THE SAVANNAH RIVER SITE REPLACEMENT HIGH LEVEL RADIOACTIVE WASTE EVAPORATOR PROJECT

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ABSTRACT

The Replacement High Level Waste Evaporator Project was conceived in 1985 to reduce the volume of the high level radioactive waste currently stored at the DOE Savannah River Site Tank Farm. Process of the high level waste has been accomplished up to this time using Bent Tube type evaporators and therefore, that type evaporator was selected for this project.

The Title I Design of the project was 70% completed in late 1990. The Department of Energy at that time hired an independent consulting firm to perform a complete review of the project. The DOE placed a STOP ORDER on purchasing the evaporator in January 1991. Essentially, no construction was to be done on the project until all findings and concerns dealing with the type and design of the evaporator are resolved.

This report addresses two aspects of the DOE design review:

- Comparing the Bent Tube Evaporator with the Forced Circulation Evaporator,
- The design portion of the DOE Project Review - concentrated on the mechanical design properties of the evaporator.

DESCRIPTION

Bent Tube Evaporator

The Bent Tube Evaporator (Bundle-in-Column or Horizontal-Tube Thermozyphon Reboiler) is one of the simplest type evaporators in use today. A horizontal tube bundle is inserted inside a cylindrical vessel. The vessel has an opening at the top and bottom. The vessel is filled with liquid and the tube bundle is then filled with saturated steam. The energy in the saturated steam is transferred into the surrounding liquid inside the vessel. The additional energy then causes the liquid to boil. The boiled off steam (with out the contaminates) then exits the vessel through the deentrainer at the top opening and flows to the condensers for condensation. As the liquid boils off, the remaining liquid becomes concentrated with contaminates. The remaining liquid is allowed to concentrate until it reaches a specificate gravity and then is transferred out of the vessel through the bottom opening. In this application, the batch operation is not used, rather controls are used to continuous feed and concentrates drain the vessel for an extended time. As the remaining liquid concentrates, because of the laminar flow past the steam tubes, certain constituents are attracted to the higher temperature on the out side of the steam tubes and begin to form a layer of scale on the tube. This scale build up continues until it is no longer economical to operate the evaporator. The evaporator is shut down, drained of the concentrated liquid and refilled with clean water at ambient temperature. Then the steam tube is rapidly pressurized with saturated steam again. The thermal shock then knocks off the scale off of the steam tubes. The thermal shock also causes the length of the steam tube to increase. Since the design of the vessel does not allow expansion of distance between the tube sheets, the tubes must "flex" between the sheets. In order to direct and control the "flexing" of the tubes, each tube is bowed (bent) prior to installation into the tube sheet. This is where the term "Bent Tube" evaporator derived from.

The advantages (1) for the Bent Tube Evaporator are;

- Since all of the process takes place in one single vessel, no separate rooms for each component of the process are required.
- The design provides a large surface area for vapor-liquid disengagement which reduces the "carry-over" of contaminates.
- Since there are no rotating machinery, there is low construction and maintenance cost.
- Submergence of the tube bundle provides a good heat transfer coefficient.
- This evaporator is used when sever scaling is anticipated during operation because the design of bent tubes provides ease of the descale/desalt processing.

The disadvantages (1) are;

- Depending upon the constituency of the liquid being processed the frequency of the descale/desalt process may substantially increase.

Forced Circulation Evaporator

The design of the Forced Circulation Evaporator essentially removes the tube bundle and the deentrainer from the vessel. The concentrated liquid drains from the vessel to the suction of a high capacity pump. The pump discharges the liquid through the tubes of the tube bundle (heat exchanger). The liquid is heated close to the boiling point using saturated steam in the shell side of the heat exchanger. Then, as the liquid leaves the heat exchanger and enters the vessel, it begins boiling. The steam leaves the vessel through the top opening and flows through the deentrainer and on to the condenser to be condensed. As the liquid concentration increases, an additional pump, also taking suction from the bottom of the vessel, begins to transfer a portion of the liquid to a concentrates receiver tank. This evaporator uses a continues "feed and bleed" process for long term operation.

The advantages (1) of the Forced Circulation Evaporator are;

- Use of a high capacity recirculation pump insures turbulent flow through the heat exchanger which develops a high heat transfer coefficient.
- The continues recirculation maintains a thorough mixing of the concentrated liquid.
- Because of the high velocity of the liquid through the heat exchanger, this evaporator can be used in solutions which are proned to salting, scaling and fouling.

The disadvantages (1) are;

- Because of the equipment, piping and arrangement required for this type evaporator, the construction and maintenance cost are high.
- Because of the high capacity requirements of the recirculation pump, power demand is high.

Frequent difficulties (1) with Forced Circulation Evaporators;

- If, during operation, a salt deposit which often develops over time, were to detach from the equipment or piping inside wall, and flow to the heat exchanger, tube inlets may be restricted. When restricted, salt and scale would deposit in the restricted tube until it was completely plugged.
- If the viscosity of the concentrates liquid were to substantially increase above design limits, the recirculation pump flow rate would decrease. When the flow rate decreases, salt and scale would deposit inside the heat exchanger tubes which would lower the heat transfer coefficient.
- If the temperature of the inside wall of the heat exchanger tubes increases or if the liquid pressure were to decrease, boiling inside the tubes would begin. Tube boiling causes scaling and salting to develop inside the tube.

BENT TUBE VERSES FORCED CIRCULATION EVAPORATORS

In the selection of the type of evaporator to be used for processing high level radioactive waste at the Savannah River Site, several aspects were compared between Bent Tube and Forced Circulation evaporators. They were cost (construction, operation and maintenance), operating history (associated with high level radioactive waste), over all efficiency (volume reduction) and ALARA (as low as reasonably achievable) man rem associated with the evaporators.

COST

The cost of constructing a Bent Tube Evaporator at the Savannah River Site has been estimated at $93,000,000. The cost would increase significantly if a Forced Circulation Evaporator was chosen because of the three additional shielded rooms needed for the heat exchanger, the recirculation and transfer pumps, and the separator deentrainer. Additionally, because of the sensitivity of the operation of the Forced Circulation Evaporator, additional instrumentations and controls would be required.

Operating cost of a Forced Circulation Evaporator would be higher than that of a Bent Tube Evaporator due to the high power demand from the recirculation pump (37854 liters/min. / 100 horse power).

Maintenance cost of the Bent Tube Evaporator is low because there are no rotating machinery. Maintenance cost of the Forced Circulation Evaporator is much higher because of the maintenance required associated with the two pumps and additional instrumentation and control.

OPERATING HISTORY

Since the evaporator is to be used to process high level radioactive waste (50 Ci/gal or 13200 μCi/ml), evaporator operating history processing that level of high level radioactive waste is limited to the Savannah River Site. Two other sites process radioactive waste one to two orders of magnitude less severe than the Savannah River Site waste. The sites are the Hanford Reservation and West Valley, New York. West Valley Demonstration Facility designed a simple Kettle type evaporator to process its high level waste and it has not as yet been operated.

The Hanford Reservation has used evaporators to process the low level ($\leq$5 Ci/gal or 1320 μCi/ml) radioactive waste. Two Kettle type evaporators were placed in operation in 1952. One operated until 1955. The other operated until 1976 or 24 years. Little or no operating history was available for those evaporators.

Forced Circulation

Two Forced Circulation evaporators were designed and constructed at the Hanford Reservation. One operated from 1973 until 1980 with no intention to upgrade and operate in the future. The other Forced Circulation evaporator ("242 A" evaporator) operated from 1977 until 1989. The evaporator is undergoing a design modifications to improve the heat exchanger heat transfer and fouling characteristics.

Annual reports describing the operation of the 242 A evaporator were reviewed to determine the amount of unplanned downtime was experienced during the "campaign".

Unplanned downtime was split into two areas; evaporator caused downtime and "other". The evaporator caused downtime was then further broken down into;

Pumps	Recirc. pump, Slurry Out pump, pump seals, pump bearings, seal water supply, etc.
Reboiler	Fouling, scaling, and salting.
I&C	Flow controllers, temperature switches, etc.
Demister	Foaming, plugging, burping, etc.

Of all downtime, 56% was due to evaporator problems while 44% was caused by others. Of the evaporator caused downtime, 68% was pump related, 16% reboiler related, 7% I&C and 2% demister.

Bent Tube

The Savannah River Site records from 1979 through 1990 provide the downtime information. The Bent Tube evaporator downtime is as follows;

Desalt/Descale	Thermal shocking of the built up scale on the outside of the steam tube bundle.
Pluggage	Plugging of the concentrates transfer line

I&C	I&C used to control feed rate, steam pressure, vessel pressure, etc.

In reviewing the comparable records, Hanford Reservation and the Savannah River Site experience roughly the same downtime caused by "others". At the Savannah River Site, of all downtime 17% was due to evaporator problems while 83% was caused by others. Of the evaporator caused downtime, 68% was desalt/descale, 21% process pluggage, 11% I&C.

EFFICIENCY - THROUGH PUT

Forced Circulation

At the Hanford Reservation, from 1980 through 1989 the 242 A evaporator was operated with the exception of one year which was downtime caused by "other". During that time the evaporator processed (through put) 435,000,000 liters from the tank farm. The net available volume gain produced by the process was 125,000,000 liters. The overall efficiency was 28.7%.

Bent Tube

At the Savannah River Site, the 242-16F evaporator was operated from 1980 through 1989 with one year downtime caused by "others". During that time, the evaporator processed (through put) 230,000,000 liters from the tank farm. The net available volume gain produced by the process was 57,000,000 liters. The overall efficiency was 24.6%.

ALARA

Forced Circulation

The most frequent entries into high radiation areas associated with the evaporator are caused by pump problems. Historically, it is pump seal failures. Records indicate that limited to maintenance personnel, it takes 2 to 3 men, 2 to 3 hours for each cell entry to replace a seal. Each seal replacement requires an average of 3 entries. That averages to 18 man hours for each seal replacement. The average for each entry produces 200 man rem per person per entry. That averages to 1.25 rem expended per seal replacement. By factoring in the remaining evaporator caused downtime, the average of 1 rem per evaporator caused shut down equates to 56 man rem from 1979 through 1989 or 5.6 man rem expended per year.

Bent Tube

The design of the Bent Tube evaporator at the Savannah River Site eliminated the need of entries. No rotating machinery was used and instrumentation is remotely mounted. How ever, the bent tube evaporators have experienced failure (pin hole) of the steam tubes. The average frequency of the failure ever 12 years evaporator operation. Tube failure caused the replacement the whole evaporator. The last vessel replacement expended 28.4 man rem which averages to 2.4 man rem per year. Because of the steam tube failure frequency and the associated man rem expended, the design of the new Replacement High Level Radioactive Waste Evaporator replaced the 304L stainless steal tube bundle with Hastelloy™ G series material. This material will eliminate tube failure.

EVAPORATOR SELECTION

In final evaluation as to type of evaporator to be used at the Savannah River Site to process high level radioactive waste, five aspects based upon operation history and current design data were considered and compared with Forced Circulation (FC) and Bent Tube (BT) evaporators.(In the evaluation, the type with least points is the most appropriate.)

	FC	BT
Cost of design and construction - $30M/point	4	3
Maintenance - Machine/point	2	0
Downtime - each 20% of total/point	3	1
Efficiency - 100% = 0 points	3	3
ALARA - 1 Man Rem/year/point	5	2
TOTAL	17	9

RESOLVED DOE DESIGN CONCERNS OF THE SAVANNAH RIVER REPLACEMENT HIGH LEVEL RADIOACTIVE WASTE EVAPORATOR

Concern

Evaporator configuration is not conducive to achieving DF required; no reasonable basis provided to substantiate that required DF will be attained.

Response

De-entrainment Unit

The design of the de-entrainment system was developed by the Engineering Services Division of Dupont. The design calculations for the de-entrainment section of the RHLWE were performed by Mr. D. McIntosh. The results of his calculations were reported to United Engineering & Construction (UE&C) by his letter to N. Greenberg on 9/16/88. The letter is referenced in the Project Calculation Logs. Design inputs were provided to Mr. McIntosh by the Project Management Team (PMT) section of Waste Management Operations.

The design input was for a decontamination factor (DF) of 1.4 x 10E+8 (revision 1 of the Basic Data document states 1.0 x 10E+8 as the established project goal). This required DF was based on a concentration of 26 Curies (Ci)/L (bottoms) and an overhead activity downstream of the de-entrainment system of between 400 and 1500 d/min/ml. All activities were based on Cesium (Cs)-137.

Design of the de-entrainment device must be suitable for a wide range of operating conditions. The selection of a 91 cm (36 inches) diameter, 46 cm (18 inches) thick demister is based on operating at overhead condensate rates between 30 liters/min. and 87 liters/min (8 to 23 gpm).

It should be noted that currently designed Tank Farm evaporators consistently operate with a DF of 10E+6. When the feedstock has an extremely high Ci content the over-heads are processed through a cesium removal column to provide final decontamination.

Mr. McIntosh pointed out that no actual test data utilizing SRS feedstock existed to back up his calculation of achieving a DF of 1.4 x 10E+8. He recommended procedures that should be followed for future testing. The Evaporator Services and Consulting, Inc. (ESC), after review of the design calculation, states in their report that "possibly a DF of 4.5 x 10E+7 is attainable, from the prior data".

In accordance with a letter from Larry E. Snyder, Director (DOE), Project Management Division, to Gary Hohmann, Acting Manager (W), Project Management Department, November 12, 1991, the Project Engineering Services Contractor (PESC) performed an Independent Design Review (IDR) which provided a documented and retrievable design basis for the expected DF founded upon the current evaporator configuration. The report concluded that the vessel configuration and mesh pad specification will achieve the required DF.

Concern

Design criteria for evaporator tube bundle configuration is not identified.

Response

Due to the hostile environment within the evaporator severe scaling of the tube bundle is expected, with a subsequent loss in efficiency and reduction in performance. One of the primary concerns is that descaling take place with the greatest degree of efficiency and thoroughness thereby reducing the frequency of this operation. The bent tube arrangement allows for a greater degree of flexing (than a straight tube design) with a subsequent increase in the efficiency of the operation, thereby reducing the frequency with which descaling must be performed.

Perry & Chilton, Chemical Engineer's Handbook, 5th Edition indicates that the bent tube design lends itself to good heat transfer coefficients; large vapor-liquid disengaging area and easy semi-automatic descaling. It is noted that very low headroom is required with a bent tube arrangement which is critical when considering movement of the vessel on site. Perry & Chilton lists limited headroom and severely scaling liquids as the best applications for a bent tube evaporator.

In accordance with a letter from Larry E. Snyder, Director (DOE), Project Management Division, to Gary Hohmann, Acting Manager (W), Project Management Department, November 12, 1991, the PESC performed an IDR of the vessel and appurtenance and provided additional documented and retrievable design basis analysis. The design criteria for the tube bundle configuration and tube angle were assessed and concluded that current design is appropriate.

Concern

Tube bundle heat exchange surface area is not adequate.

Response

The process design of the evaporator vessel was done by the Engineering Services Division of Dupont. The design calculations for the evaporator were performed by A. E. Jones, PHD. Design input were provided by the Project Management Team (PMT) section of Waste Management Operations.

These calculations show that a tube bundle consisting of 54 horizontal rows by 11 vertical rows of 1.9 cm diameter cubes on a 3.8 cm square pitch with a total heat transfer surface of 132 square meters is required. The calculation also established the design liquid level to be 15 cm above the top tube.

The tube bundle design is based on a horizontal thermosyphon reboiler. The depth of the tube bundle and the pitch are critical to achieving a maximum "pumping rate". The tube bundle is kept as shallow as possible to promote vaporization below the liquid level, maximizing the internal pumping rate. The depth of liquid over the tubes is set to minimize the effect of liquid head on the pumping rate.

UE&C has performed calculations to validate the tube bundle design. These calculations utilized the Heat Transfer Research Institute Computer Program RKH 2. The results indicate that in the unfouled condition there is twenty eight percent excess surface.

The improvements to the existing design section of the SMS report recommends an 2.4 meter diameter vessel and an increased depth of liquid over the tubes. This design would be less efficient since the pumping rate would be significantly lower. The evaporation achieved with this design would be primarily by surface boiling only. Since this design is less efficient more tube surface would be required.

In accordance with a letter from Larry E. Snyder, Director (DOE), Project Management Division, to Gary Hohmann, Acting Manager (W), Project Management Department, November 12, 1991, the PESC has performed an IDR of the evaporator vessel and appurtenance and provided additional documented and retrievable design basis analysis. The tube bundle heat exchange surface area sizing initially performed by Dr. Jones was reviewed and, in addition, the PESC Evaluation Team performed several sets of calculations which verified that the tube bundle is firmly based upon practical plant operating experience and confirmed by theoretical calculations.

Concern

Evaporator vessel is significantly oversized for application. Basis for vessel size not apparent from documentation."

Response

The calculations done by A. E. Jones dated 5/16/88 established the vessel diameter. Once the tube bundle is designed the evaporator diameter is set because the diameter of the evaporator is driven by the size of the tube bundle. To house a bundle having 132 square meters of surface area with 11 vertical rows requires 54 horizontal rows of tubes 3.7 meter long. This bundle configuration requires a vessel 4.3 meters in diameter.

The statement by SMS that the vessel is oversized is apparently based on their "Recommended Improved Design" which would have a 2.4 meter diameter and a surface area of 204 square meters. The resulting tube bundle would be 55 vertical rows, which would result in a minimal pumping rate.

In accordance with a letter from Larry E. Snyder, Director (DOE), Project Management Division, to Gary Hohmann, Acting Manager (W), Project Management Department, November 12, 1991, the PESC performed an IDR which provided documented and retrievable design basis for the vessel sizing. The analysis which led to the basis of the vessel size took into consideration several variables which included; evaporator freeboard, steam lance/lift, *overhead vent diameter*, tube bundle size and configuration and deentrainment. All of these factors were reviewed to verify Dr. Jones calculations which determined the size and configuration of the vessel. The report concluded that the vessel as designed is appropriate for use at the Savannah River Site.

Concern

Process steam supply pressure is too high and not desuperheated."

Response

Per the Basic Data Report the operating temperature of the evaporator can vary between 130 and 180 degrees C. The higher steam pressures are required for those times when the evaporator operating temperature is between 160 and 180 degrees C.

The steam supply to the evaporator is currently available as superheated high pressure steam. There is no reason to require an additional desuperheating unit. We expect in the worst case that desuperheating would occur in the first few inches of the tube bundle.

UE&C used an alternate method to determine the vaporization rate from an internal tube bundle. Heat Transfer Research Institute's (HTRI) computer program RKH-2 Mod 0.11-1.04 was used in the "internal coil in a column," mode. HTRI's computer calculation indicated that there was no advantage in using an external desuperheater.

In accordance with a letter from Larry E. Snyder, Director (DOE), Project Management Division, to Gary Hohmann, Acting Manager (W), Project Management Department, November 12, 1991, the PESC performed an IDR and addressed the issues of process steam and desuperheating concerns. The review pointed out that the supply pressure is an operating requirement. Steam desuperheating was addressed as not required. In a letter, the PESC stated that even in a "worst case" situation, approximately 25.4 cm (10 inches) or 7% of each tube surface area was required to desuperheat the steam. In short, steam desuperheating will have a negligible effect on heat transfer performance of the steam bundle.

Concern

Condenser configuration is not conducive to effective venting of non-condensible gases. Lack of vent gas cooler increased likelihood that contamination will be introduced through vent line into evaporator cell.

Response

Keeping the process on the tube side of the condenser is preferred to having the process on the shell side since it makes the cleaning and decontaminating the condenser easier.

There is ample sub-cooling in the current vertical design with condensation on the tube side, therefore, a separate vent condenser would not be required.

Adequate surface is being provided in a single shell to sub-cool the condensate to the proper temperature level required to meet project design objectives. This single vertical condenser with condensation in the tubes and a non condensible vent located at the bottom and bell of the condenser is standard technology. Also, it has been used successfully at SRS in other tank farm evaporator installations.

In accordance with a letter from Larry E. Snyder, Director (DOE), Project Management Division, to Gary Hohmann, Acting Manager (W), Project Management Department, November 12, 1991, the PESC performed an IDR which provided documented and retrievable design basis for the condenser. The IDR verified that the condenser configuration supported the design approach and that a vent gas cooler for the non-condensible gas vent line is not justified. Calculations also indicated that for a postulated upset condition (double ended tube failure in the vessel with rapid boil-off near the surface of concentrate) the back pressure in the evaporator would exceed its design rating of 2.6 kg/cm gage (15 psig). The Project Team concurred with the recommendation in the IDR to prevent pressure build-up in the vessel in event of the double ended tube failure by increasing the NCG vent line from 10.16 cm (4 inches) to 15.24 cm (6 inches). It was concluded that the remaining design and safety considerations are appropriate as is.

REFERENCES

1. Perry & Chilton, Chemical Engineer's Handbook, Fifth Edition