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MODELING OF THE SAVANNAH RIVER SITE HIGH LEVEL WASTE EVAPORATOR SYSTEMS (U)

by

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ABSTRACT

Three evaporators are used to reduce the volume of waste in the waste tank farm at the Savannah River Site (SRS). Evaporators are crucial operation in the SRS waste processing and management system. Using the Aspen Custom Modeler™ (ACM) software package marketed by Aspen Technology, Inc., the evaporator dynamic flowsheet models have been constructed to simulate the behavior of the evaporator systems. The evaporator models are used to assist operations and planning. The models account for the basic arrangement and flowpath for the evaporators: 1) Feed system, 2) Concentrate system, 3) Overheads system, and 4) Steam system.

This paper provides a detailed description of the model development, and presents the result of a typical simulation scenario.

BACKGROUND

The SRS tank farm has a system of evaporators to reduce the volume of the waste. There are currently three operational evaporators designated as 2F, 2H and 3H. The 2F and 2H evaporators were built in the late 70's and identical in their capacities, general construction, and mode of operation. The 3H was built in the 90's and is similar to the 2F and 2H evaporators except it is about five times larger than 2F/2H.

The Evaporator System provides the dewatering facilities required to continue material production and waste solidification programs at SRS. The Evaporator System evaporates water from liquid radioactive waste so that less tank volume is needed for long term storage. The Evaporator System concentrates both high-heat and low-heat liquid wastes from various feed sources consisting of mainly water and a variety of radionuclides and some inorganic salts in soluble or suspended form. The basic arrangement of the Evaporator System can be divided into four sub-systems: Feed system, Concentrate system, Overheads system, and Steam system. The evaporator flowsheet to be modeled is shown in Figure 1.

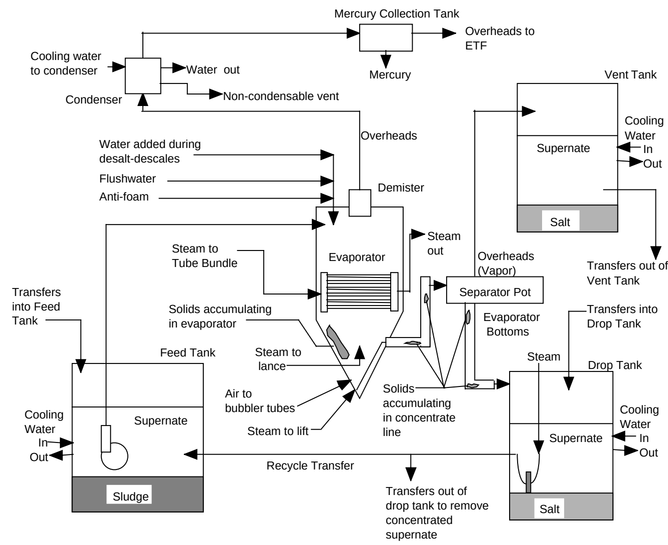

Figure 1. Evaporator system flowsheet

Supernate (liquid) waste from the feed tank is transferred to the evaporator vessel. The waste in the pot is boiled by a steam tube-bundle heat exchanger. Once a desired specific gravity is reached, the concentrate from the evaporator vessel bottom will be drawn off by a steam lift and sent to a receiver tank (i.e., drop tank) via a gravity drain line. The vapors will pass through a de-entrainment unit (demister) to remove any entrained liquids or solids prior to being condensed in a water-cooled condenser. The condensed water will be passed through a mercury removal system and then held in an overhead receiver tank where it will be sampled and released to the Effluent Treatment Facility. The evaporators operate on a continuous mode. That is, during evaporation, waste is continuously transferred to and lifted from the evaporator pot while the liquid concentrate in the pot is maintained at a constant level.

MODEL DEVELOPMENT

ACM Modeling

The Evaporator System Flowsheet Model is created using the Aspen Custom Modeler™ (ACM) software package marketed by Aspen Technology, Inc. ACM was selected for two reasons. First, ACM as a new generation of SPEEDUP™ provides an excellent platform for chemical process modeling, particularly when dynamic simulation is desired. The architecture of ACM makes it very well suited to modeling both continuous and/or batch operations. The ACM modeling structure offers the advantage of easy modification to expand capabilities, allowing models to be built in phases. Second, complex and sophisticated SPEEDUP™ and ACM models have been successfully developed by SRS researchers in the past [Gregory et al. 1994, Hang and Dimenna 2000, Dimenna et al. 2000, Smith 2000].

Physical properties of compounds and mixtures in the evaporator models are predicted using Aspen Properties Plus® that is bundled with the ACM package.

Evaporator Configuration

Figure 2 displays the features of the flowsheet which have been included in the current evaporator models. The following items have yet to be incorporated in future development: Mercury collection tank, vent tank, streams to the evaporator pot (i.e., water during desalt-descales, flush water, and anti-foam), solids accumulation in the evaporator pot and concentrate line, air to bubbler tubes in the evaporator pot, and transfers into drop tank.

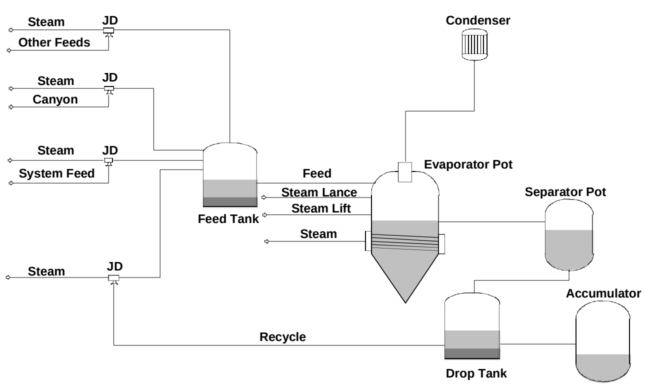

Figure 2. Currently modeled evaporator configuration

As shown in Figure 2, the evaporator feed system is composed of three sources of feeds: (1) System feed for supernate waste from a designated tank, (2) Canyon feed for waste from the canyon, and (3) Other feeds.

(1) and (2) are considered as scheduled transfers, i.e., feeds are transferred to the feed tank based on a specified schedule. Feeds of type (3) are unscheduled transfers since they are only transferred in the absence of scheduled transfers and when the feed tank liquid level is low. This feed system setup provides the users with a high degree of flexibility to select feeds to be transferred to the evaporator system. In addition to waste feeds, the feed tank also receives the concentrate supernate recycled from the drop tank.

Chemical Compounds

The 13 chemical compounds handled by the current evaporator models are: H_2O, Na_2CO_3, Na_2SiO_3, Na_2SO_4, Na_3PO_4, $NaAlO_2$, NaCl, NaF, $NaNO_2$, $NaNO_3$, NaOH, $CsNO_3$, and PuO_2. $CsNO_3$ and PuO_2 are trace components that are used to track radionuclides present in the system.

Tasks

Tasks are a major feature of ACM. Tasks provide an effective structure to handle batch processes and discrete-event simulation. Using tasks, the following actions can be easily implemented during the simulation: changing the value of some variables, writing messages, suspending the simulation, creating snapshots, invoking scripts etc. Figure 3, adopted from the Aspen Technology Inc. Course Notes Material, illustrates how the task manager interacts with the simulation server and the Graphical User Interface within ACM.

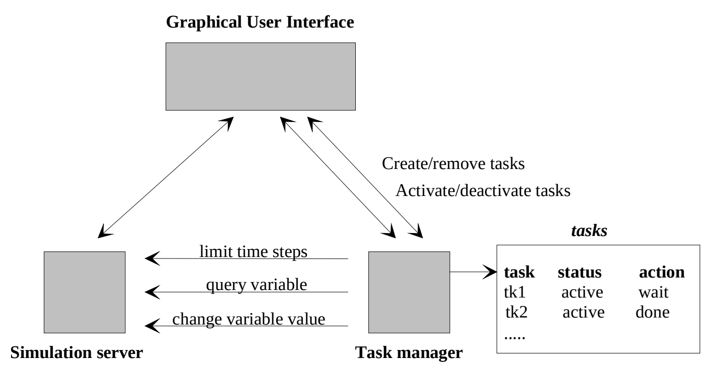

Figure 3. ACM task manager

The Evaporator System models make use of the ACM Task feature. A number of event-driven tasks are created to serve different functions such as filling and draining tanks, making feed transfers, recycling concentrated supernate. There are two categories of tasks:

1. "Fixed" tasks are tasks created within ACM. Fixed tasks do not change with simulations.
2. "On-the-fly" tasks are tasks created by the GUI input/output (using Microsoft Visual Basic). Form and number of these tasks change with each simulation, depending on user specifications.

Samples of "fixed" and "on-the-fly" tasks are shown in Tables 1 and 2, respectively. In Table 1, the FeedTankDrain task triggers the Drain_Signal variable in the feed tank based on the feed tank level. In Table 2, the SchTankTransfer1 task is used to specify the scheduled system feed transfer to the feed tank. 1 is the sequential order number of this type of transfer (e.g., SchTankTransfer1, SchTankTransfer2 etc.).

Table 1. Fixed task to drain the feed tank

```
Task FeedTankDrain Runs When Time == 0
  DrainSignal_ON as realparameter;
  DrainSignal_OFF as realparameter;
  DrainSignal_ON: 1;
  DrainSignal_OFF: 0;
  If FeedTank.Drain_Signal == 0 Then
    // Tank level goes from low to high
    Wait For FeedTank.Total_Level >= FeedTank.High_Decant_Level;
    FeedTank.Drain_Signal: DrainSignal_ON;
    Restart When FeedTank.Total_Level < 1.1 *
      FeedTank.Low_Decant_Level;
  Else
    // Tank level goes from high to low
    Wait For FeedTank.Total_Level <= FeedTank.Low_Decant_Level;
    FeedTank.Drain_Signal: DrainSignal_OFF;
    Restart When FeedTank.Total_Level > 0.9 *
      FeedTank.High_Decant_Level;
  EndIf
End
```

Table 2. "On-the-fly" task to transfer the system feed to the feed tank

```
Task SchTankTransfer1 Runs Once When Time == 30
  FeedSignal_ON as realparameter;
  FeedSignal_OFF as realparameter;
  FeedSignal_ON: 1;
  FeedSignal_OFF: 0;
 Wait For SystemFeed.TaskNum == 1;
  SystemFeed.FV_Feed: 27.254964;
  SysFd_JD.Dilution_Factor: 5;
  SystemFeed.T: 35;
  SystemFeed.conc("H2O"): 51.8597210008829;
  SystemFeed.conc("NaOH"): 1.99390066462564E-02;
  SystemFeed.conc("NaNO3"): 0.767651752568466;
  SystemFeed.conc("NaNO2"): 1.18637089030676;
  SystemFeed.conc("Na2CO3"): 1.2661269165097;
  SystemFeed.conc("Na2SO4"): 4.17722187419746E-02;
  SystemFeed.conc("Na3PO4"): 1.39573045929256E-03;
  SystemFeed.conc("NaCl"): 1.39573045927841E-03;
  SystemFeed.conc("NaF"): 5.28383673986024E-04;
  SystemFeed.conc("NaAlO2"): 9.9695032906154E-03;
  SystemFeed.conc("Na2SiO3"): 1.83765926067964E-14;
  SystemFeed.radconc("CsNO3"): 0;
  SystemFeed.radconc("PuO2"): 0;
  If DropTank.Drain_Signal < 0.5 Then
    SystemFeed.Feed_Signal: FeedSignal_ON;
  Else
    SystemFeed.Feed_Signal: FeedSignal_OFF;
  EndIf
  SystemFeed.Volume: 0.0;
  OrderedFeed.Feed_Signal: FeedSignal_OFF;
 Wait For SystemFeed.Volume >= 378.5412;
  SystemFeed.Feed_Signal: 0;
  SystemFeed.FV_Feed: 0;
  SystemFeed.TaskNum: 2;
  OrderedFeed.Feed_Signal: FeedSignal_ON;
End
```

Model Description

The model flowsheet shown in Figure 2 above consists of blocks and streams that are based on block and stream models. Table 3 lists all the blocks, streams and the underlying models. The following sections focus on the three major block models: Evap, DropTank and FeedTank.

Table 3. List of Blocks, Streams and Models

Block	Block Model
FeedTank	FeedTank
Evaporator	Evap
Separator	Separator
Condenser	Condenser
DropTank	DropTank
Accumulator	AccumulateTank
OrdFd_JD	JetDilution
Canyon_JD	JetDilution
SysFd_JD	JetDilution
Rec_JD	JetDilution
Stream	**Stream Model**
OrdFdJD_Steam	Steam
CanyonJD_Steam	Steam
SysFdJD_Steam	Steam
RecJD_Steam	Steam
Lance	Steam
Lift	Steam
Steam	Steam
OrderedFeed	Feed
Canyon	Feed
SystemFeed	Feed

Evap Model

This model represents the most important block of the evaporator system, i.e., the evaporator pot. Major assumptions include:

- Well-mixed vessel
- Precipitation accounted for by instantaneous chemical equilibrium.
- Homogeneous bulk phase, i.e., there is no separation

between the liquid and solid phases

- Thermodynamic equilibrium between the liquid concentrate and the vapor phase
- Steam is the only component in the vapor phase
- Ideal heat exchange between tube bundle steam and liquid concentrate
- Total condensation of steam in the tube bundle

The following calculations are performed within the *Evap* model:

1. Overall and component mole balances
2. Energy balance
3. Vapor-liquid equilibrium (VLE)
4. Steam-lifted concentrate
5. Vapor overheads
6. True composition of concentrate
7. Levels and liquid level control
8. Specific gravity control

VLE is calculated to determine the boiling temperature of the liquid concentrate. Precipitate solids, if any, are identified by applying "true composition" approach in ACM. A correlation is developed for the steam lift performance based on test data for each evaporator system. For the 3H Evaporator System, Figure 4 displays concentrate flow in gpm at different specific gravities as a function of lift steam flow in lbs/hr. A simple level control scheme is added to the *Evap* model to maintain the liquid level in the pot at a user-specified level value (Set point). Liquid level is controlled by regulation of the lift steam flow. Specific gravity of the liquid concentrate must be controlled also. Specific gravity is controlled by regulation of the tube bundle steam flow. Specific gravity increases with increasing steam flow.

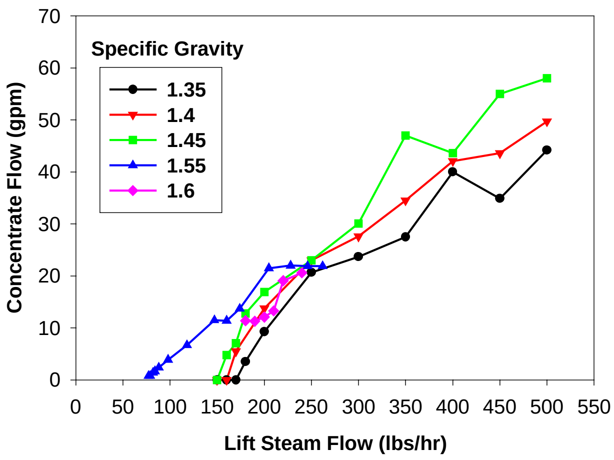

Figure 4. Steam lift performance for the 3H Evaporator System

DropTank Model

The *DropTank* model describes the drop tank operation. The tank content includes both supernate (liquid) and salt (solid). Precipitation and dissolution are accounted for by instantaneous chemical equilibrium. Major assumptions involve:

- Well-mixed vessel
- Precipitation accounted for by chemical equilibrium
- Salt cake is composed of the solid phase only
- Instantaneous thermodynamic equilibrium between supernate and salt cake

The model includes the following calculations:

1. Overall and component mole balances
2. Energy balance
3. Split of the tank holdup into supernate (liquid phase) and salt cake (solid phase)
4. Cooling system
5. Tank level
6. Decant logic
7. Transfer logic

Instantaneous chemical equilibrium is applied to account for precipitation. Those compounds in the bulk phase of the tank holdup that exceed the solubility limit are precipitated as solids and leave the supernate, adding to the salt phase. The solubility limit is determined by Aspen Properties Plus®. Transfer of the drop tank supernate is activated by a task similar to the *FeedTankDrain* task shown in Table 1. Supernate can be recycled to the feed tank or transferred to an accumulate tank. A logic is set up to decide which transfer should be made.

FeedTank Model

The *FeedTank* model is used to describe the feed tank operation. The model is very similar to the *DropTank* model. In the *FeedTank* model, there are four input streams connected to the feed tank: (1) The unscheduled feed stream, (2) the scheduled feed stream from canyon, (3) the scheduled feed stream from designated tanks, and (4) the recycle stream from the drop tank. This structure is designed to allow the feed tank to handle three sources of input streams, i.e., scheduled feeds, unscheduled feeds, and recycle. A fill logic is set up to facilitate the feed tank acceptance of either waste feed streams or recycle stream. The fill logic is carried out by a number of tasks.

Different types of tank level are calculated in the *FeedTank* model: Total level, supernate level, solids level, high decant level, and low decant level. Low and high decant levels are used for supernate transfer. Additionally, a new level, i.e., working space level, is introduced and derived from a specified working space volume (e.g., 100,000 gals). The working space concept is applied to avoid the volume deadlock case in which both feed and drop tanks are completely full. This would result in a shutdown of the evaporator system, since there is no place to recycle the drop tank concentrate. A pre-defined working space volume would reserve a minimum volume that is always available for the recycle stream.

SAMPLE CALCULATION

For demonstration, a sample run of the 3H Evaporator Flowsheet model is provided. The case presented here corresponds to the following operational sequence:

1. Initial tank volumes: 400,000 gals supernate in the feed tank and 1,000,000 gals concentrated supernate in the drop tank
2. Scheduled feed transfers: 50,000 gals from canyon (on 2/15/2003 at 12PM), and 200,000 gals from the first designated tank (Tank I) (on 2/28/2003 at 6AM)
3. Unscheduled feed transfers: 600,000 gals from the second designated tank (Tank II), and 1,000,000 gals from a third designated tank (Tank III)
4. Recycle: Supernate in the drop tank is recycled to the feed tank whenever the drop tank is full
5. Specific gravity control: Concentrate in the evaporator pot is maintained at specific gravity of 1.5
6. Process time: 1000 hours (Start: 2/15/2003 at 0:00 hr; End: 3/28/2003 at 16:00 hr)

The simulation results are shown in Figure 5 for the feed tank, Figure 6 for evaporator pot and Figure 7 for the drop tank.

The results show that the model performs as expected. First, 50,000 gals of the canyon feed are transferred to the feed tank at 12. At ~59 hours, when the feed tank level reaches the low level operating limit set at 2.54 m, the unscheduled feed transfer from Tank II is made since there is no feed transfer scheduled at this time. At 78 hours, 200,000 gals of waste are transferred to the feed tank from Tank I. The unscheduled feed transfer is turned off during the scheduled transfer of Tank I waste. Upon completion of Tank I waste transfer, the unscheduled feed transfer resumes its operation. At ~540 hours, another unscheduled feed transfer from Tank III is activated. This event is triggered by the feed tank level reaching the low level operating limit in the absence of scheduled feed transfers. At ~675 hours, the drop tank is full triggering the recycle of the concentrated supernate. The onset of the recycle stream turns all feed transfers off. Finally, the recycle stream is terminated when the feed tank level reaches the high level operating limit at 9.144. During the entire operation, the concentrate in the evaporator pot is maintained at specific gravity ~1.5. Specific gravity is controlled within 0.3% (no recycle) and within 1.33% (with recycle) of the setpoint.

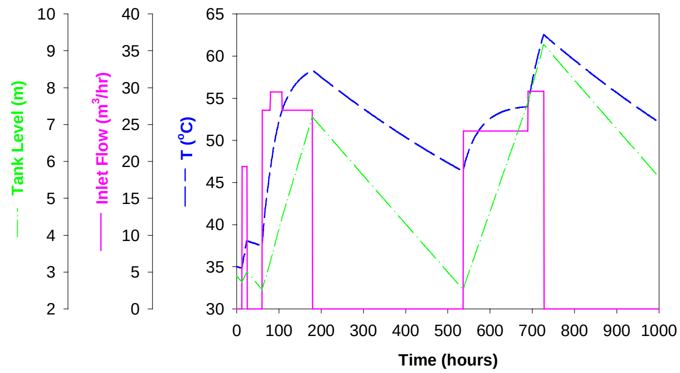

Figure 5. Feed tank of the 3H Evaporator System

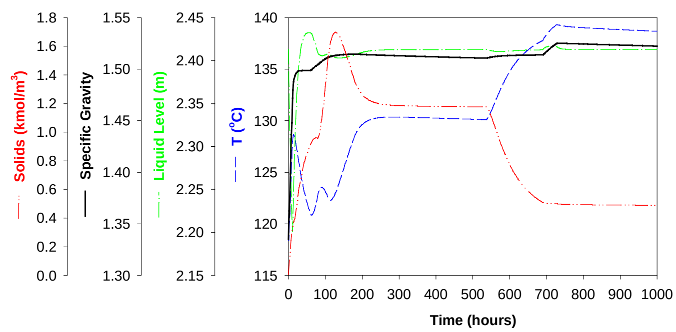

Figure 6. Evaporator pot of the 3H Evaporator System

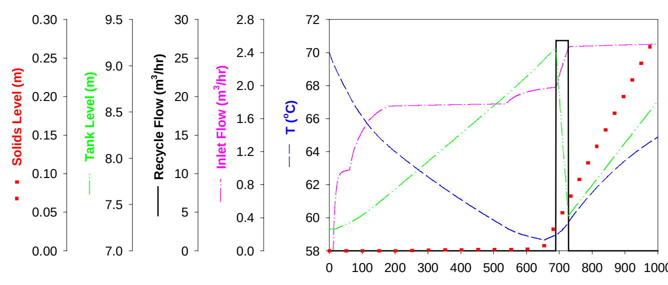

Figure 7. Drop tank of the 3H Evaporator System

CONCLUSIONS

Using the Aspen Custom Modeler™ (ACM) software package, the flowsheet models for three evaporator systems at the Savannah River Site have been developed. Accomplishments in model development include:

- Major operations units of the evaporator systems (i.e., feed system with steam jet dilution to handle system/canyon feeds and supernate recycle from the drop tank; feed tank with cooling water; evaporator pot including steam lance, steam lift and tube bundle steam; separator pot; drop tank with cooling water)
- Thirteen chemical compounds that comprise ~95% of wastes
- Overall and component mass balance, and energy balance in each operation unit
- Precipitation accounted for by chemical equilibrium. Precipitation kinetics are currently not implemented.
- Control of level and specific gravity of concentrate in the evaporator pot at user-specified values (Setpoints)
- Event-driven tasks at the ACM flowsheet level to fill or drain tanks, to make scheduled and unscheduled feed transfers, and to recycle supernate from the drop tank to the feed tank.

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