Sloped Bottom Tanks and Areal Density – Part I: Case Study in H-Canyon Decanters

Tracy Stover, John Lint, Meagan Strachen

Savannah River Nuclear Solutions, LLC
ANS Annual Conference June 2018
Introduction - Process

• HM-Process to separate and purify Highly Enriched Uranium for downblend to Low Enriched Uranium
  – 1\textsuperscript{st} cycle separates
  – 2\textsuperscript{nd} cycle purifies

• Solvent extraction carried out in mixer settler banks – counter current flow chemical contactor systems

• Product solution passed through decanters between cycles
  – Adds hold up time
  – Allows further separation of aqueous product from remaining trace organic solvent phase
Decanters

• Product decanters come in 8’x11’ and 10’x11’ sizes, similar internal design

• Sloped bottom
  – Matches H-Canyon floor slope
  – 3.125% grade
  – Air pocket between bottom head and canyon floor ~3”

• 3 internal sections
  – Settling, organic, aqueous
  – Piping, heating/cooling coils
Decanters

- During processing, subject to 11.5 g U-235/L single parameter limit
- Once processing stops, subject to 700 g U-235 single parameter limit
  - Not permitted for interim storage
  - Volume of 13500 to 21000 L results in concentration as low as 0.03 g U-235/L
  - Requires multiple flushes into downstream tanks
  - Taxes system and operators
  - Creates dilute solution that must be re-concentrated
Methodology – Modeling & Assumptions

• Operations asked Criticality Safety for relief from the 700 g U-235 limit, perhaps using the areal density value already listed as a facility control.

• Fixed U-235 masses based on areal density value of 0.40 g U-235/cm² and SETTLING CHAMBER cross sectional area.
  – For 8x11 tank: 3324.5 g U-235 (3.3 kg)
  – For 10x11 tank: 6243.1 g U-235 (6.2 kg)
  – Both much greater than 700 g

• Acid neutral, pure uranyl nitrate solution at 73 wt.% enrichment
Methodology – Modeling & Assumptions

- **Fixed fissile mass, variable concentration → variable height**
  - Concentration limited to near precipitation of 650 g U/L down to the point of overflow of the center chamber at ~1.3 g U/L
- **Tank modeled as stainless steel cylinder with inner chamber**
- **Stainless steel wedge used to model sloped bottom**
  - Left as solid steel, eliminating air pocket in model
  - Conservatively increases reflection into fissile solution
Methodology – Partially Filled Sloped Bottom

• Solution concentrates until its volume eventually becomes flush with, then drops below shallow end of bottom head
• Significance of sloped bottom tank and why we don’t use areal density outright here!
  – Areal density is typically projected onto surface ORTHONORMAL to the other two dimensions. This bottom is not.
• Solution takes the shape of a truncated wedge:

• To model this, must have method to determine volume and convert back and forth with height and concentration
Methodology – Partially Filled Sloped Bottom

- Volume require numerical integration
  - Integrate area over height
- If deep end depth is $h$ and fraction slope of the tank is $l$, then volume of the solution is:

\[
V_S = \int_0^h \left\{ \frac{-r^2}{2} \left[ 2 \cos \left( 1 - \frac{2r - h'/l}{r} \right) \right] \right\}
\]

- Line $a$ is the line solution makes with the shallow end of the tank
Methodology – Partially Filled Sloped Bottom

- As is the surface area we are interested in
- Area of the yellow segment is

\[ \frac{r^2}{2} (\theta - \sin \theta) \]

- Knowing \( 2r = Q + L \)
- \( L \) is determined by depth of solution and fractional slope
- At a solution depth of \( h' \)

\[ \theta = 2 \cos \left( 1 - \frac{2r - h'/l}{r} \right) \]
Mechanical Tolerance

• Dilution cases assumed nominal geometry of tank
• Peak cases between 9.2 and 70 g U-235/L were rerun
• Selection of mechanical tolerances examined for each concentration in each diameter decanter:
  – 1) replace all steel with water
  – 2) replace bottom head wedge of steel with wedge of void
  – 3) reduce inner diameter of settling chamber by 2.54 cm
Leaks

• A known small slow leak exists between the settling chamber and the aqueous chamber, at the bottom weld, in at least one decanter

• Given enough time, solution would equilibrate through the leak

• Analyze bounding cases with equilibrated solution and solution only in aqueous section
Leaks
Computational Modeling & Limit

- All modeling is performed in the KENO-VI module of SCALE 6.1
- Validated internally for applications to HEU solution processing
- K-safe determined, with margin, to be 0.9664
Results – Concentration

Decanters with Areal Density Based Fissile Mass

- Green line: 8x11 Decanter, 3.3 kg
- Purple line: 10x11 Decanter, 6.2 kg
- Red line: ksafe, 0.9664

Critical

k-eff + 2*sigma vs. Concentration (g U-235/L)
Results – Mechanical Tolerances

8' x 11' Decanter Mechanical Tolerance Cases

- 8x11 Decanter, 3.3 kg
- k_{safe} = 0.9664
- Critical
- No Steel
- Reduced Diameter
- Void Wedge

Concentration (g U-235/L)
Results – Mechanical Tolerances

10' x 11' Decanter Mechanical Tolerance Cases

- 10x11 Decanter, 6.2 kg
- ksafe = 0.9664
- Critical
- No Steel
- Reduced Diameter
- Void Wedge

Concentration (g U-235/L) vs. \( k_{eff} + 2\sigma \)
Results – Leaks

8' x 11' Decanter Chamber Leak Cases

- **8x11**: Decanter, 3.3 kg
- **ksafe**: 0.9664
- **Critical**
- **Equilibrated**
- **Outer Chamber**

Graph showing the relationship between concentration (g U-235/L) and k-eff + 2*sigma.
Results – Leaks

10' x11' Decanter Chamber Leak Cases

- 10x11
  Decanter,
  6.2 kg
- k_{safe} 0.9664

k_{eff} + 2\sigma

Concentration (g U-235/L)
Conclusions

- Despite the slight slope of 3.125% the areal density based mass is usable as a limit
- All cases remained safely subcritical for 3324.5 g U-235 in the 8x11 decanter and 6243.1 g U-235 in the 10x11 decanter
- Reduces operator burden, operational time, and process waste
- Impetus for further investigation...
Further Investigation

- Why does areal density work? Small mass? Slight slope?
- Does it work in other sloped cases?
- What does areal density mean in a system where the plane of projection is NOT orthonormal to the other dimensions?
- Is there a functional relationship between slope of the tank and the areal density projected onto that non-orthonormal surface?
- Further investigation was warranted and is presented in Part II
Acknowledgements

• This work was funded as part of DOE-EM operational budget for H-Canyon.
• Thanks to the men and women of facility engineering for prompting this study.
Cooling/Heating Coils
Analytical Breakdown of Tank Volumes

\[ V(h) = V_1(h) + V_2(h) + V_3(h) + V_4(h) - V_{coils}(h) \]

\[ V_{outer}(h) = V_1(h) + V_3(h) - V_{coils}(h) \]