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Blend Pump Mixing in Tank 27 Evaluation

M. R. Poirier

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REVIEWS AND APPROVALS

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EXECUTIVE SUMMARY

For future waste disposal operations, Savannah River Mission Completion (SRMC) plans to operate Tank 27 as a blend tank. It is desirable to avoid additional worker exposure by using the planned commercial submersible mixing pump (CSMP) installations in Risers B2 and B4 to function as the blend pumps for prolonged blend tank operations. The purpose of this task is to evaluate the impacts to mixing across a range of pump installation heights from 1 to 201 inches. Specifications include: A maximum pump diameter of 22.5 inches, dual nozzles placed tangentially opposed with nominal inside diameter of 2 inches, a total flow range (both nozzles combined) of 500 to 1950 gallons per minute (gpm) and a maximum revolutions per minute (RPM) of 1800. Tank 27 is expected to have a maximum fill height of 360 inches.

SRNL performed engineering analysis applying the results from pilot-scale testing conducted to determine the specifications for sizing pumps to blend miscible liquids to prepare feed for the Salt Waste Processing Facility (SWPF). The pilot-scale testing was conducted in 2010-2011 utilizing a 1/10.85 pilot-scale tank model of Tank 50. The testing evaluated the impact of pump nozzle diameter and pump nozzle discharge velocity on the miscible liquid blend time. The testing was based on a Tank 50 liquid volume of 1,225,000 gallons (~349 inches of liquid) and a pump elevation of 174 inches. The testing recommended a minimum U_0D of 5.1 ft^2/s to ensure the liquids were adequately blended and a maximum U_0D of 6.1 ft^2/s to prevent the jets from disturbing and suspending the solid particles settled at the bottom of the waste tank.[a]

This analysis began by using results from the 2010 testing and applying them to the Tank 27 design to calculate a mixing time as a function of pump flow rate. These results were modified to account for the higher liquid level in Tank 27. Once the liquid level was increased to 360 inches, the results were modified to account for a higher viscosity in Tank 27 than in the testing. Once the viscosity was increased, the effect of changing pump elevation was applied to calculations of the mixing time in Tank 27. Finally, the uncertainty from the testing was included in the analysis to recommend a blend time as a function of pump flow rate and elevation.

The analysis finished by considering the effect of multiple pumps, the effect of operating parameters on sludge disturbance, and the potential for stratification.

The conclusions from this study follow.

- Based on the 2010 and 2011 pilot-scale miscible blending testing, a minimum pump flow rate of 600 gpm is recommended.
- With a single pump operating at a flow rate of 600 - 1950 gpm, the expected blend time in Tank 27 is between 94 and 712 minutes depending on pump elevation and flow rate. The blend times for specific conditions are listed in Tables 4 – 7. These results assume the density difference between the fluids to be blended is less than 5%.
- Using two pumps in Tank 27 would reduce the blend time by approximately 29%, using three pumps would reduce the blend time by 42%, and using four pumps would reduce the blend time by 50%.
- To reduce the risk of stratification, the density deference between liquids in Tank 27 should be less than 5%. If the density difference is greater than 5%, additional parameters should be considered in determining the required blend times outlined in Tables 4 – 7 for Tank 27 (e.g., height of waste, overall density differences, etc.).
- Since the pump nozzles are horizontal, solids disturbance is likely in Tank 27.
- Computational Fluid Dynamics simulations with the M-Star software should be performed when resources are available to reduce the uncertainty in these calculations. It should be of note, that the model assumes the nozzles on the CSMP(s) are stationary and do not oscillate (similar to the submersible blend pumps). If the CSMP(s) are to oscillate, mixing times required are likely to decrease but further analysis is required to determine exact mixing times

[a] 5.1 ft^2/s corresponds to a flow rate of 600 gpm for the pumps in Tank 27.

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LIST OF ABBREVIATIONS

C_i	Constants
C_D	Drag coefficient
CSMP	Commercial submersible mixing pump
D	Pump or jet nozzle diameter
D_p	Pump assembly diameter
F_D	Drag force
Fr	Froude number
g	Gravitational acceleration
gpm	Gallons per minute
H	Height of tank or fluid
L	Length travelled by jet from pump center to tank wall
L_p	Length of pump assembly
$\widehat{m}$	Jet momentum
Re	Reynolds number
rpm	Revolutions per minute
SRMC	Savannah River Mission Completion
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
SWPF	Salt Waste Processing Facility
T	Tank diameter
TTR	Task Technical Request
U_0	Nozzle discharge velocities
U	Velocity
y	Horizontal distance from pump center to tank wall
ρ	Liquid density
θ	Blend Time
ν	Kinematic viscosity

1.0 Introduction

For future waste disposal operations, Savannah River Mission Completion (SRMC) plans to operate Tank 27 as a blend tank. It is desirable to avoid additional worker exposure by using the planned commercial submersible mixing pump (CSMP) installations in Risers B2 and B4 to function as the blend pumps for prolonged blend tank operations. The purpose of this task is to evaluate the impacts to mixing across a range of pump installation heights from 1 to 201 inches. Specifications include: A maximum pump diameter of 22.5 inches, dual nozzles placed tangentially opposed with nominal inside diameter of 2 inches, a total flow range (both nozzles combined) of 500 to 1950 gallons per minute (gpm) and a maximum revolutions per minute (RPM) of 1800. Tank 27 is expected to have a fill height maximum of 360 inches.

SRNL performed engineering analysis applying the results from pilot-scale testing conducted to determine the specifications for sizing pumps to blend miscible liquids to prepare feed for the Salt Waste Processing Facility (SWPF).[1,2] The pilot-scale testing was conducted in 2010-2011 utilizing a 1/10.85 pilot-scale tank model of Tank 50. The testing evaluated the impact of pump nozzle diameter and pump nozzle discharge velocity on the miscible liquid blend time. The testing was based on a Tank 50 liquid volume of 1,225,000 gallons (~349 inches of liquid) and a pump elevation of 174 inches. The testing recommended a minimum U_0D of 5.1 ft^2/s to ensure the liquids were adequately blended and a maximum U_0D of 6.1 ft^2/s to prevent the jets from disturbing and suspending the solid particles settled at the bottom of the waste tank.[b]

SRMC requested SRNL to perform engineering analysis to investigate the impact on operating parameters for mixing of Tank 27 as a feed tank for SWPF. The parameters to be investigated include the pump flow rate, the pump elevation, liquid level, liquid viscosity, and the number of pumps operating. This work uses the same approach used to assess the impact of changing pump elevation and liquid height in Tank 41.[3]

The analysis will begin by using results from the 2010 testing and applying them to the Tank 27 design to calculate a mixing time as a function of pump flow rate. These results will be modified to account for the higher liquid level in Tank 27. Once the liquid level has been increased to 360 inches, the impact of viscosity will be discussed, and the results will be modified to account for a higher viscosity in Tank 27 than in the testing. Once the viscosity has been increased, the effect of changing pump elevation will be discussed and applied to calculations of the mixing time in Tank 27. Finally, the uncertainty from the testing will be included in the analysis to recommend a blend time as a function of pump flow rate and elevation.

The analysis will finish by considering the effect of multiple pumps, the effect of operating parameters on sludge disturbance, and the potential for stratification.

2.0 Approach

2.1 Changing Pump Flow Rate

The testing performed in 2010 developed a correlation to predict the blend time (θ) in a waste tank as a function of pump discharge velocity and pump nozzle diameter. Equation [1] shows the correlation

$$\theta = 7.26 \frac{T^2}{U_0 D} \qquad [1]$$

where T is the tank diameter, U_0 is the nozzle discharge velocity, and D is the nozzle diameter. Equation [1] is based on a pump nozzle elevation of 174 inches, a liquid level of 349 inches, a liquid viscosity of 1 cP (i.e., water), and the pump nozzles being horizontal.

[b] 5.1 ft^2/s corresponds to a flow rate of 600 gpm for the pumps in Tank 27. The 5.1 ft^2/s is to ensure that the liquid is blended to 95% homogeneity. The 6.1 ft^2/s is to prevent significant solids disturbance and meet the SWPF acceptance criteria of < 1,200 mg/L insoluble solids.

Figure 1 shows the blend time as a function of pump flow rate per the 2010 testing.

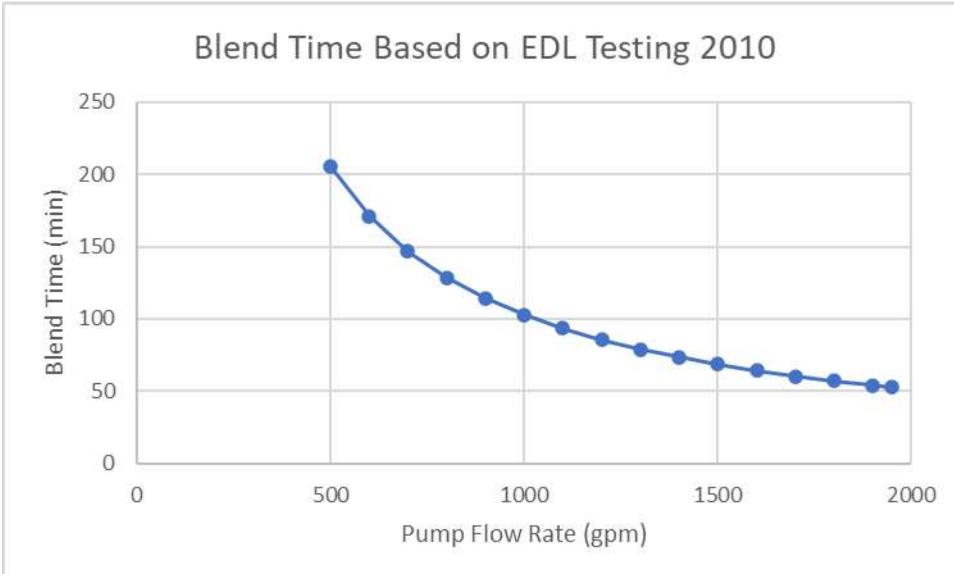

Figure 1. Liquid Blend Time as a Function of Pump Flow Rate

2.2 Changing Liquid Viscosity

The tests were performed with water rather than salt solution. Water has a kinematic viscosity ~ 0.01 cm^2/s. The salt solution could have a density greater than or equal to 1.26 g/mL and a viscosity greater than or equal to 2.5 cP.[4] Therefore, the kinematic viscosity could be greater than or equal to 0.02 cm^2/s.

The higher viscosity will have an impact 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

$$U_x = 1.41\, Re^{0.135}\, (U_0 D/x)\ \alpha\ \nu^{-0.135} \qquad [2]$$

where U_x is the centerline velocity at a distance x from the pump, Re is the Reynolds number, U_0 is the jet nozzle discharge velocity, D is the jet nozzle diameter, x is the distance from the pump, and ν is the kinematic viscosity.[4,5] According to Equation [2], increasing the kinematic viscosity by 2X reduces the centerline jet velocity by 9%. The pump nozzle velocity would need to increase by 10% (1/0.91 = 1.1) to have the same centerline velocity as a function of distance with the higher viscosity.

The impact 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 [3].[6,7,8,9]

$$f\ \alpha\ \nu^n, \text{ where } n = 0.145, 0.15, \text{ or } 0.2 \qquad [3]$$

Therefore, a 2X increase in viscosity would increase the friction factor by 15%. Equation [4] shows a mechanical energy balance.

$$\Delta U^2/2g_c + g\Delta z/g_c + \Delta P/\rho + 2fLU^2/g_c D = 0 \qquad [4]$$

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 [4] reduces to Equation [5]

$$\Delta U^2/2g_c = -2fLU^2/g_cD \qquad [5]$$

and a 15% increase in friction factor produces a 7% decrease in jet velocity.

These two effects (the decrease in axial velocity and the increased friction factor) need to be combined to quantify the effect of the increased viscosity. Figure 2 shows the effect of increasing viscosity on the liquid blend time. As the viscosity increases from 0.01 cm^2/sec to 0.04 cm^2/sec, the blend time increases by approximately 40%.

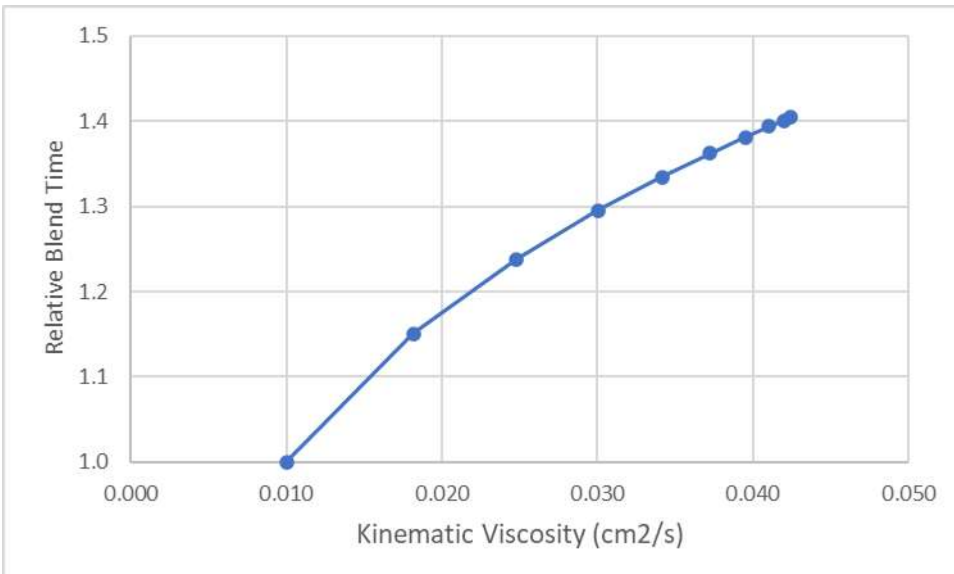

Figure 2. Effect of Viscosity on Liquid Blend Time

2.3 Changing Distance between Pump Nozzle and Liquid Surface or Sludge Surface

Two approaches were employed to assess the impact of changing the distance between the pump nozzle and the liquid surface or the solids surface in the blend tanks for SWPF.[c] The approaches are matching the Froude number and examining existing jet mixing correlations.

2.3.1 Equal Froude Number

In analyzing and modeling the effects of changes in distance between the pump discharge nozzle and the liquid surface on mixing processes, a Froude number is often used.[10] The Froude number is the ratio of inertial forces to gravitational forces, and is described by equation [6]

$$Fr = \frac{U^2}{g \cdot H} \qquad [6]$$

[c] These are the same approaches used in SRNL-STI-2019-00176

where U is the fluid velocity, g is the acceleration due to gravity, and H is the fluid height above the discharge nozzle.

To maintain equal liquid surface motion for two different levels, the Froude number is assumed to be constant. For constant Froude number and gravitational acceleration, the relationship between fluid height and nozzle discharge velocity is described by equation [7].

$$U_1^2 \cdot H_2 = U_2^2 \cdot H_1 \qquad [7]$$

In equation [7], U_1 and H_1 refer to the nozzle discharge velocity and liquid height for the baseline conditions, and U_2 and H_2 refer to the nozzle discharge velocity and liquid height for the modified conditions. Given that mixer pump discharge nozzle diameter is constant, multiplying equation [7] by D^2 and solving for U_2D yields equation [8].

$$U_2D = U_1D\sqrt{\frac{H_2}{H_1}} \qquad [8]$$

The baseline condition is U_1D of 5.1 ft^2/s, liquid level of 348.28 inches, and pump elevation of 174 inches; hence H_1 is 174.28. If the distance between pump discharge nozzle and the liquid surface is increased to 190 inches, the U_2D required for equal surface motion is calculated in equation [9].

$$U_2D = 5.1\frac{ft^2}{s}\sqrt{\frac{190\ in}{174.28\ in}} = 5.3\frac{ft^2}{s} \qquad [9]$$

Equation [1] shows that an ~4% increase in U_0D would be required to have equivalent mixing at the liquid surface. If the U_0D is maintained at 5.1 ft^2/s, the blend time will increase, slightly. Equation [10] is a general expression for blend time in a jet mixed tank

$$\theta = C_1\frac{f(T,H)}{U_0D} \qquad [10]$$

where C is a constant and T is the tank diameter.[11] Since blend time is inversely proportional to U_0D and U_0D is not being increased, increasing the height will increase the blend time approximately 4%.

2.3.2 Miscible Liquid Blend Time Correlations

Another approach to assess the impact of changing liquid height and pump elevation on liquid blending is to look at the impact of liquid height in blend time correlations. The correlations were developed for open tanks with no cooling coils. However, the testing performed by SRNL showed a similar influence of U_0D on blend time with and without coils, with a different constant to account for the cooling coils.[1,2] One correlation that includes the impact of liquid height on blend time is described by equation [11][12]

$$\theta = C_2\frac{T^{1.5}H^{0.5}}{U_0D} \qquad [11]$$

where θ is blend time. Equation [11] shows that the blend time increases with the square root of the change in tank liquid elevation. Since the mixer pump is located in the middle region of the tank rather than the bottom of the tank, the height used in equation [11] is the distance between the pump nozzle and the liquid surface or the difference between the pump nozzle and the solids layer on the bottom of the tank.

Increasing the distance between the pump discharge nozzle and the liquid surface from 174.28 inches to 190 inches, is a 9% increase. Since the blend time is proportional to the square root of the height (equation [11]), this increase would lead to an ~4% increase in blend time.

Increasing the distance between the pump discharge nozzle and the solids layer from 165.86 inches to 220 inches, is a 33% increase. Since the blend time is proportional to the square root of the height, this increase would lead to an ~15% increase in blend time.

Fox and Gex (equation [12]) and Lane and Rice (equation [13]) developed correlations that show the same dependence of mixing time on height, but a different influence of U_0D as compared to equation [6].[13]

$$\theta = C_3 \frac{TH^{0.5}}{(U_0D)^{2/3}} \qquad [12]$$

$$\theta = C_4 \frac{TH^{0.5}}{(U_0D)^{2/3}} \qquad [13]$$

Using equations [12] and [13], increasing the distance between the pump discharge nozzle and the liquid surface from 174.28 to 190 inches would increase the blend time by ~4%, and increasing the distance between the pump discharge nozzle and the sludge surface from 165.86 inches to 220 inches, would increase the blend time by 15%.

Grenville and Tilton developed a correlation to predict the blend time in a jet mixed tank. Their correlation is described by equation [14].[14]

$$\theta = C_5 \frac{TH}{(U_0D)\ L} \qquad [14]$$

In equation [14], L is the distance travelled by the jet prior to hitting the wall of the tank. The CSMP discharge nozzle is located 29 feet from the center of the tank having a radius of 42.5 feet.[15,16] The horizontal distance between the CSMP center and the tank wall (y) is described by equation [15] and Figure 3.

$$29^2 + y^2 = 42.5^2 \qquad [15]$$

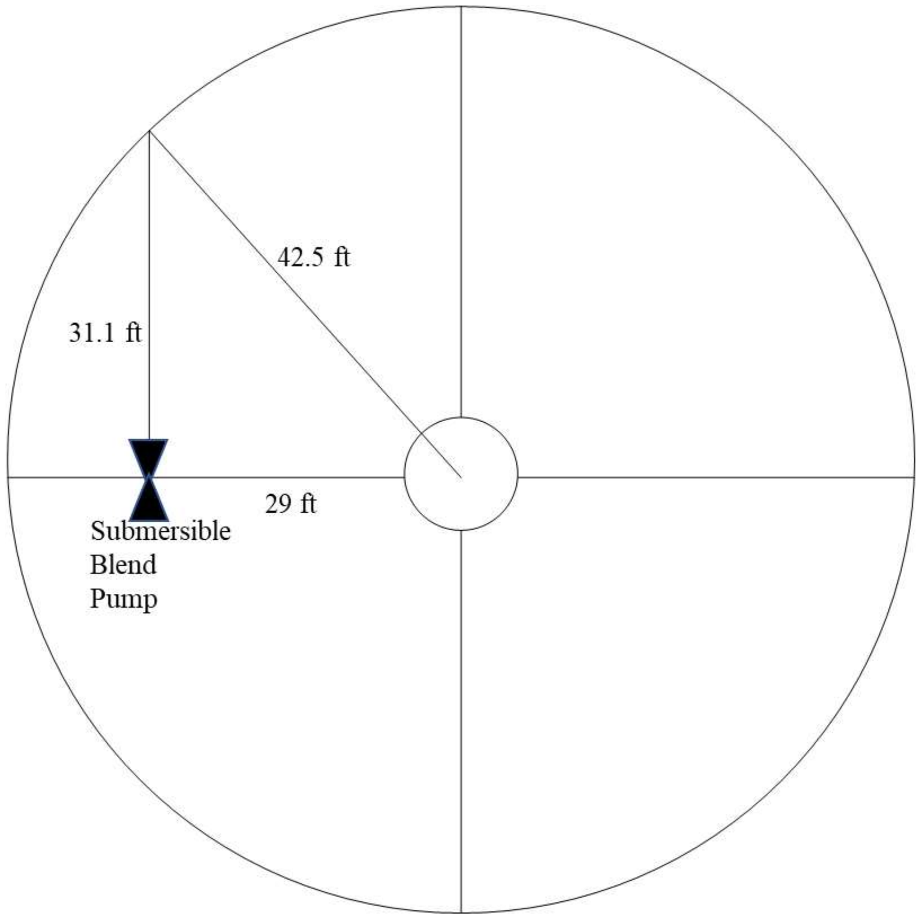

Figure 3. Layout of CSMP in Type IIIA Waste Tank

Solving equation [15] for y gives a distance of 31.1 feet.

The value of L will not change as the liquid level or pump elevation change, so any change in the distance between the pump nozzle and the liquid height or the pump nozzle and the tank bottom will lead to a proportional change in the liquid blend time.

2.4 Quality Assurance

The work scope is defined in M-TTR-F-00032. The TTR requested that a TTQAP not be prepared.[17]

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

3.0 Application to Tank 27

Applying equation [1], which was obtained from reference 1, with a pump flow rate of 500 – 1950 gpm, the predicted blend time in Tank 27 is between 50 minutes and 205 minutes (see Figure 1). Increasing the liquid height from 349 inches to 360 inches will increase the blend time by 3 – 7%. At a pump flow rate of 500 – 1950, the revised blend time would be between 52 and 219 minutes, respectively.

The analysis of the impact of viscosity found that increasing the kinematic viscosity by a factor of 2 (from water to 1.26 g/mL density and 2.5 cP viscosity) would reduce the pump centerline velocity by 9%, increasing the blend time by 10%. The increased viscosity would increase the drag or friction factor from the cooling coils by 15%, leading to a 7% increase in blend time. Combining the two effects, a 2X increase in viscosity would increase the blend time by 18%. Increasing the kinematic viscosity by 4X (1.5 g/mL density and 6 cP) would increase the blend time by 39% (see Figure 2). Figure 4 shows the predicted blend time in Tank 27 as a function of flow rate and viscosity when the pump nozzle is placed at a height of 174 inches.

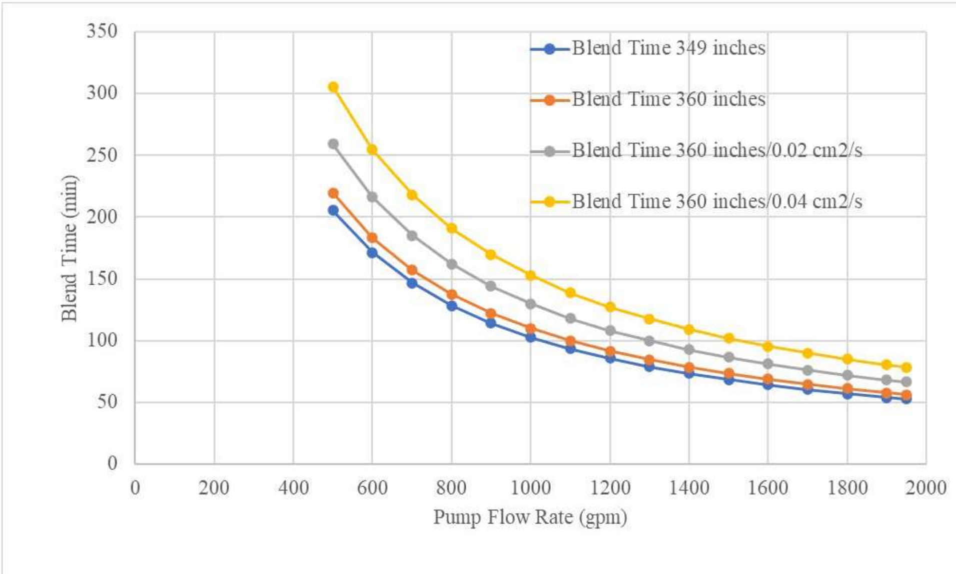

Figure 4. Predicted Blend Time in Tank 27

The 2010 testing is based on a nozzle height of 174 inches. This height assumes that the bottom of the pump screen is located at 153.65 inches. The pump height and nozzle height were adjusted to assess the impact on blend time in Tank 27. Figure 5 shows the effect of pump height on blend time at a pump flow rate of 600 gpm.

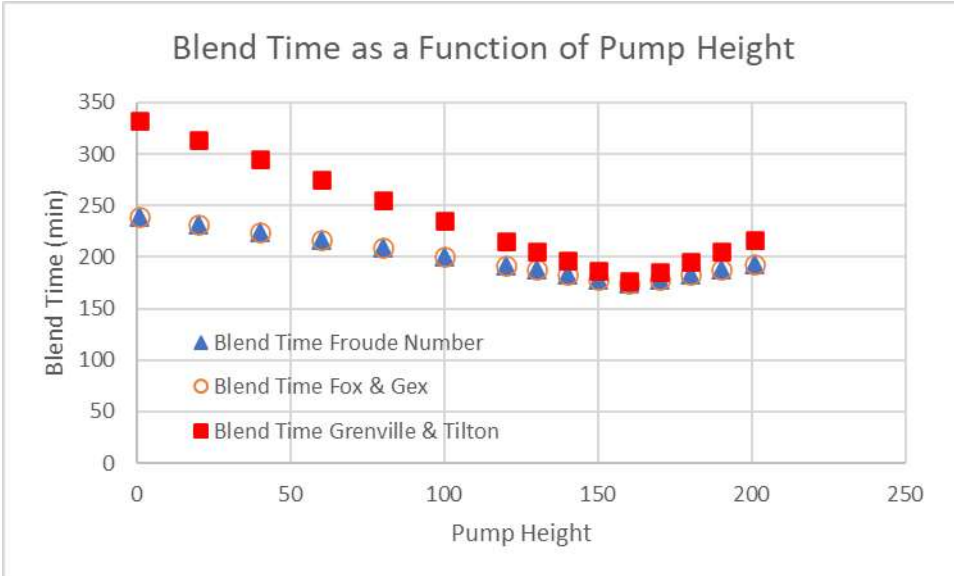

Figure 5. Effect of Pump Height on Blend Time in Tank 27

Figure 6 shows the expected blend time in Tank 27 as a function of pump nozzle elevation with a liquid height of 360 inches and a kinematic viscosity of 0.04 cm^2/sec.

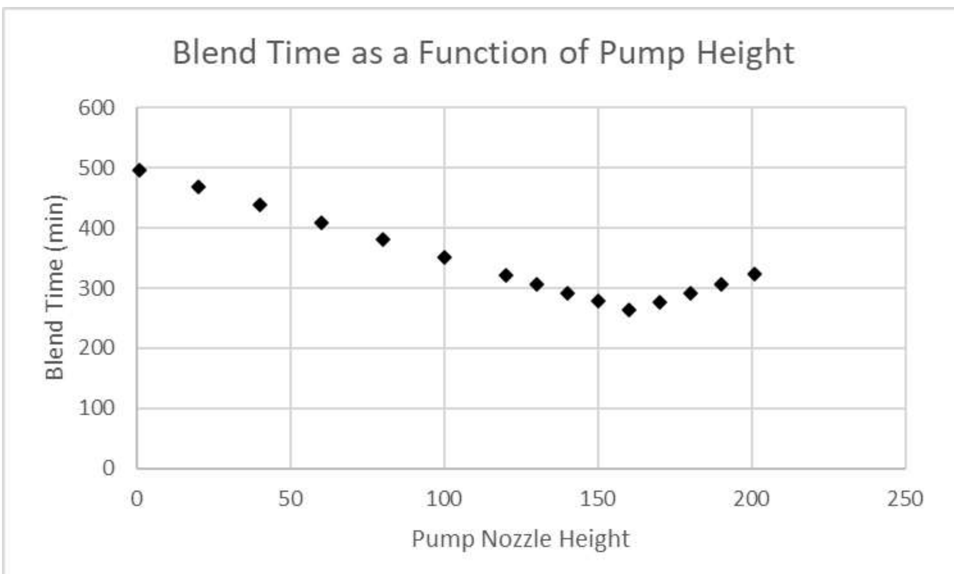

Figure 6. Effect of Pump Height and Liquid Viscosity on Blend Time in Tank 27

The 2010 testing assessed the test uncertainty at ~ 25%. That uncertainty was added to the calculated blend time in Figure 6. In addition, the figure adds two times the uncertainty to obtain a 95% confidence for the blend time. Blend times range between 400 and 750 minutes.

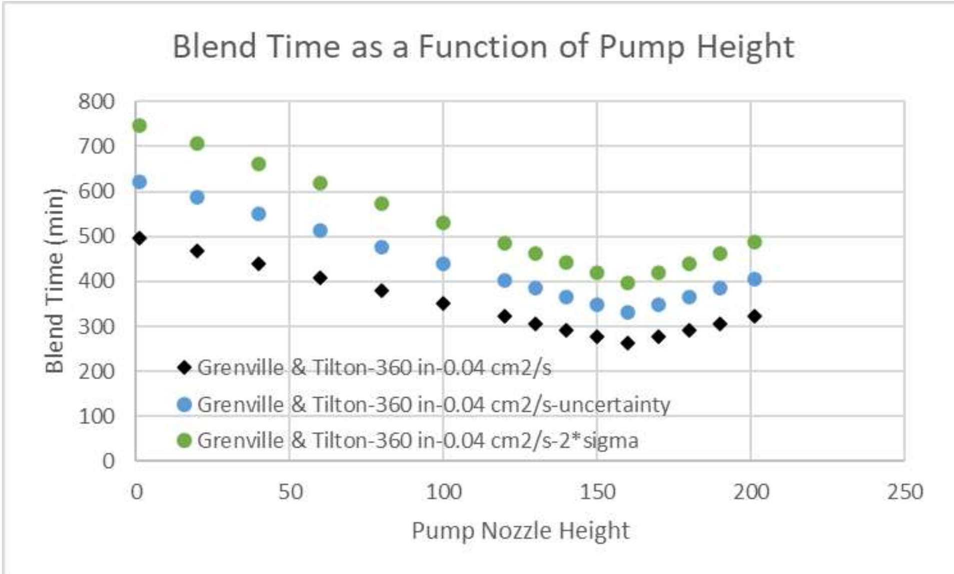

Figure 7. Predicted Blend Time in Tank 27 as a Function of Pump Nozzle height

SRMC requested the author to calculate the expected blend time as a function of liquid specific gravity. For these calculations, the liquid level in the tank is 360 inches. The liquid specific gravity is 1.2, 1.3, 1.4, and 1.5.

The correlations described in Section 2.0 do not show an effect of liquid density on the blend time, but they do show an effect of liquid viscosity. Previous work by Walker and Georgeton measured the liquid density and viscosity as a function of sodium concentration for an "average SRS supernate".[4] Table 1 shows the results. The density in Table 1 was measured at 23 °C, and the viscosity was measured at 30 °C. No attempt was made to correct the density to 30 °C. Comparing the points at which the density was measured at 23 °C and 30 °C, the density difference was less than 3%.

Table 1. Density and Viscosity as a Function of Sodium Concentration for SRS Supernate

Na (M)	Density (g/mL)	Viscosity (cP)	Kinematic Viscosity (cm2/s)
6	1.274	2.64	0.0207
5	1.232	2.12	0.0172
4	1.184	1.66	0.014
3	1.13	1.35	0.0119
2	1.07	1.09	0.0102

The data in Table 1 were fit with an equation of following form

$$\rho = 1 + b\, C^{a} \qquad [16]$$

$$\mu = 1 + b\, C^{a} \qquad [17]$$

where ρ is the liquid density (g/mL), μ is the liquid viscosity (cP), C is the sodium concentration (M), a is a constant, and b is a constant. Equations [18] and [19] describe the liquid density and viscosity as a function of sodium concentration.

$$\rho = 1 + 0.0366\, C^{1.14} \qquad [18]$$

$$\mu = 1 + 0.0283\, C^{2.27} \qquad [19]$$

Table 2 shows the sodium concentration, liquid viscosity, and kinematic viscosity for the selected liquid densities. The data above 6 M sodium are extrapolated, but they are the best estimate that could be obtained for the viscosity in Tank 27. Since the maximum sodium concentration at which the density and viscosity were measured was 6 M, the data in Table 2 and Table 3 should be used with caution. In addition, if the sodium concentration is greater than 6 M, the salts in the solution may precipitate, which would prevent the liquid density from exceeding 1.3 g/mL.

Table 2. Density and Viscosity as a Function of Sodium Concentration for SRS Supernate

Na (M)	Density (g/mL)	Viscosity (cP)	Kinematic Viscosity (cm^2/s)
4.44	1.20	1.83	0.0153
6.33	1.30	2.87	0.0221
8.15	1.40	4.31	0.0308
9.90	1.50	6.15	0.0410

Using equations [2] – [5] and the data in Table 2, we can calculate the increase in blend time due to the increase in liquid density and viscosity.

Table 3. Effect of Density on Liquid Blend Time in Tank 27

Density (g/mL)	Kinematic Viscosity (cm^2/s)	Relative Blend Time
1.0	0.01	1.0
1.2	0.0153	1.1
1.3	0.0221	1.2
1.4	0.0308	1.3
1.5	0.0410	1.39

Table 4 shows the predicted blend time as a function of pump elevation and flow rate with a liquid density of 1.2 g/mL. Flow rates of 600, 800, 1000, 1200, and 1950 gpm were selected to perform the calculations. Pump elevations (measured from the bottom of the pump suction) of 1, 20, 40, 60, 80, 100, 120, 140, 160, 180, 200, 220, 240, 260, 280, and 300 inches above the tank bottom were selected to perform the calculations.[d] If the pump flow rate or pump elevation are between these values, the data can be interpolated to calculate the blend time. The blend times have been increased 50% (two sigma) to account for uncertainty and provide 95% confidence. Equation [14] was selected to account for the effect of changing pump elevation on blend time, because it gives the most conservative answer.

[d] The pump discharge nozzle is located 12 inches above the pump bottom.

Table 4. Blend time as a Function of Flow Rate and Pump Elevation for a 1.2 g/mL Liquid

Elevation\Flow Rate	600 gpm	800 gpm	1,000 gpm	1,200 gpm	1,950 gpm
300 in	506 min	380 min	304 min	253 min	156 min
280 in	474 min	355 min	284 min	237 min	146 min
260 in	441 min	331 min	265 min	221 min	136 min
240 in	408 min	306 min	245 min	204 min	126 min
220 in	376 min	282 min	226 min	188 min	116 min
200 in	343 min	258 min	206 min	172 min	106 min
180 in	311 min	233 min	186 min	155 min	96 min
160 in	306 min	229 min	184 min	153 min	94 min
140 in	338 min	254 min	203 min	169 min	104 min
120 in	371 min	278 min	223 min	186 min	114 min
100 in	404 min	303 min	242 min	202 min	124 min
80 in	436 min	327 min	262 min	218 min	134 min
60 in	469 min	352 min	281 min	234 min	144 min
40 in	501 min	376 min	301 min	251 min	154 min
20 in	534 min	400 min	320 min	267 min	164 min
1 in	565 min	424 min	339 min	282 min	174 min

Table 5 shows the predicted blend time as a function of pump elevation and flow rate with a liquid density of 1.3 g/mL. The blend times have been increased 50% (two sigma) to account for uncertainty and provide 95% confidence. If the pump flow rate or pump elevation are between these values, the data can be interpolated to calculate the blend time.

Table 5. Blend time as a Function of Flow Rate and Pump Elevation for a 1.3 g/mL Liquid

Elevation\Flow Rate	600 gpm	800 gpm	1,000 gpm	1,200 gpm	1,950 gpm
300 in	552 min	414 min	331 min	276 min	170 min
280 in	517 min	387 min	310 min	258 min	159 min
260 in	481 min	361 min	289 min	241 min	148 min
240 in	446 min	334 min	267 min	223 min	137 min
220 in	410 min	308 min	246 min	205 min	126 min
200 in	375 min	281 min	225 min	187 min	115 min
180 in	339 min	254 min	203 min	170 min	104 min
160 in	334 min	250 min	200 min	167 min	103 min
140 in	369 min	277 min	222 min	185 min	114 min
120 in	405 min	304 min	243 min	202 min	125 min
100 in	440 min	330 min	264 min	220 min	135 min
80 in	476 min	357 min	285 min	238 min	146 min
60 in	511 min	383 min	307 min	256 min	157 min
40 in	547 min	410 min	328 min	273 min	168 min
20 in	582 min	437 min	349 min	291 min	179 min
1 in	616 min	462 min	370 min	308 min	190 min

Table 6 shows the predicted blend time as a function of pump elevation and flow rate with a liquid density of 1.4 g/mL. The blend times have been increased 50% (two sigma) to account for uncertainty and provide 95% confidence. If the pump flow rate or pump elevation are between these values, the data can be interpolated to calculate the blend time.

Table 6. Blend time as a Function of Flow Rate and Pump Elevation for a 1.4 g/mL Liquid

Elevation\Flow Rate	600 gpm	800 gpm	1,000 gpm	1,200 gpm	1,950 gpm
300 in	597 min	448 min	358 min	298 min	184 min
280 in	559 min	419 min	335 min	279 min	172 min
260 in	520 min	390 min	312 min	260 min	160 min
240 in	482 min	361 min	289 min	241 min	148 min
220 in	443 min	333 min	266 min	222 min	136 min
200 in	405 min	304 min	243 min	203 min	125 min
180 in	367 min	275 min	220 min	183 min	113 min
160 in	361 min	271 min	217 min	180 min	111 min
140 in	399 min	299 min	240 min	200 min	123 min
120 in	438 min	328 min	263 min	219 min	135 min
100 in	476 min	357 min	286 min	238 min	146 min
80 in	514 min	386 min	309 min	257 min	158 min
60 in	553 min	415 min	332 min	276 min	170 min
40 in	591 min	443 min	355 min	296 min	182 min
20 in	630 min	472 min	378 min	315 min	194 min
1 in	666 min	500 min	400 min	333 min	205 min

Table 7 shows the predicted blend time as a function of pump elevation and flow rate with a liquid density of 1.5 g/mL. The blend times have been increased 50% (two sigma) to account for uncertainty and provide 95% confidence. If the pump flow rate or pump elevation are between these values, the data can be interpolated to calculate the blend time.

Table 7. Blend time as a Function of Flow Rate and Pump Elevation for a 1.5 g/mL Liquid

Elevation\Flow Rate	600 gpm	800 gpm	1,000 gpm	1,200 gpm	1,950 gpm
300 in	639 min	479 min	383 min	319 min	196 min
280 in	597 min	448 min	358 min	299 min	184 min
260 in	556 min	417 min	334 min	278 min	171 min
240 in	515 min	387 min	309 min	258 min	159 min
220 in	474 min	356 min	285 min	237 min	146 min
200 in	433 min	325 min	260 min	217 min	133 min
180 in	392 min	294 min	235 min	196 min	121 min
160 in	386 min	289 min	232 min	193 min	119 min
140 in	427 min	320 min	256 min	214 min	131 min
120 in	468 min	351 min	281 min	234 min	144 min
100 in	509 min	382 min	306 min	255 min	157 min
80 in	550 min	413 min	330 min	275 min	169 min
60 in	591 min	443 min	355 min	296 min	182 min
40 in	632 min	474 min	379 min	316 min	195 min
20 in	673 min	505 min	404 min	337 min	207 min
1 in	712 min	534 min	427 min	356 min	219 min

Even if solid particles are disturbed by the mixing pumps in Tank 27, when the pumps are stopped the disturbed solids will settle. The author calculated the time for the particles to settle 360 inches using equations [20] – [23]

$$v_s = g(s-1)d_p^2/18\nu \quad \text{for } Re_p < 1.4 \quad [20]$$

$$v_s = 0.13[g(s-1)]^{0.72}d_p^{1.18}\nu^{-0.45} \quad \text{for } 1.4 < Re_p < 500 \quad [21]$$

$v_s = 1.74[g(s\text{-}1)\ d_p]^{0.5}$ for $Re_p > 500$ [22]

$Re_p = d_p v_s/\nu$ [23]

where v_s is the settling velocity, g is the acceleration due to gravity, s is the ratio of particle and fluid densities (s = particle density/fluid density), d_p is the particle diameter, and ν is the fluid kinematic viscosity ($\nu = \mu/\rho$).[18]

Figure 8 and Table 8 show the time required for a 2.5 g/mL particle to settle 360 inches as a function of particle size and liquid density. The data show that particles less than 2 micron in size could take months to settle 360 inches. Particles 5 micron in size would take 9 – 32 days to settle 360 inches. Particles greater than 10 micron in size would settle 360 inches within 8 days. The settling times are proportional to the distance that the particles need to settle (i.e., how high the particles are lifted off the tank bottom).

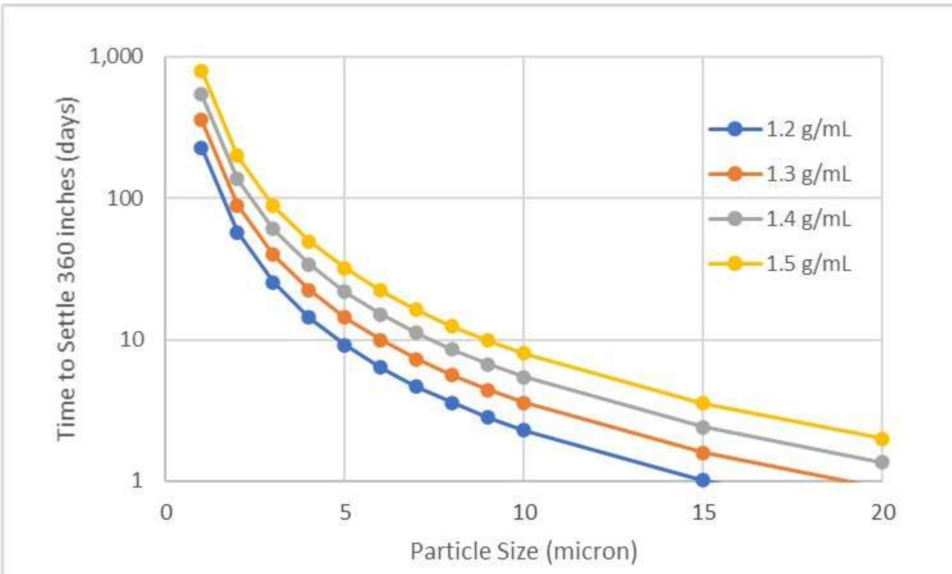

Figure 8. Time for Particle to Settle 360 inches as a Function of Particle Size and Liquid Density

Table 8. Time for Particle to Settle 360 inches as a Function of Particle Size and Liquid Density

	1.2 g/mL	1.3 g/mL	1.4 g/mL	1.5 g/mL
d_p (micron)	Time (days)	Time (days)	Time (days)	Time (days)
1	229	358	544	797
2	57	89	136	199
3	25	40	60	89
4	14	22	34	50
5	9	14	22	32
6	6	10	15	22
7	5	7	11	16
8	4	6	9	12
9	3	4	7	10
10	2	4	5	8
15	1.02	1.59	2.42	3.54
20	0.57	0.89	1.36	1.99
40	0.14	0.22	0.34	0.50
80	0.04	0.06	0.09	0.12

SRMC may elect to blend Tank 27 with two pumps rather than one pump. Previous work investigating jet mixing found the mixing time to be inversely proportional to the square root of the number of mixers.[19] Using two pumps in Tank 27 would reduce the blend time by approximately 29%, using three pumps would reduce the blend time by 42%, and using four pumps would reduce the blend time by 50%.

The 2010 testing investigated bottom sludge suspension with the goal of determining conditions under which the solids would not be disturbed in SWPF blend and feed tanks. With horizontal nozzles, significant solids disturbance was observed. The data does not allow the author to identified conditions under which the solids on the bottom of Tank 42 would not be disturbed.

Testing performed in 2011 looked at adding water to a concentrated salt solution. This testing observed stratification in the tank, and a dramatic increase in the blend time. When concentrated salt solution was added to water, the blend time was reduced significantly.[2] Revill recommends a density difference of less than 5% between liquids to avoid stratification.[12] Therefore, consideration should be given when formulating a salt batch in which the density differences between incoming streams is going to be greater than 5%. One option could be to ensure the lower density material is transferred in prior to the heavier density material. This option should help facilitate some natural mixing as the heavier density material passes through the lower density material and through the formation of a "plunging jet" that leads to fluid mixing that has been analyzed in other reports.[20] Other options may include increased blend times, blending during the receipt of material with density differences greater than 5%, or blending periodically as a salt batch is being formed.[21]

4.0 Conclusions

The conclusions from this study follow.

- Based on the 2010 and 2011 pilot-scale miscible blending testing, a minimum pump flow rate of 600 gpm is recommended.
- With a single pump operating at a flow rate of 600 – 1,950 gpm, the expected blend time in Tank 27 is between 94 and 712 minutes depending on pump elevation and flow rate. The blend times for specific conditions are listed in Tables 4 – 7. These results assume the density difference between the fluids to be blended is less than 5%.
- Using two pumps in Tank 27 would reduce the blend time by approximately 29%, using three pumps would reduce the blend time by 42%, and using four pumps would reduce the blend time by 50%.
- To reduce the risk of stratification, the density deference between liquids in Tank 27 should be less than 5%. If the density difference is greater than 5%, additional parameters should be considered in determining the required blend times outlined in Tables 4 – 7 for Tank 27 (e.g., height of waste, overall density differences, etc.).
- Since the pump nozzles are horizontal, solids disturbance is likely in Tank 27.
- Computational Fluid Dynamics simulations with the M-Star software should be performed when resources are available to reduce the uncertainty in these calculations. It should be of note, that the model assumes the nozzles on the CSMP(s) are stationary and do not oscillate (similar to the submersible blend pumps). If the CSMP(s) are to oscillate, mixing times required are likely to decrease but further analysis is required to determine exact mixing times

5.0 References

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