BORIC ACID RECLAMATION SYSTEM (BARS)

B. G. Kniazewycz
Joseph Markind
KLM Technologies, Inc.
2700 Ygnacio Valley Road, Suite 160
Walnut Creek, California 94598

ABSTRACT

KLM Technologies was recently awarded a contract by the Department of Energy for a Phase II demonstration of an optimized full-scale prototype membrane system including performance evaluation under plant operating conditions. The program will serve as the catalyst for developing technology to augment the industry's incentive toward innovative and compact volume reduction alternatives for PWRs. The development and demonstration of the KLM Boric Acid Reclamation System, which is readily retrofitted into existing PWR facilities, will provide a positive means of reducing PWR waste volumes without requiring the $25-50 million equipment and support facility expenditures associated with most liquid waste volume reduction systems. This new application for membrane separation technology can reduce waste by upward of 50 percent for two-thirds of the operating nuclear plants in the U.S.

The use of membrane technology has demonstrated significant process potential in radwaste and related applications. Reverse Osmosis (RO) and Ultrafiltration (UF) can provide selective filtration capability and concentrate contaminants without the need of filter aids, thus minimizing the requirements of chemical regeneration, costly resins, and major process equipment with large auxiliary heat supplies. KLM Technologies' personnel have identified a Boric Acid Reclamation System (BARS) utilizing RO and UF to produce a recyclable grade of otherwise waste boric acid at PWRs, thus reducing a major source of low-level radwaste. The design of a prototype BARS as a compact volume reduction system was the result of KLM's Phase I Program, and based upon a preliminary feasibility program, which assessed the applicability of membrane technology to refurbish and recycle waste boric acid from floor and equipment drain streams. The analysis of the overall program indicated a substantial savings regarding off-site disposal costs.

Today's economic scenario indicates that optimization of volume reduction operation procedures could significantly reduce waste management costs, especially where burial penalties have become more severe (e.g., burial site closeout, volumetric restriction, substantial increase in burial costs, etc.). As a reaction to the economic burden imposed by final disposal, many nuclear plants are currently modifying their design and operating philosophies concerning liquid radwaste processing systems in order to meet stricter environmental regulations, and to derive potential economic benefits by reducing the ever-increasing volumes of wastes that are produced. To effect these changes, innovative practices in waste management and more efficient processing technologies are being successfully implemented.

INTRODUCTION

The use of membrane technology has demonstrated significant process potential in radwaste and related applications. Reverse Osmosis (RO) and Ultrafiltration (UF) can provide selective filtration capability and concentrate contaminants without the need of major capital and support facilities typically associated with major process equipment. KLM Technologies' personnel have identified a Boric Acid Reclamation System (BARS) which utilizes RO and UF to produce a recyclable grade of otherwise waste boric acid at PWRs. The design of a prototype BARS as a compact volume reduction system was the result of KLM's Phase I Small Business Innovation Research (SBIR) Program for the U.S. Department of Energy.

This design was based upon a preliminary development program at Commonwealth Edison's Zion Generating Station in 1980 which assessed the applicability of membrane technology to refurbish and recycle waste boric acid from floor and equipment drain streams. The analysis of the overall program indicated a substantial savings regarding off-site disposal costs.

BORIC ACID RECOVERY SYSTEM DEVELOPMENT

The application of membrane technology to radioactive waste treatment has evolved slowly since 1970 from both small prototype and test units at RG&E's Ginna Plant and CP&L's H. B. Robinson 2 Steam Electric Plant, WEPCO's Point Beach, and full-size RO units used for laundry and floor drain applications at numerous plants. During this time, various other potential applications were identified but not developed beyond laboratory or pilot scale.

Background

The concept of utilizing cellulose acetate RO membranes to treat borated wastes evolved from basic work performed by KLM's Mr. Joseph Markind while with the Westinghouse Membrane Technology Division for Public Service of New Jersey in 1971. Early in the design of the two PWRs at Salem Nuclear Generating Station, Public Service as well as other nuclear facilities, recognized that primary to secondary side steam generator leakage could add significantly to the station's volume of liquid radwaste. To provide greater operating flexibility in the event of such a leak, separate provisions for processing steam generator blowdown were considered, including flash distillation, ion exchange and RO. A preliminary analysis led to the rejection of both the thermal process, on the basis of equipment size and cost, and the ion exchange process because of excessive resin replacement costs. This left only RO to be more fully explored.

Westinghouse, through the Water Products and Environmental Systems Group in Lester, Pennsylvania, displayed interest in the application and instituted test programs at their own R&D laboratories and Public Services' Burlington Station to investigate the behavior of their RO membranes on simulated PWR borated blowdown. Westinghouse's test results revealed the relationship of boron rejection to pH and other chemical species variations with respect to typical cellulose acetate (CA) membrane material. Further analysis indicated that the utilization of RO for steam generator blowdown applications offered the most efficient method, technically and economically, for handling the potential blowdown problems.

Pilot System Test Results at Zion Generating Station

The boric acid recovery system is based upon two membrane technologies: ultrafiltration and reverse osmosis. The major weakness of RO (plugging and fouling) have been alleviated through the addition of UF at the front end. Variations in the boric acid waste stream characteristics will have minimal impact on the RO system since UF will remove all potential colloide and remaining suspended solids. This system, developed by KLM's Principals, Mr. George Kniazewycz and Mr. Joseph Markind, is the evolutionary design predicated on preliminary work in the early 1970s and the basis for a proof of feasibility program.

The pilot membrane system was originally installed and tested in the Fall of 1980 to determine the feasibility of volume reduction through boric acid reclamation or controlled discharge. The program was designed to determine the optimal performance parameters required for boric acid passage while removing other contaminant species for further downstream treatment. Preliminary evaluations were initiated to investigate overall membrane configuration efficiency. Assessments were also conducted to verify system performance, reproducibility under extended plant operation, and to quantify boric acid purity and the extent of system recovery.

The system utilized integrated UF and RO membrane components and was tested and operated in a batch mode process. Makeup feed was supplied from the Auxiliary Building Equipment Drain Analysis Tank to a 400 gallon feed tank. A low pressure pump was used to supply the feed to the UF stage following initial pre-treatment through a train of cartridge prefilters located on the main skid. A high pressure (≯400 psi) centrifugal pump fed the resultant UF permeate through the RO system and the final effluent was composited in a calibrated tank to provide a confirmatory basis for quantifying system performance. The reject streams from both the UF and RO modules were recycled through a heat exchanger to the feed supply tank.

Processing proved optimal until 7-10 percent of the original volume remained in the feed tank. This translates into an achievable system volume recovery rate of >90 percent. Rejection rates for boron averaged 10-12 percent, while values for other ionic contaminants, consisting of chlorides, fluoride, sodium, lithium, and silica varied between 70-90+ percent. The data tends to confirm that radiological and inorganic ionic contaminants other than boron have been substantially removed from the process stream.

Pilot Program Conclusions

Results of Zion's membrane pilot system indicated the following significant conclusions:

- The boric acid rejection curve was revalidated for cellulose acetate spiral and hollow fiber configurations. Certain chemical species must be carefully monitored and controlled.
- Raw feed can be concentrated by a factor of 10-15X. To achieve optimum volume reduction, the contrates could be further processed by a down-stream evaporator/crystallizer resulting in a final slurry up to 50 percent solids.
- Operating savings for Zion station (based on a scaled-up system and extremely conservative analysis) were estimated at $1.43 million (1980 dollars) per year for radwaste. At this rate, capital payback could be realized well within the first year following system implementation.
- Based on the pilot program results, the Phase II demonstration of a prototype BARS would provide the benchmark for evaluating full scale performance and to realistically quantify its effectiveness in treating borated streams under a variety of plant operating conditions.

KLM'S BARS PROJECT

On July 15, 1985, KLM implemented its Phase II Program, a Demonstration Program for a PWR Waste Boric Acid Reclamation System (BARS). Within the scope of the project, a variety of contaminated process stream sources as well as mixed radwaste feed streams will be evaluated for processing by KLM's BARS. These boric acid streams will originate from the following sources:

- Spent Fuel Pool (SFP)
- Chemical Volume and Control System (CVCS)
- Refueling Water Storage Tanks (RWSTs)
- Floor and Equipment Drains

Pursuant to the program, KLM will design, fabricate and execute a test program at Northern States Power's (NSP) Prairie Island Nuclear Generating Station, located in Welch, Minnesota. NSP was chosen, after detailed review and meetings with two other potential test sites, on the basis of schedule and design impact on the BARS prototype. The design of an advanced prototype BARS as an optimized process system was the result of KLM's Phase I program. This program was originally based upon a preliminary development program in 1980, which assessed the applicability of membrane technology to refurbish and recycle contaminated boric acid streams. The analyses of the overall program indicated a substantial savings regarding off-site disposal costs due to reduced waste generation.

A rather unique feature of BARS requires the development of a fully integrated computer-based system for process control and monitoring. The system is based on the IBM/PC microcomputer and will include an "expert system" and a real-time data acquisition interface for collection of process data from pumps, filters, heat exchanger/chiller temperature control components and other process sensing and control devices.

TECHNICAL OBJECTIVES AND TECHNICAL APPROACH

The purpose of this section is to review the Phase II Technical Objectives and Approach as accomplished through January 1986. The Phase II design development activities under Program Initiation are directed toward a series of technical objectives which will allow the preliminary BARS design to be engineered into a fully integrated process system combining progressive levels of filtration, and consisting of three major subsystems:

- Prefiltration (PF) and Clean In-Place Subsystem
- Ultrafiltration (UF) and Reverse Osmosis (RO) Subsystem
- Microprocessor Control Subsystem, including the modules for real-time computer interface

The positive inclination toward joint participation by operating nuclear utilities in the Phase II Demonstration Program was indicated through "Letters of Intent" from three PWR stations and verified in Phase I. This was a major step toward a successful implementation program confirming the potential of BARS as a commercial product. Pursuant to the written notification from DOE regarding the selection of KLM for a Phase II continuation of the BARS Program, KLM initiated efforts to screen the list of tentatively committed host site candidates and make a final determination. It was important to maintain the continuity of interest with the identified Plant Organization, and so these efforts commenced immediately following the above referenced notification from the SBIR Program Manager. The major technical objectives are:

1. Design, fabricate and factory test a 25 gpm full-scale prototype BARS.

2. Install startup and optimize operation of the prototype BARS in an operating PWR.

3. Support operations of the prototype BARS over an eleven (11) month period, including all necessary performance.

4. Assure cost-effective optimal design, manufacturing, and operational features while providing superior performance commensurate with a nuclear plant's design basis.

The technical approach taken to each objective follows.

Objective 1

The design, fabrication and factory "shakedown" testing required that a final design basis be confirmed and implemented. A preliminary system design was developed in the BARS Phase I Program. This design has been confirmed and finalized in combination with KLM project engineering and cognizant host site participants. Subsequent to the development of a BARS final design specification, a purchase order was issued to the KLM selected membrane system vendor, reflecting the corporation of a component chiller package to make BARS more flexible, and to alleviate the potential impact and dependency on plant cooling control systems. Based on information developed during the pilot testing experience at Zion Station, prefiltration subsystem components and the potential need to shield them were initially evaluated. Further analysis will be made during startup and operations in an ALARA assessment review to assure conformance with good ALARA practices.

Objective 2

BARS installation, startup and optimization will be implemented at Northern States Power's Prairie Island Plant, following completion of fabrication and functional testing at Osmonics. Manpower requirements will be primarily supplied by the host site for BARS installation, with KLM providing technical supervision. KLM has, in previous meetings and communications with Prairie Island, determined the logistics governing the plant access route for the BARS placement and the key BARS interface connections to plant facilities. A definitive BARS startup and optimization procedure based upon an operations protocol will be developed and exercised by KLM. KLM will assume the prime role during startup and optimization efforts, including efforts associated with training plant personnel. Operations, affecting both unit processes and system efficiency will be defined and confirmed through chemical quantification of performance parameters from each interstage process subsystem.

NSP produced drawings showing favorable interface conditions and flexibility for treating a variety of borated waste and process stream applications. Pertinent QA requirements were in conformance with the BARS design modification to a self-sustaining chiller package. A dependency on plant primary or component cooling water interface would have influenced QA requirements to satisfy safety-related compliance. Subsequent to their participatory confirmation, Prairie Island executed a Confidential Disclosure Agreement with KLM. With this information and commitment from Prairie Island Plant, KLM implemented the Phase II program.

Objective 3

During the demonstration program, KLM will stage support personnel to monitor on-site system operation and performance. BARS performance characteristics will be analytically validated through an on-going regime, utilizing the Station laboratory facilities for work of a routine nature and off-site commercial laboratory services for non-routine support requirements. Selected parameters governing performance assessment consist of the following chemistry, whenever possible:

Radiochemistry	Stabilized Species
Gross Beta	Conductivity
Gamma Spectroscopy for:	pH
Cobolt -58, -60	Boron
Cesium -134, -137	Chloride
Tritium	Fluoride
	Sulfate
	Sodium
	Lithium
	Silica
	Total Solids
	TOC*
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* Case Basis
** Other Special Parameters

KLM's integrated computer-based system linked to the microprocessor control system will enhance the capability for real-time monitoring and remote process monitoring and control. The system is designed to access performance data from pumps, filters, temperature control components and other process sensing devices through a modem interface and incorporates software associated with what is commonly known as an "expert system."

Feed stream characterization efforts, as discussed above, will be an integral part of KLM's on-going confirmatory program. Other tasks receiving continued attention over the extended cycle operation will include:

- ALARA Review Analysis
- Training
- Economic Analysis

Objective 4

Based on the data base established above, the design basis will be reviewed and optimized. After assuring that all functional design elements comply with applicable criteria, the design will be reviewed from the perspective of Quality Assurance/Quality Control, performance, cost savings and other pertinent features of a nuclear power plant environment.

Summary

Of all the problems associated with the nuclear power industry, probably none is so chronic and its solution so controversial as that of management of generated radioactive waste. Management of these wastes is complicated because of the physical and chemical characteristics and the nature and duration of containment required for some of the radioactive and chemical constituents.

A solution to the problem lies with the industry's ability to recognize that waste management entails an understanding of chemical treat processes in addition to the conventional methods that have received most of the attention. The development of optimized facilities and equipment to collect and process liquid radwaste will enhance the ability to control releases of liquid effluent within applicable regulatory limits. These limits are most readily achieved by reducing the volume of liquids discharged or by refurbishing the liquids to enable reuse. An efficient liquid radwaste processing system, then, should provide the capability to allow the maximum reuse of wastewater in the plant consistent with the overall plant water balance. Above all, the acceptable methodology must meet the criteria that are technically and economically sound as well as politically and socially acceptable.

Based on the proven efficiency of membrane technology, a number of process and environmental advantages could be realized through the innovative implementation of a permanently installed BARS in PWR nuclear plant operations. The following examples are intended to lend credence to the claim:

- Augmentation of existing plant capacities for processing variable waste loadings.
- Significant reduction of generated waste intended for off-site disposal, thereby extending burial site capacities.
- Recovery of costly chemicals (i.e., boric acid), thereby affecting discharge practice.
- Improvement of silica removal enhancement governing the maintenance of fuel integrity.
- Positive environmental conformance through the diminished release of low activity boric acid to large receiving streams (i.e., lakes and oceans).
- Advancement of the plant perception and effective waste management combines innovative and conventional physiochemical processes.

For these reasons, KLM believes that BARS will meet a growing need at PWRs. At present, there are no anticipated problems or changes with respect to program objectives or technical approach.