank 50H might be acceptable for Saltstone, and the blend time would be reduced.

SRNL-STI-2011-00362 estimated a blend time of 1.1 hours and multiplied the blend time by 4X to account for differences between the pilot-scale testing and Tank 50H. This analysis looked at the effect of pump rotation, pump elevation, liquid level, and viscosity on liquid blend time to better define the required time in Tank 50H.

The pilot-scale mixing data collected to estimate the blend time in SRNL-STI-2011-00362 was reviewed, and a new blend time for Tank 50H was calculated.

A previous SRNL analysis of Tank 49H calculated the blending that occurred within the plunging jet created by the addition of liquid through the downcomer in the tank. That analysis was repeated using the conditions in Tank 50H.

The contents of Tank 50H are transferred to the SPF using a transfer pump. The suction of the transfer pump will draw fluid from throughout Tank 50H, so the added liquid will mix with the contents of the tank prior to being transferred to the SPF. This analysis evaluated the influence of the pump suction on mixing the feed to the SPF.

Inputs:

The following input parameters were provided by SRR and used in the assessment.[13]

- Planned additions
  - Effluent Treatment Plant (ETP): 30,000 gallons – 8.55 inches in Tank 50H
  - SWPF: 33,000 gallons – 9.4 inches in Tank 50H
  - Tank Closure Cesium Removal (TCCR): 120,000 gallons – 34.2 inches in Tank 50H
- Tank 50 volume
  - 41.5 inches minimum
    - 145,665 gallons minimum
  - 76 inches current minimum
    - 266,760 gallons current minimum
  - 346.25 inches maximum
    - 1,215,000 gallons maximum
- Tank 50H Influent Flow Rate
  - ETP: 100 gpm
  - Tank 11 (TCCR Operation): 96 gpm
  - SWPF: 150 gpm
- Inner diameter of Tank 50H inlet pipe

    - 3.26 inches
- Distance between Tank 50H inlet pipe (downcomer outlet) and liquid surface
    - 346.25 – 41.5 = 304.75 inches
    - 346.25 – 76 = 270.25 inches
- Distance of mixer pump nozzle above Tank 50H bottom
    - 5.5 + 6 = 11.5 inches
- Distance of transfer pump suction above Tank 50H bottom
    - 3.625 inches
- Horizontal distance between Tank 50H addition downcomer and transfer pump
    - 15.6 feet
- Tank 50H uses a standard slurry pump to mix the Tank. The pump has a nozzle diameter of 1.5 inches and a discharge velocity of 109 ft/s

2.1 Reduced Mixing Efficiency

For most industrial mixing applications, a 95% mixing efficiency is desired. The 95% mixing time is the time required after adding a tracer to a tank, not containing the tracer, for the tracer concentration to be within 5% of the bulk concentration everywhere in the tank. In some applications (e.g., the pharmaceutical industry), a higher mixing efficiency is desired. When mixing two very different liquids (e.g., sodium hydroxide and water), the 95% mixing efficiency is a desirable target. When mixing similar streams, such as SWPF effluent and TCCR effluent, a lower mixing efficiency may be acceptable.

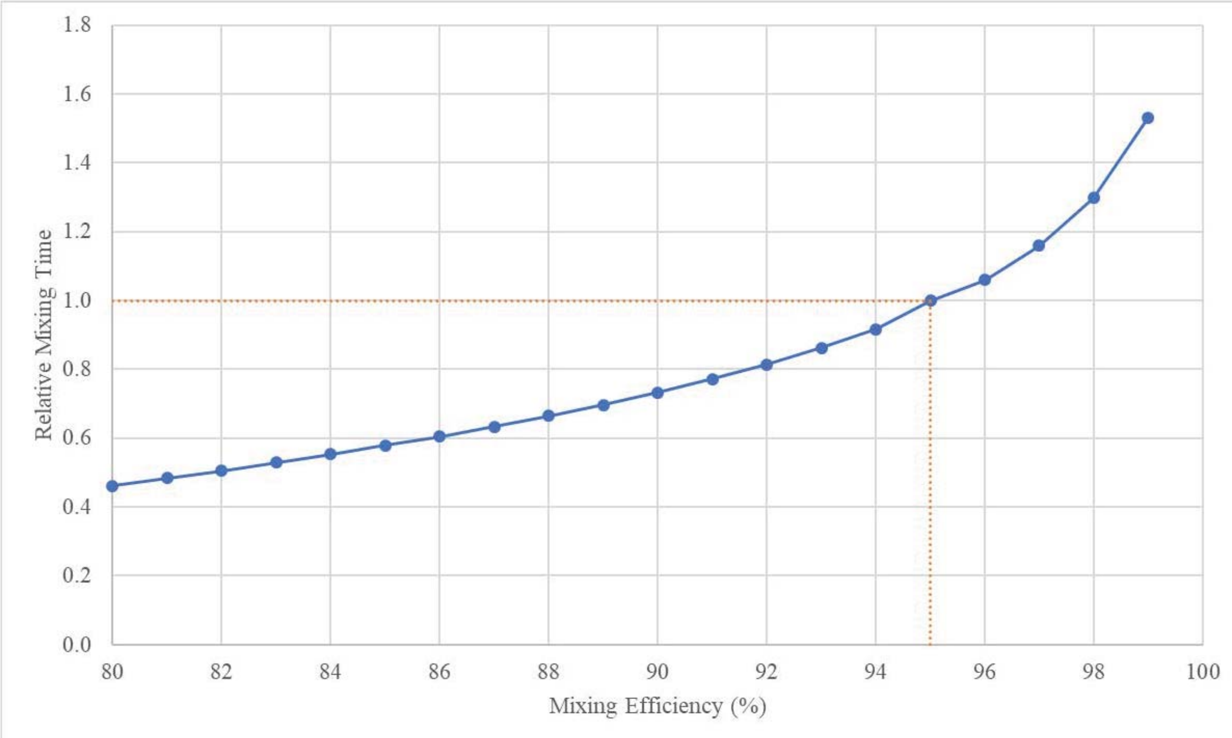
For example, if Tank 50H were to contain a 5.6 M sodium salt solution with 2.0 M free hydroxide, and a stream containing 5.6 M sodium and 1.8 M free hydroxide was added to the tank. The free hydroxide in the added stream would be within 10% of the free hydroxide concentration in Tank 50H. In this example, a 50% mixing efficiency might be acceptable.

Reducing the required mixing efficiency from 95% to 90, 85, or 80% would reduce the mixing time required in Tank 50H. The effect of mixing efficiency on blend time is described by equation [1] and Figure 1.[8]

$$\theta_m = -(1/3)\ \theta_{95} \ln[(100-m)/m] \qquad [1]$$

In equation [1], θ_m is the mixing time at the specified mixing efficiency, θ_{95} is the mixing time at 95% mixing efficiency, and m is the specified mixing efficiency. In Figure 1 the x-axis is the mixing efficiency, and the y-axis is the relative mixing time, the mixing time divided by the mixing time for 95% efficiency. Mixing times for specific Tank 50H conditions are described later. The analysis shows the mixing time could be reduced by as much as 50% by changing the required mixing efficiency, provided the contents of Tank 50H are still acceptable for the SPF.

Figure 1. Impact of Mixing Efficiency on Mixing Time



2.2 Review Conservatism in SRNL-STI-2011-00362

A previous SRNL analysis calculated a mixing time of 1.1 hours in Tank 50H based on pilot-scale testing to size pumps for blending feed solution for SWPF.[5] There are several differences between the conditions in the pilot-scale testing and Tank 50H. Because of these differences, the estimated blend time was increased 4X in that document. This analysis examined the effects of these differences and modified the blend time to account for them.

Nordkvist et al looked at the influence of rotating jets on mixing in a tank.[14] The work looked at rotating jet head mixers. Their test vessel had an aspect ratio (H/D = 2.5) much different from Tank 50H (H/D ~ 0.35). The jet mixers rotated in vertical and horizontal directions, while the jet mixers in Tank 50H rotate only in the horizontal direction. With water, mixer jet rotation decreased the mixing time by ~ 20%.

A previous SRNL analysis looked at the influence of changing liquid height and pump elevation on blend time.[9]

The approach looked at having an equal Froude number for equivalent mixing at the liquid surface. The Froude number is defined by equation [2]

$$\mathrm{Fr} = \frac{\mathrm{U}^2}{\mathrm{g \cdot H}} \qquad [2]$$

where U is the fluid velocity, g is the gravitational acceleration, and H is the vertical distance between the pump discharge nozzle and the liquid surface.

For equal fluid motion (i.e., mixing) at the surface, the Froude number should be the same (see equation [3])

$$\mathrm{U_1^2 \cdot H_2 = U_2^2 \cdot H_1} \qquad [3]$$

Given no change in nozzle diameter (D), equation [3] can be modified to produce equation [4].

$$\mathrm{U_2 D = U_1 D \sqrt{\frac{H_2}{H_1}}} \qquad [4]$$

Based on the pilot-scale testing, the full-scale H_1 = 174.28 inches [174.28 inches was the equivalent height of the liquid level above the pump discharge nozzle in a full-scale waste tank based on the pilot-scale testing performed in 2010[6]]. Assuming the pump nozzle is 11.5 inches above the tank bottom, H_2 = 346.25 – 11.5 = 334.75 inches, and solving equation [4] produced equation [5] which is solved for the change in U_0D to produce equivalent mixing at the liquid surface.

$$U_2D = 13.6\frac{\text{ft}^2}{\text{s}}\sqrt{\frac{334.75\text{ in}}{174.28\text{ in}}} = 18.85\frac{\text{ft}^2}{\text{s}} \qquad [5]$$

Equation [5] shows that an ~39% increase in U_0D would be required to have equivalent mixing at the liquid surface. Since U_0D is not being increased, the effect on mixing will be the same as decreasing U_0D by 39% (see equation [6]).

$$\theta = C_1\,\frac{f(T,H)}{U_0D} \qquad [6]$$

If the U_0D is maintained at 13.6 ft^2/s, the blend time will increase by 39%.

The pilot-scale testing report included an assessment of the effect of viscosity on blend time.[6] Tests were performed with water rather than salt solution. Water has a kinematic viscosity ≈ 0.01 cm^2/s. The salt solution in Tank 50H could have a density of 1.26 g/mL and a viscosity of 2.5 cp.[15] Therefore, the kinematic viscosity could be as high as 0.02 cm^2/s. The higher viscosity will have an influence on the turbulent jet produced by the mixer pump. The effect will be seen in the decay of the centerline jet velocity and in the impact of the cooling coils.

Rushton investigated the decay of a turbulent jet as a function of fluid viscosity and found the jet behavior to be described by equation [7]

$$U_x = 1.41\, Re^{0.135}\,(U_0D/x)\ \alpha\ \nu^{-0.135} \qquad [7]$$

where U_x is the centerline velocity at a distance x from the pump, Re is the Reynolds number, U_0 is the jet velocity, D is the jet nozzle diameter, x is the distance from the pump, and ν is the kinematic viscosity.[16] Increasing the kinematic viscosity by 2X reduces the centerline jet velocity by 9%. The pump nozzle velocity needs to increase by 10% (1/0.91 = 1.1) to account for the higher viscosity.

The influence of cooling coils on the jet produced is similar to the flow of fluid across a tube bank in a shell and tube heat exchanger. Investigations of friction factors in flow across tube banks show the friction factor as a function of viscosity to be described by equation [8].[17,18,19,20]

$$f\ \alpha\ \nu^n,\ \text{where } n = 0.145,\ 0.15,\ \text{or } 0.2 \qquad [8]$$

Therefore, a 2X increase in viscosity would increase the friction factor by 10 - 15%. A mechanical energy balance is described by equation [9]

$$\Delta U^2/2g_c + g\Delta z/g_c + \Delta P/\rho + 2fLU^2/g_cD = 0 \qquad [9]$$

where U is velocity, g is gravitational acceleration, z is elevation, P is pressure, ρ is density, f is friction factor, L is length, and D is diameter. Assuming no change in elevation or pressure, equation [9] is simplified to equation [10],

$$\Delta U^2/2g_c = -2fLU^2/g_cD \qquad [10]$$

and a 15% increase in friction factor produces a 7% decrease in jet velocity, which produces a 7% increase in blend time.

2.2.1 Predicted Blend Time

Following the assessment of the influence of mixer pump rotation, liquid elevation above the pump discharge nozzle, and viscosity, the mixing time of 4.4 hours recommended in SRNL-STI-2011-00362 can be reassessed.[5] Tank 50H will be mixed with a single standard slurry pump that has a U_0D of 13.6 ft^2/s for each discharge nozzle. Since the pilot-scale testing was conducted in a 1/10.85 geometrically scaled tank, the equivalent U_0D in the pilot-scale tank is 13.6/10.85 = 1.25 ft^2/s. From Figure 3-35 in the pilot-scale blending test document[6], the blend time is described by equation [11].

$$\theta_{95}\ (\text{min}) = 7.2634/U_0D\ (ft^2/s) = 7.2634/1.25 = 5.8\ \text{min} \qquad [11]$$

Multiplying by the scale factor of 10.85 yields a blend time of 63 minutes for Tank 50H.

Based on the work of Nordkvist et al.[14], the blend time can be reduced by 20% to account for the rotating pump.

Based on the work of Poirier[9], the blend time must be increased by 39% to account for the pump not being located in the center of the tank (i.e., discharge nozzle at 11.5 inches).

Based on the work of Leishear et al.[7], the blend time must be increased by 10% to account for the higher viscosity in Tank 50H than in the blending testing. The blend time must be increased by an additional 7% to account for the increased drag from the cooling coils due to the higher viscosity. In addition, that work identified an uncertainty of 12.2%.

Combining these effects, the calculated blend time is 93 minutes (see equation [12]).

$$\theta_{95} = 63\ \text{min}\ (0.8)\ (1.39)\ (1.10)\ (1.07)\ (1.122) = 93\ \text{min} \qquad [12]$$

The Tank 50H blend time was calculated for other liquid levels in Tank 50H and is shown in Figure 2. Figure 3 shows the calculated blend time as a function of tank level and mixing efficiency.

Figure 2. Effect of Liquid Height on Mixing Time compared with Original Value in SRNL-STI-2011-00151

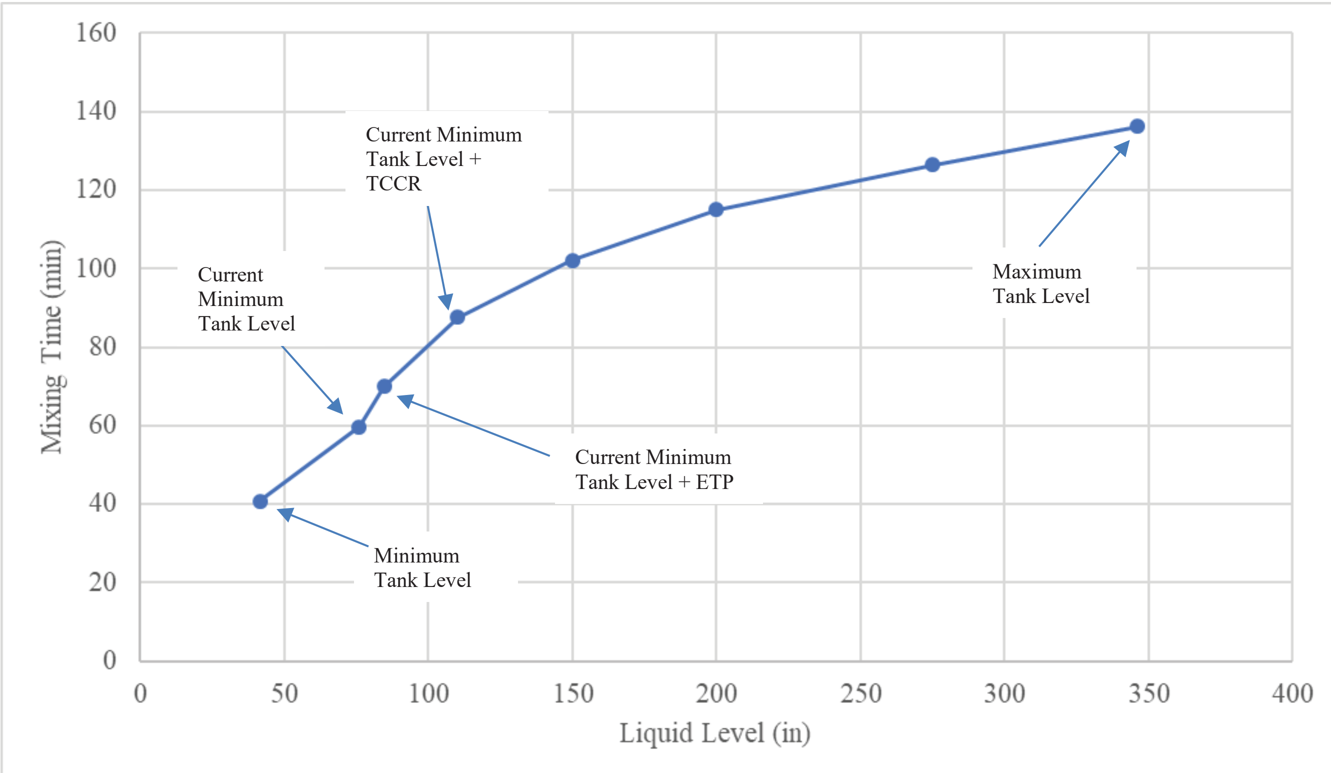
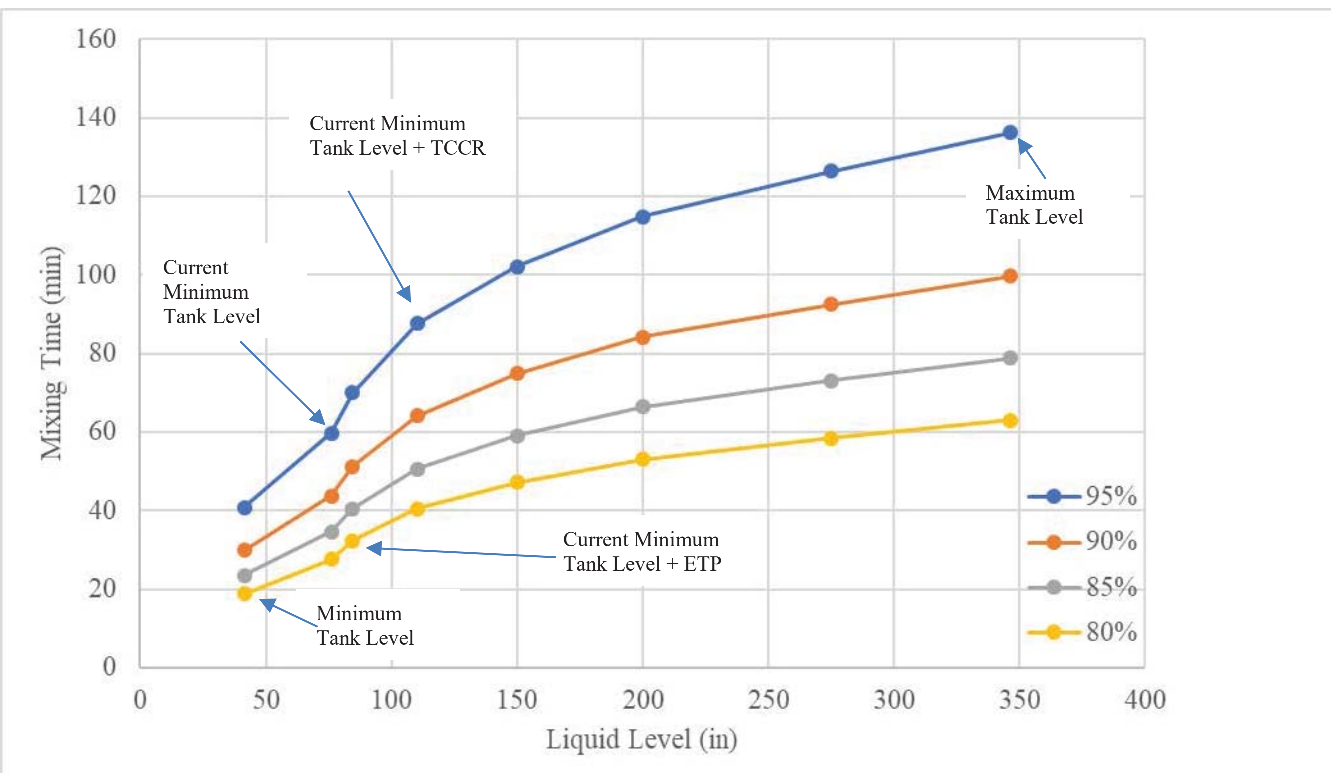


Figure 3. Mixing Time as a Function of Liquid Height and Mixing Efficiency



2.3 Reviewing Pilot-Scale Mixing Data

The author reviewed the data from the pilot-scale miscible liquid blending tests to attempt to better define the required blend time in Tank 50H.[7] The data most applicable to Tank 50H mixing was selected and fit with a model described by equation [13]

$$\theta_{95} = 7.06/\ U_0D \qquad [13]$$

For a standard slurry pump in Tank 50H U_0D = 13.6 ft^2/sec. Dividing the Tank 50H U_0D by the scale factor gives a U_0D of 1.25 ft^2/s for the pilot-scale tank. Solving equation [13] produces a blend time of

$$\theta_{95} = 7.06/\ U_0D = 7.06/1.25 = 5.65 \text{ minutes} \qquad [14]$$

Multiplying the result in equation [14] by the scale factor produces a blending time of

$$\theta_{95} = 5.65\ (10.85) = 61 \text{ minutes} \qquad [15]$$

for Tank 50H, which is very close to the mixing time given in SRNL-STI-2011-00362.[5] The corrections for rotating pump, changes in liquid level, viscosity, and uncertainty described earlier can be added.

This analysis, as well as the analysis in section 2.2 assumes that the density of the added liquid is approximately the same as the density of the existing liquid in Tank 50H. In previous SRNL testing[7], miscible liquid blending tests, liquids with significantly different densities were blended. One test involved adding $NaNO_3$ solution (1.257 g/mL density) to water (1.0 g/mL density), and another test involved adding water to $NaNO_3$ solution. When the $NaNO_3$ solution was added to water, entrained air bubbles were observed to travel to within 6 inches of the bottom of the tank, and the blend time was much less than the blend time when mixing liquids with the same density. When water was added to the $NaNO_3$ solution, stratification of the two liquids was observed, and the blend time was much longer than the blend time when mixing liquids with the same density. These test conditions were extreme, and unlikely to exist in Tank 50H.

Revill recommends a density difference between the existing fluid in a tank and the added fluid of less than 5% to avoid stratification.[8] If the density difference between the added fluid and the existing fluid in Tank 50H is more than 5%, the potential for stratification should be assessed before the material is added.

If the contents of Tank 50H have a density of 1.26 g/mL, to avoid stratification, the liquid added to Tank 50H should have a density between 1.20 and 1.32 g/mL. If the density of the added liquid is outside this range, the potential for stratification should be evaluated.

SRNL performed computational fluid dynamics simulations of miscible liquid blending in Tank 50H to complement the pilot-scale testing.[21] The analysis simulated the blending in Tank 50H and determined fluid velocities as a function of position. The results were consistent with the analysis in this document. However, the pump elevation, pump rotation, and U_0D were different than the present conditions for Tank 50H, so that work was not used for this analysis.

2.4 Plunging Jet

Some mixing will occur between the added fluid and the tank contents when a fluid addition is made to Tank 50H. The author addressed this problem by treating the added salt solution as a plunging liquid jet.[22,23] The following input parameters were used for the analysis:

- Downcomer pipe diameter = 3.26 inches
- Liquid flow rate = 96 gpm and 150 gpm
- Downcomer elevation = 346.25 inches
- Liquid level = 76 inches

The exit velocity of the downcomer is calculated with equation [16]

$$V_0 = \frac{4Q}{\pi D^2} \qquad [16]$$

where Q is the flow rate and D is the downcomer internal diameter. For a flow rate of 96 gpm, the exit velocity is 3.69 ft/s. For a flow rate of 150 gpm, the exit velocity is 5.77 ft/s. Because the jet is moving vertically downward, its velocity will increase due to gravity. The velocity at the liquid surface can be calculated with equation [17]

$$V_j = \sqrt{V_0^2 + 2gL} \qquad [17]$$

where V_0 is the downcomer exit velocity, g is gravitational acceleration, and L is the distance between the downcomer exit and the liquid surface (L = 346.25 – 76 = 270.25 inches = 22.52 feet). For a downcomer exit velocity of 3.69 ft/s, the velocity at the surface is 38.3 ft/s. For a downcomer exit velocity of 5.77 ft/s, the velocity at the surface is 38.5 ft/s. Because the jet is accelerating, its diameter will decrease to conserve mass. The diameter of the jet at the surface is described by equation [18].

$$D_j = \sqrt{\frac{4Q}{\pi V_j}} \qquad [18]$$

With a downcomer discharge flow rate of 96 gpm, the jet diameter at the liquid surface is 1.01 inches. With a downcomer discharge flow rate of 150 gpm, the jet diameter at the liquid surface is 1.26 inches.

The penetration depth of the jet is described by equation [19]

$$H_p = 2.1\, V_j^{0.775}\, D_0^{0.67} \qquad [19]$$

where V_J is the jet velocity at the liquid surface (in m/s) and D_0 is the jet diameter at the exit of the downcomer (in m). With a flow rate of 96 gpm out of the downcomer, the penetration depth is 105 inches. If the flow rate is increased to 150 gpm, the penetration depth is 105 inches. This distance is greater than the minimum liquid level in the tank (76 inches). Since the plunging jet penetration depth is greater than the liquid depth in the tank, the depth must be adjusted to account to the effects of the tank bottom.

Beltaos and Rajaratnam investigated impinging jets and found the jets to behave as free jets when the length of the jet was less than 86% of the distance between the jet source and the boundary.[24] Multiplying the liquid level by 86% produces a distance of 65.4 inches. A value of 65.4 inches should be used for the length of the plunging jet.

After the jet enters the liquid, it will expand at an angle of ~22º. Equation [20] describes the diameter of the jet as a function of depth

$$D_z = Z \tan(\theta/2) = Z \tan(22^\circ/2) = Z \tan(11^\circ) \qquad [20]$$

where Z is the depth below the liquid surface. For a penetration depth of 65.4 inches, the jet diameter would be 12.7 inches. If the diameter of the jet at the liquid surface is 1.01 inches (i.e., 96 gpm flow rate), the increase in cross sectional area would be $(12.7/1.01)^2 = 158$. By the time the jet reached a depth of 65.4 inches, it would by diluted 157:1 with the tank contents. If the diameter of the jet at the liquid surface is 1.26 inches (i.e., 150 gpm flow rate), the increase in cross sectional area would be $(12.7/1.26)^2 = 102$. By the time the jet reached a depth of 65.4 inches, it would by diluted 101:1 with the tank contents. Therefore, the material added to Tank 50H will be significantly blended with the bulk fluid in the tank as it is added. Additional dilution will occur in the radial wall jet that forms from the jet impinging on the tank bottom, but that dilution is not included in this calculation for conservatism.

Table 1 and Figure 4 summarize the results of the analysis. The analysis shows that significant mixing and dilution of the constituents in the added fluid with the tank contents will occur in the plunging jet, and that the dilution is a function of liquid level in the tank. Figure 4 shows a peak in the dilution factor at a Tank level of 150 inches. The dilution factor is a function the diameter of the plunging jet at its maximum penetration depth (see equation [20]), which is a function of the penetration depth of the jet (see equation [19]). With a low liquid level in the tank, the jet has a large length to accelerate before it reaches the liquid surface, but only a small length to expand after it reaches the liquid surface. With a high liquid level in the tank, the jet has a small length to accelerate before it reaches the liquid surface, but a large length to expand after it reaches the liquid surface. If the liquid level is too close to the down comer (i.e., greater than 325 inches, the jet does not have space to accelerate before reaching the liquid surface, and the "plunging jet" model may not be valid. In this case the added liquid is very far from the transfer pump and would be mixed with other fluid in the tank before being transferred to the SPF.

Figure 5 shows the concentration of a given species in the blended plunging jet as a function of dilution factor given a concentration of 1 (no units) in Tank 50H and a concentration of 10 (no units) in the added liquid.

Figure 6 shows the concentration of a given species in the blended plunging jet as a function of influent concentration (no units) given a concentration of 1 (no units) in Tank 50H and a dilution factor of 100.

Figure 7 shows the concentration of a given species in the blended plunging jet as a function of dilution factor given a concentration of 100 (no units) in Tank 50H and a concentration of 10 (no units) in the added liquid.

Figure 8 shows the concentration of a given species in the blended plunging jet as a function of influent concentration (no units) given a concentration of 100 (no units) in Tank 50H and a dilution factor of 100.

These figures show that significant dilution will occur, and slight changes in influent concentrations will not dramatically change the overall concentration in the plunging jet, and the contents of Tank 50H. To prevent accumulation of the added material under the downcomer, the slurry pump in Tank 50H should be indexed toward the riser through which material is added to Tank 50H, and operated during the addition.

Table 1. Behavior of Plunging Jet in Tank 50H at 41.5, 76, and 325 inch Liquid Level

Liquid Leve;	41.5 inches	41.5 inches	76 inches	76 inches	325 inches	325 inches
Downcomer flow rate	96 gpm	150 gpm	96 gpm	150 gpm	96 gpm	150 gpm
Downcomer exit velocity	3.7 ft/s	5.8 ft/s	3.7 ft/s	5.8 ft/s	3.7 ft/s	5.8 ft/s
Downcomer exit diameter	3.26 inches	3.26 inches	3.26 inches	3.26 inches	3.26 inches	3.26 inches
Jet velocity at liquid surface	40.6 ft/s	40.9 ft/s	38.3 ft/s	38.5 ft/s	11.3 ft/s	12.1 ft/s
Jet diameter at liquid surface	0.98 inches	1.22 inches	1.01 inches	1.26 inches	1.86 inches	2.25 inches
Penetration depth	35.7 inches	35.7 inches	65.4 inches	65.4 inches	40.6 inches	42.9 inches
Jet diameter at penetration depth	6.9 inches	6.9 inches	12.7 inches	12.7 inches	7.9 inches	8.3 inches
Dilution at penetration depth	50:1	32:1	157:1	101:1	18:1	14:1

Figure 4. Dilution Factor from a Plunging Jet with Inlet Flow Rate of 96 GPM or 150 GPM as a Function of Liquid Level

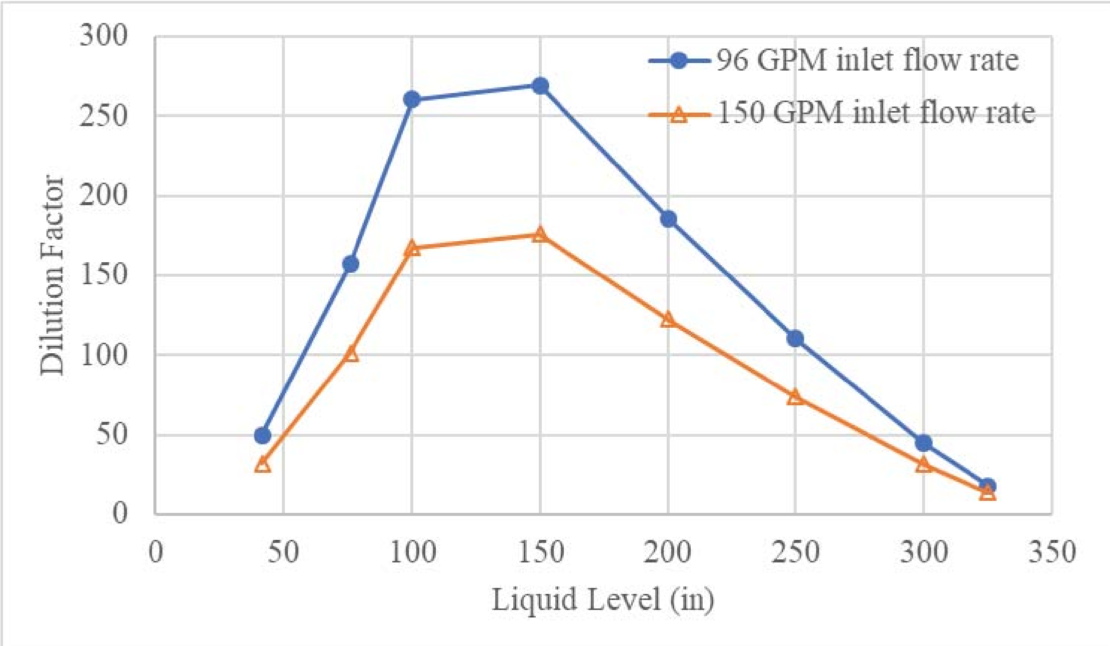


Figure 5. Blended Concentration in a Plunging Jet as a Function of Dilution Factor given a Concentration of 1 in Tank 50H and a Concentration of 10 in the Influent

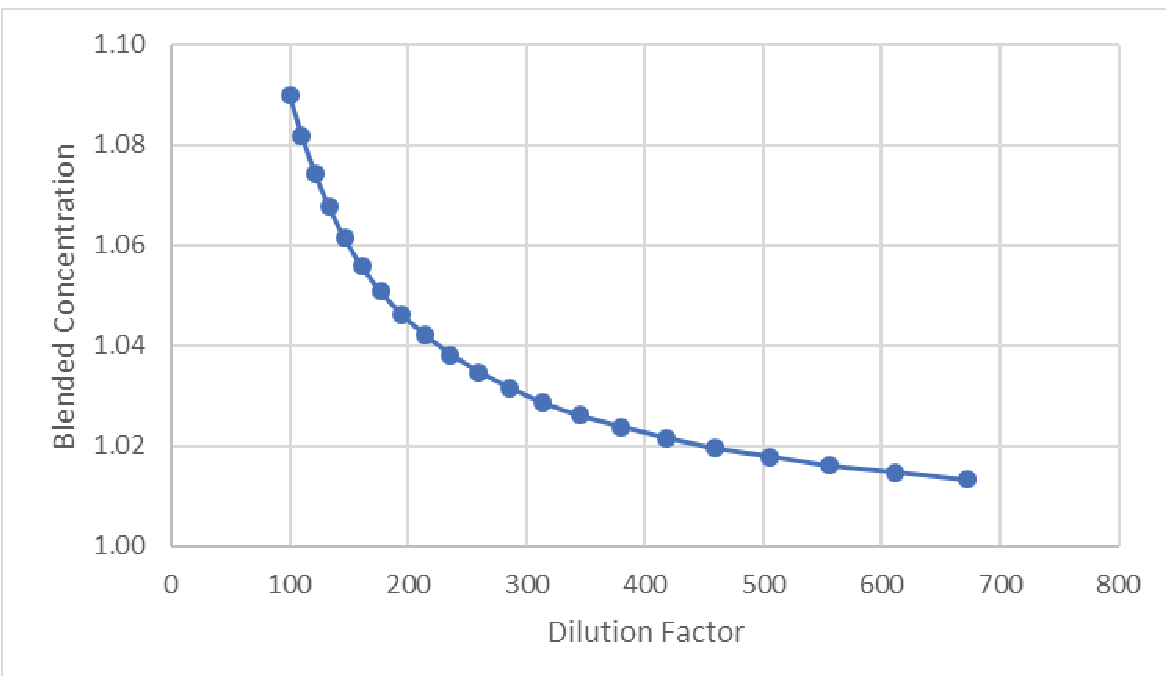


Figure 6. Blended Concentration in a Plunging Jet as a Function of Influent Concentration given a Concentration of 1 in Tank 50H and a Dilution Factor of 100

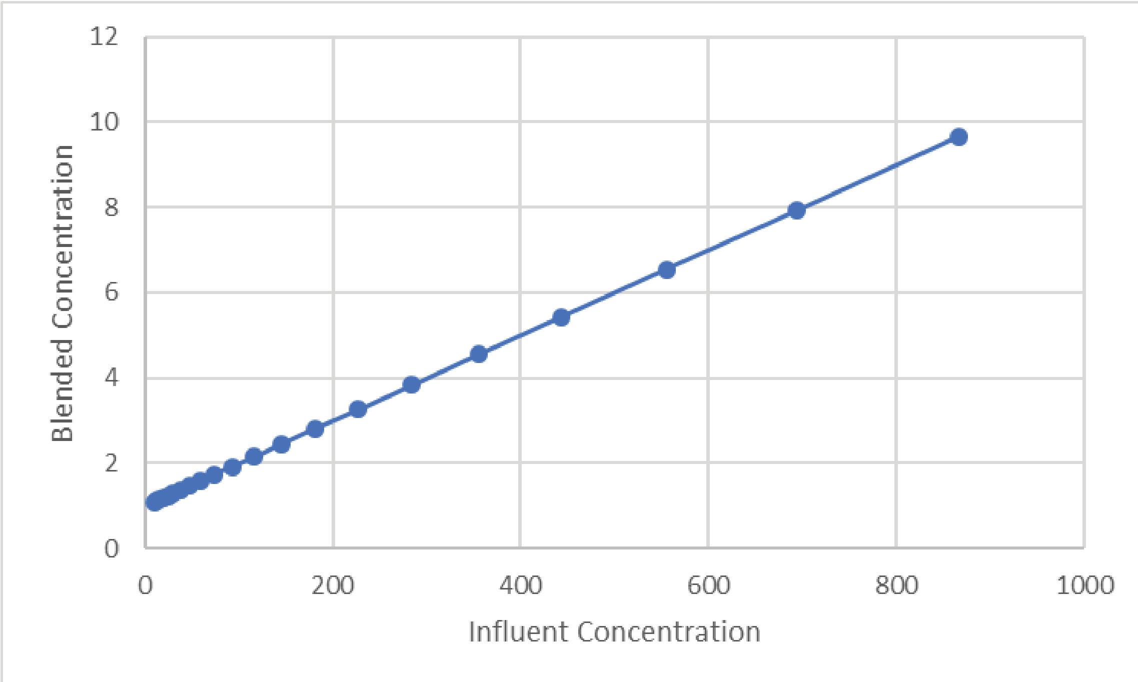


Figure 7. Blended Concentration in a Plunging Jet as a Function of Dilution Factor given a Concentration of 100 in Tank 50H and a Concentration of 10 in the Influent

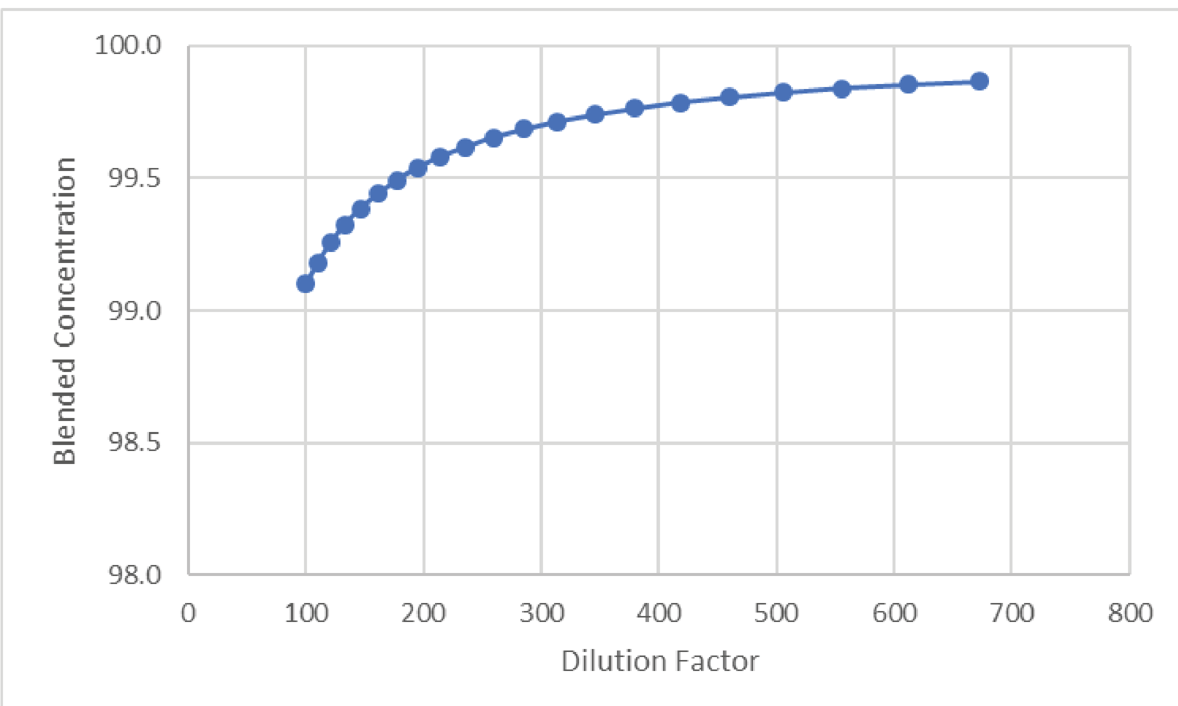
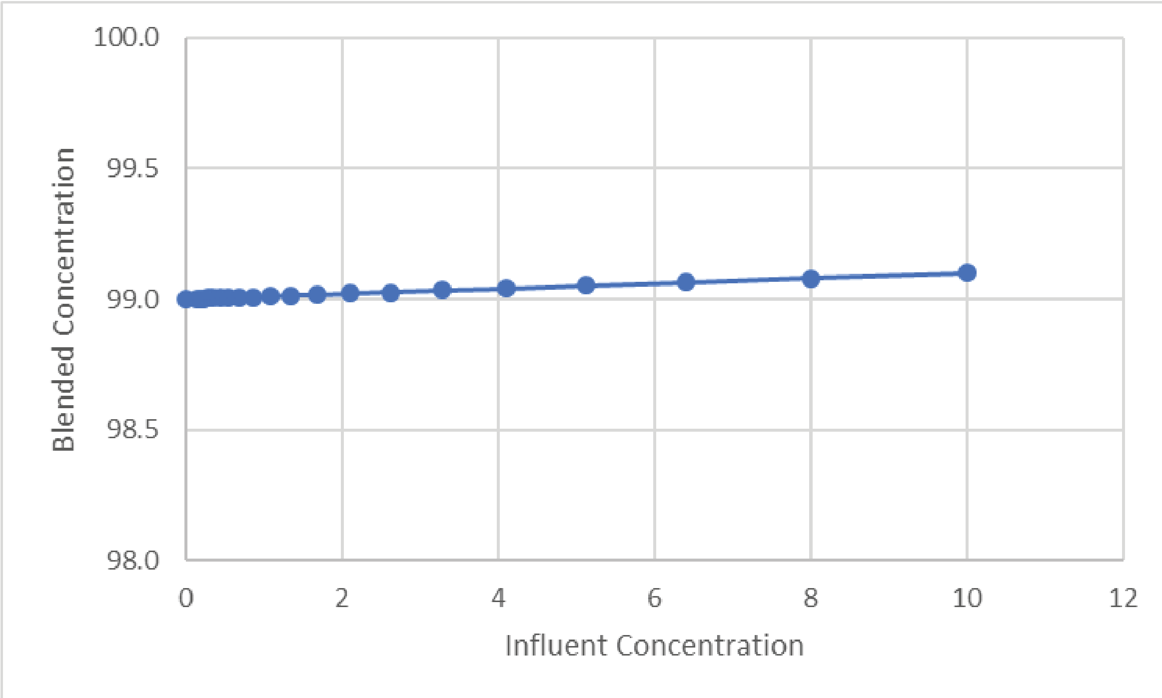


Figure 8. Blended Concentration in a Plunging Jet as a Function of Influent Concentration given a Concentration of 100 in Tank 50H and a Dilution Factor of 100



2.5 Suction Flow into Transfer Pump

Prior to being transferred to Saltstone, the salt solution added to Tank 50H must enter the transfer pump suction. The transfer pump is located in Riser B5 which is 15.6 feet from riser C1 where the influents are added. As the added salt solution moves from the addition point to the transfer pump suction, it will contact and blend with other material that is in Tank 50H. This effect was assessed by treating the flow of liquid into the transfer pump suction as a converging channel flow.

Because transfer pump suction is 3.625 inches above tank bottom, assume the channel is 3.625 inches high. The transfer pump is 13.5 feet from tank wall. The radius of the converging channel flow to the transfer pump suction is assumed to be 10 ft. The circumference of the converging channel is $2 \pi r = 2 \pi (10 \text{ ft}) = 62.8 \text{ ft}$. The maximum diameter of plunging jet is 1.06 ft. The dilution from mixing added fluid with other tank material in the transfer pump is 59:1.

Because the material added to the tank creates a plunging jet and mixes with some of the surrounding fluid after it enters the liquid in the tank, the calculation was repeated using the diameter of the jet when it reaches the liquid surface and before it is diluted. The maximum diameter of jet at liquid surface is 0.105 ft. Dilution from mixing added fluid with other tank material in the transfer pump is 600:1

Pump suction will draw material from above 3.625 inches, so this calculation is likely conservative.

3.0 Conclusions

Assessing the impact of differences between the pilot-scale miscible liquid blending tests and Tank 50H, shows that the 4X factor used in SRNL-STI-2011-00362 is overly conservative, and that the required blend time in Tank 50H can be reduced. At the current minimum liquid level in Tank 50H (76 inches), the calculated blend time is 60 minutes. The blend time would be longer at higher liquid levels in the tank. The analysis showed that reducing the required blending efficiency from 95% to 80% could reduce the required blending time to as low as 30 minutes (at a liquid level of 76 inches), provided the contents of Tank 50H are still acceptable for Saltstone.

An alternative to using the slurry pump to mix the tank contents is to use the “plunging jet” created by the added liquid and blending that occurs as fluid is drawn into the transfer pump suction. Adding liquid to Tank 50H through the downcomer in riser C1 creates a “plunging jet” that will blend the added material with the current contents of Tank 50H. The dilution factor could be as much as 250X. If the plunging jet is used to provide mixing in Tank 50H, the mixer pump should be indexed toward the downcomer through which the material is added to the tank to prevent accumulation of added material under the downcomer. As the liquid in Tank 50H enters the transfer pump suction to be transferred to Saltstone, the recently added material will blend with the other contents of Tank 50H, and the dilution factor could be as much as 600X. These two effects are multiplicative and can be combined. Mixing during the transfer into Tank 50H, combined with the mixing that occurs at the pump suction during the transfer from Tank 50H to Saltstone, would mix Tank 50H contents and would eliminate the slurry pump mixing required before transferring to Saltstone.

While unlikely, stratification could occur when liquid is added to Tank 50H. If the density difference between the added fluid and the existing fluid in Tank 50H is more than 5%, the potential for stratification exists. If the contents of Tank 50H have a density of 1.26 g/mL, the liquid added to Tank 50H should have a density between 1.20 and 1.32 g/mL to avoid stratification. If the density of the added liquid is outside this range, the potential for stratification should be evaluated.

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