Clean Up Optimization at Savannah River Site

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Introduction

The Savannah River Site (SRS) has started processing its 33.4 million gallons of High Level Waste (HLW) which was accumulated during last 40+ years of operations to support the nation’s defense programs. The processing of all SRS’s HLW into a permanent waste disposal form will take several decades and involve billions of tax payer’s dollars. An integrated computational tool can guide the decades long process operations in an efficient and optimum manner, and can save millions to billions of dollars. A simulation code ProdMod has been developed based on Aspen Technology’s SPEEDUP software development package to perform dynamic simulation of the entire SRS HLW complex. A general purpose optimization scheme has been devised which performs dynamic optimization for the SRS waste complex. This paper discusses optimization aspects of the computational tool suitable for the SRS’s HLW processing operations.

System Description

The 33.4 million gallons of HLW stored in 49 underground tanks at SRS has been categorized as: a) 15.4 million gallons in liquid form called supernate, b) 14.5 million gallons in crystalline solid form called saltcake, and c) 3.5 million gallons of suspended solid particles called
sludge. The In-Tank Precipitation (ITP) is a pre-treatment facility which separates supernate and dissolved salt into decontaminated (minimally radioactive) salt solution and highly radioactive precipitate slurry. The decontaminated salt solution is transformed into cement grout and disposed of at the Saltstone Vaults as treated low level waste. The highly radioactive processed precipitate and sludge are transformed into borosilicate glass at DWPF for final disposal at the repository. The entire supernate and saltcake will be processed in different ITP cycles. In an ITP cycle, there are a number of ITP batches. In an ITP batch, the supernate and dissolved salt from different waste tanks are blended in Tank 48, dilution water (if needed) is added to reduce Na concentration of the blended salt solution for optimum precipitation, and then precipitating reagent sodium tetraphenylborate (STPB) is added. The precipitate slurry is then concentrated to 10 wt% solids through filtration. The sequencing of wastes from different tanks in an ITP batch is subject to a number of operating rules and priorities which arise due to operational limitations, meeting the regulatory requirements, and budgetary constraints. The left column in Table 1 lists the operating rules and priorities.

Methodology

A general purpose optimization scheme has been devised which can handle different optimization algorithms, such as linear, nonlinear, etc. suitable to the specific problem. A stand-alone optimization driver written in FORTRAN models the optimization problem in the form of constraint equations and the objective function and calls the appropriate optimization routine. The optimization driver is interfaced with the ProdMod simulator to exchange information between the optimizer and the simulator. The interface provides necessary initial and simulated variables from the simulator to the optimizer. The optimization driver then calculates the parameters of the constraint equations and the objective function, and generates optimized parameters by calling the optimization routine. The optimization parameters are then passed to the simulator for the next stage of advancement. The driver again extracts the necessary information for the next stage of
optimization. This process of alternating between the simulator and the optimizer will continue until the desired period of simulation is complete.

Implementation

The optimization scheme has been implemented to sequence wastes for the ITP process for each batch sequentially in an optimal manner. Performing optimization for each batch independently is termed as batch optimization in this paper. The dynamic nature of the problem and the strict operating window has justified the batch optimization instead of global optimization to mimic the SRS waste complex operation. The constraint equations and the objective function which model the rules and priorities are shown in right column in Table 1. Some of the priorities and constraints are implemented by initializing the parameters at the beginning and then updating those for each batch interactively as required, by the user manually or by the optimization driver automatically.

Results and Discussions

A sequence has been generated with the object of removing wastes from Tanks 1 through 24 as rapidly as possible. Tanks 1 through 24 are given high priority-ranks starting 100 for Tank 1 and decreasing by 1 for the subsequent tanks to achieve the objective. Waste removals from Tanks 27, 29, and 41 are also given high priorities because each evaporator system must have enough space for concentrated solution. The remaining tanks are set to 0 priority-rank number. The optimization scheme has successfully cleaned all the first 24 tanks but one. The first batch and the last two batches could not hit the maximum batch size limit, because there has not been enough supernate or dissolved salt available after satisfying the constraints. It is also observed that in most batches, wastes have been blended from tanks which range from two to four tanks. Another observation is that in most cases once tanks have been selected for supernate or dissolved salt removal in a batch,
the same tanks remain selected in subsequent batches until all their supernate or dissolved salt is removed. A tank of zero priority-rank has been selected in several batches although its addition does not increase the value of the objective function because of its zero priority-rank. The addition of that tank has been necessary only to satisfy the constraint equations.

References


Table 1. Implementation of Operating Rules and Priorities

<table>
<thead>
<tr>
<th>Operating Rule and Priorities</th>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintain emergency tank space as required by the Tank Farm Safety Analysis Report (SAR).</td>
<td>Objective Function: Maximize waste removal in a batch from the high prioritized tanks. Maximizes [ \sum_{i=1}^{49} c_i x_i + \sum_{i=1}^{49} c_i y_i ] Decision variables: ( x_i ) and ( y_i ) (i = 1, 2, 3, ........., 49)</td>
</tr>
<tr>
<td>Enable continued operation of the evaporators by providing enough space for the evaporator drop tanks.</td>
<td>Assigning higher number for ( c_i ) (in the objective function) for the evaporator drop tanks</td>
</tr>
<tr>
<td>Have priority to remove waste from tanks with a history of leakage and tanks with no secondary containment and leak detection equipment.</td>
<td>Assigning higher number for ( c_i ) (in the objective function) for those tanks</td>
</tr>
<tr>
<td>Waste from certain tanks can not be removed for certain period of time due to operational procedure. Waste removal instrumentation must be in place before waste removal can take place from a tank. Dissolved salt is not available until all supernate is decanted form a tank.</td>
<td>Assigning 0 to tankavail of the constraint equations: ( x_i \leq e_i \cdot tank _ avail _ i ) i = 1, 2, 3, ........, 49 ( y_i \leq f_i \cdot tank _ avail _ i ) i = 1, 2, 3, ........, 49</td>
</tr>
<tr>
<td>Cs concentration in the 10 wt% precipitate slurry should not exceed the SAR dictated limit (39 Ci/gal).</td>
<td>[ \sum_{i=1}^{49} Cs_{x_i} \cdot x_i + \sum_{i=1}^{49} Cs_{y_i} \cdot y_i \leq batch _ vol \cdot Cs _ lim ]</td>
</tr>
<tr>
<td>Na, K, Cs concentrations in the blended salt solution should be uniformly distributed over the batches, if possible.</td>
<td>Upper limit and lower limit: [ \sum_{i=1}^{49} (X_{x_i} - X_{u _ lim}) \cdot x_i + \sum_{i=1}^{49} (X_{y_i} - X_{u _ lim}) \cdot y_i \leq 0 ] [ \sum_{i=1}^{49} (X_{x_i} - X_{l _ lim}) \cdot x_i + \sum_{i=1}^{49} (X_{y_i} - X_{l _ lim}) \cdot y_i \geq 0 ]</td>
</tr>
<tr>
<td>Dilution water needs to be added if Na concentration of the blended salt solution (supernate + dissolved salt + spent wash water, if any) exceeds a specified limit (~ 5 molar).</td>
<td>[ \sum_{i=1}^{49} (Na_{x_i} - dl _ lim) \cdot x_i + \sum_{i=1}^{49} (Na_{y_i} - dl _ lim) \cdot y_i + (Na_{w_d} - dl _ lim) \cdot w_d \leq (dl _ lim - Na_{w_{lw}}) \cdot w_{lw} ]</td>
</tr>
<tr>
<td>The size of each batch consisting of salt solution, spent wash water, dilution water, and NaTPB can not exceed ITP tank capacity or any other operating set limit.</td>
<td>[ \sum (1 + STPB_{x_i}) \cdot x_i + \sum (1 + STPB_{y_i}) \cdot y_i + w_d \leq (batch _ size - w_{lw}) ]</td>
</tr>
<tr>
<td>The amount of precipitate produced in a batch must meet DWPF demand.</td>
<td>[ \sum_{i=1}^{49} PF_{x_i} \cdot x_i + \sum_{i=1}^{49} PF_{y_i} \cdot x_i = batch _ vol ]</td>
</tr>
</tbody>
</table>

\( x_i, y_i \) = supernate, dissolved salt taken from tank \( i \) 
\( c_i \) = waste removal priority-rank of tank \( i \) 
\( e_i, f_i \) = supernate, dissolved salt volume available in tank \( i \) 
\( tank \_ avail \_ i \) = supernate/dissolved salt availability in tank \( i \) 
\( Cs_{x_i}, Cs_{y_i} \) = supernate, dissolved salt Cs concentration in tank \( i \) 
\( batch \_ vol \) = 10 wt% precipitate slurry volume produced in a batch 
\( Cs \_ lim \) = Cs concentration limit in 10 wt% precipitate slurry 
\( Na_{x_i}, Na_{y_i} \) = supernate, dissolved salt Na concentration in tank \( i \) 
\( w_d, w_{lw} \) = dilution, Late Wash water volume addition 
\( batch \_ size \) = maximum allowable volume combined in a batch 

\( X_{x_i}, X_{y_i} \) = supernate, dissolved salt \( X \) 
\( X_{u \_ lim}, X_{l \_ lim} \) = upper limit, lower limit of \( X \) 
\( Na_{w_{lw}}, Na_{w_d} \) = supernate, dissolved salt Na concentration of blended salt solution 
\( dl \_ lim \) = Na concentration limit of salt solution for dilution water addition 
\( STPB_{x_i}, STPB_{y_i} \) = STPB needed per unit vol. of supernate, dissolved salt 
\( PF_{x_i}, PF_{y_i} \) = 10 wt% precipitate slurry per unit supernate, dissolved salt volume