APPLICATION OF CRYSTALLIZERS FOR LIQUID RADWASTE VOLUME REDUCTION SYSTEMS

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ABSTRACT

The purpose of this paper is to describe the use of evaporator/crystallizers as an effective low level radwaste volume reduction system. An evaluation of operating experience, operating costs and economics of evaporators is also presented in comparison to demineralizers. Both PWR and BWR operating plants are identified, as well as design principles and materials of construction used to improve the reliability and ease of operation in the radwaste volume reduction units.

Operating Units

The successful operation of HPD Evaporator/Crystallizer Liquid Volume Reduction Systems is reflected in the number of units in operation, the length of operating time, and the economics of operating these systems.

At the present time, the following plants are utilizing and satisfactorily operating the evaporator/crystallizer system with certain units reaching product concentrations of 1.5 specific gravity.

For this presentation two of the plants shall be described and discussed with respect to design and operation. Both units have been in operation approximately the same length of time. See Table I.

SPAIN	- ZORITA STATION	5 GPM	1/2 YEAR
PUBLIC SERVICE ELECTRIC AND GAS	- SALEM UNIT	15 GPM	1 YEAR
NIAGARA MOHAWK	- NINE MILE POINT	20 GPM	9 YEARS
NEW YORK POWER AUTHORITY	- JAMES A. FITZPATRICK STATION	20 GPM	8 YEARS
TOKYO ELECTRIC	- FUKISHIMA STATION	2 x 20 GPM	2 YEARS
TAIWAN POWER COMPANY	- KUOSHENG STATION	2 x 25 GPM	2 YEARS
TVA	- SEQUOYAH	30 GPM	1 YEAR

TABLE I

The first unit is actually a second generation evaporator/crystallizer. The original evaporators, included in the complete nuclear package, were of the "pot boiler" type, constructed of stainless steel materials. The units operating strictly on boric acid have functioned for a considerable period of time. The unit designated to handle primary and secondary floor drains and other wastes failed due to corrosion within a few months of initial operation. Since the time of the failure of the waste evaporator, the liquid radioactive wastes from the plant were processed by portable demineralizers until the start-up of the HPD Evaporator/Crystallizer system.

The first generation evaporator systems, have been very difficult to operate and maintain due to the designs. High operating and maintenance costs of the original pot boiler type evaporators handling waste streams have been normal throughout the nuclear industry. Therefore, the use of evaporators, generally speaking, for handling nuclear waste developed a less than favorable reputation. The majority of operating experience with HPD systems is in Japan, where both high conductivity and detergent waste units have operated for two years in BWR plants. The plant operators, therefore, were not anxious to proceed directly with the integration of the HPD unit into their system until it was absolutely necessary. Although the unit was tested and ready for operation in early summer, it was not used on radioactive wastes until November of the same year.

Economics at this plant for the dirty waste streams required that the evaporator be utilized to minimize radwaste costs. Estimated operating costs between the evaporator system and demineralizers will be presented herein. It has been determined that the evaporator/crystallizer can provide satisfactory volume reduction waste streams containing chlorides, chromates, and laundry and decon solutions satisfactorily and economically with minimum maintenance. The evaporator/crystallizer unit has been on line for over one year, but has not yet reached full capacity because of various plant restrictions. This unit, in its operation, has proven its reliability as the primary processor of radwaste and also its capability for providing catch-up capacity due to its high processing design rate. Therefore, the unit functions in emergencies for catch-up during high volumes of decon and other waste feed streams when such inflows are received and cannot be handled by the demineralizers. The HPD Radwaste Evaporator requires only normal system monitoring and scheduled maintenance and operational checks during its first year of operation. The evaporator/crystallizer is designed for concentrating primary and secondary borated floor drain wastes from the feed concentration to approximately 50 weight percent total solids. The radwaste crystallizer is a specially designed forced circulation evaporator consisting of a vapor body, recirculation pipe, recirculation pump, and a two pass heat exchanger. Steam is applied to the shell side of the heat exchanger where it condenses on the outside of the tubes, giving heat to the liquor circulating through the tubes. Steam condensate is removed from the shell side of the heater and returned either to the boiler or condensate storage tank. The liquor circulating through the tubes is not allowed to boil in the tubes due to layout of the equipment and low temperature rise across the heat exchanger. After the liquor passes through the heat exchanger, it enters the vapor body where it releases water vapors to the entrainment separator and the condenser/subcooler system. The process system including the vapor body, recirculation pipe and pump, are all designed to operate in the crystallization mode which will achieve proper nucleation and growth rate to facilitate good operation.

During normal operation of the plant, steam is provided to the evaporator from the turbine. However, during upset conditions and during plant shut-down, the steam to operate the evaporator is from the auxiliary boiler. When the unit is operated at design rate, the following utilities are required:

1. Steam 8630 lb/hr
2. Cooling Water 795 GPM
3. Electricity 46 HP

Based upon first year operating costs information received for the crystallizer and available data from other sources concerning cost of demineralization, we have developed a cost comparison between the evaporator/crystallizer system and demineralizer processing of waste streams.

The original design of the crystallizer unit was based on slightly less than five million gallons of feed processed per year. Actual feed conditions are approximately 400,000 gallons/batch providing a final concentration of 1500 gallons. The present limitations for volume reduction is set on chlorides. The current analysis, at 1500 gallons slurry, has a maximum of less than 11000 ppm chlorides in the final slurry concentration that can be handled. However, a test program to confirm higher acceptable levels must be developed and undertaken.

All portions of the system in contact with radioactive waste liquid are constructed of Inconel 625 materials. The recirculation pump is constructed of cast Alloy 20 materials. The parts of the system in contact with vapor and distillate are constructed of 304 L S.S. material. This includes the vapor piping, entrainment separator, condenser and subcooler.

The theoretical volume of reduction factors possible with the crystallizer system are restricted by the borated waste streams which must be neutralized to allow for high concentrations to an equivalent of 50 percent boric acid. The neutralization step is not only necessary for greater volume reduction, but is also necessary for the protection of the evaporator/crystallizer materials of construction. Due to the complexity of the boric acid and various sodium borates solubilities, the operation of the system must consider solution pH, temperature and overall concentration.

The second unit is a PWR evaporative crystallizer. This unit has been in operation for approximately one year and has operated at a design capacity to 1.5 specific gravity slurry. The feed stream to this first generation volume reduction unit consists of approximately 16,000 pounds/hour of a one percent combined sodium sulfate/ammonium sulfate solution. The final bottoms concentration is approximately 1,000 pounds/hour resulting in a 1.5 specific gravity product slurry.

The unit after approximately four months of operation at 15,000 pounds/hour rate and a pH maintenance of 8.5 had a 50,000 ppm boron concentration in the bottoms, while a 120 ppm boron in the distillate was also monitored.

This system was initially designed to concentrate secondary liquid regenerate waste. However, during plant installation, additional streams were piped into the system including floor drains from the primary side of the plant. Therefore, introduction of boric acid and borated wastes required modification of the entrainment separator. The unit is being modified to include valve trays that will assist in minimizing the volatile carryover with the distillate. Specific data concerning the volatile carryover in association with the additional valve trays is not available at this time.

HPD was requested to provide a review of the operating system (approximately nine months after start-up). This review consisted of on site data gathering and interviews with the operators and supervisors at the plant. This data is currently being summarized and analyzed, however, certain conclusions can be reached as to the success of the employment of radwaste evaporative crystallizers.

One of the key items in the installation of this crystallizer, was the selection of Inconel 625 as the primary material of construction. Based upon findings throughout the industry of initial failure of stainless materials in the waste streams, as mentioned previously, the need for proper material selection became quite critical. Therefore, Inconel 625 was selected. This operating plant has maintained a regular inspection program including monitoring, recording and controlling the pH close to eight. The pH measurement is perhaps the most single important parameter available for the detection of corrosion tendency. While Inconel 625 has been shown to exhibit significantly higher corrosion resistance than other alloys for the evaporator system it has in certain environments failed by corrosion and improper pH control.

Because the initial plant was not designed to handle the borated waste streams, volatile boron has a carryover component which was not included in the initial design. However, the recent data received (and based on preliminary evaluations) indicates that although there were a few occasions of conductivity greater than 100, the overwhelming majority of the time had values less than ten.

Currently, HPD is providing design and supply of additional entrainment separator components to assure that the volatiles will be recaptured and retained thereby assuring that low conductivity in the condensate will be provided. A final observation concerning the boron and its volatility, although not fully confirmed, is that when the ammonia concentration is relatively low and the level in the vapor body is maintained at a set point, the distillate conductivity is in the range of 2 to 5. This is of course, a very pleasant surprise.

Most of the early radwaste evaporators were constructed of 304, 304L, 316 316 L materials. All of these materials are susceptible to pitting failure and/or stress corrosion cracking in radwaste service.

Chlorides enter the waste streams from water sources such as river water, caustic, decontamination solutions and detergents. These chlorides, combined with low pH, and temperatures above 150°F, provide the environment for pitting and cracking. A further problem arises if scaling develops on vessel walls. This results in a lowering of pH beneath the scale which has been observed in a number of radwaste units.

Economics

In order to convert the operating data into useful and accurate cost and economic information, certain assumptions were made. These are listed along with the basis of calculations in Table 2 below.

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BASIS: 5,000,000 GALLONS/YEAR FEED
1,500 GALLONS/BATCH SLURRY CONCENTRATION
400,000 GALLONS/BATCH FEED

ASSUMPTIONS:
UTILITY COSTS
5,485 HOURS/YEAR

EVAPORATOR COSTS:	
STEAM $6.85/1000#	$ 40,530
ELECTRICITY $0.05/KWH	$ 9,400
COOLING WATER $0.05/KWH	$ 2,740
	$ 52,670
SOLIDIFICATION, TRANSPORTATION, BURIAL	$226,935
TOTAL ANNUAL COSTS	$279,605
PER GALLON BASIS 5.6¢/GALLON	
DEMINERALIZER COSTS:	
COST PER DEMINERALIZER CASK	$ 36,000
@ 200,000 GALLONS/DEMINERALIZER	
TOTAL ANNUAL COSTS	$900,000
PER GALLON BASIS 18¢/GALLON	

TABLE II - OPERATING COST SUMMARY AND COMPARISON

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As can be seen, even with estimated cost assumptions, there is a significant savings (by a factor of 3) in the employment of evaporators. Considering that the volumes discussed are small with respect to other plants, the economics on larger volumes should be even more appreciable.

The number of recent contracts for radwaste evaporators/crystallizer have included the addition of a mechanical vapor compressor. During normal operation of the plant, the steam supply to the evaporator is from the turbine and is generally considered to be inexpensive steam. However, during upsets and plant shut-downs, the auxiliary boiler must provide steam for the evaporator. In this case, it is often more economical to provide power to the systems as electrical energy to a mechanical vapor compressor rather than as live steam to the heat exchanger. The energy savings during these time periods are substantial. For instance, the normal evaporator system requires approximately 1100 - 1200 BTU's/lb of evaporation. With mechanical vapor recompression utilizing the latent heat of vaporization plus additional electrical energy, the system requires less than 150 BTU's/lb of evaporation. Since the addition of mechanical compression does increase the capital cost, each plant must look at the overall economics that consider the amount of time that the evaporator operates as well as the cost of steam to determine if the addition of this equipment is economically justified.

Summary

Overall, the radwaste system operators and supervisors for these units have been pleased with the operation and on stream reliability, with the consistent capability to handle all types of waste streams and provide excellent volume reduction.

The two evaporator crystallizer volume reduction systems described above have each been in operation in excess of one year. The initial data being supplied from both plants confirm that evaporative volume reduction is both economical and reliable. In addition, it is also proven that it is available in its capacity to handle unusual upsets in the feed streams with respect to volume. Finally, the operating costs data and the comparison of demineralizers versus evaporators proves that there is an appreciable savings in operating costs between the two units.