# THE FEASIBILITY OF SPENT RESINS INCINERATION AT NUCLEAR POWER PLANTS

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## ABSTRACT

Over the past several years, the Tennessee Valley Authority has evaluated volume reduction (VR) systems to define, develop, and demonstrate the ability to incinerate spent ion exchange resins. In 1979, Aerojet Energy Conversion Company (AECC) had a detailed physical, chemical, and radiological analysis performed on actual samples of resins collected from nuclear power plants. This analysis indicated that for resin incineration to be acceptable, the gases produced must be sufficiently removed in an off-gas cleanup system. Subsequently, tests in prototype equipment demonstrated the ability to feed and incinerate resins while effectively removing the gases produced during the combustion process. The demonstration effort conducted by Aerojet and monitored by TVA has shown that after the physical and chemical phenomena associated with resin incineration are realized, mechanical equipment can be combined to incinerate spent resins and process the combustion by-products in a manner consistent with utility, NRC, and other federal and state requirements. This can be accomplished while providing reasonable volume reduction factors and attractive waste disposal cost savings.

## INTRODUCTION

Ion exchange resin systems are frequently used for water cleanup and liquid waste treatment at commercial nuclear power plants. Most ion exchange systems use stationary beds containing mixed anion and cation bead resins. These beds generally utilize resins with a particle size range of 0.4 to 0.7 mm and are supplied by one of four principal producers of ion-exchange resins in the United States. Each bed may contain from 30 to 180 $ft^3$ of resin material. When ionic contaminants begin to appear in the effluent from the bed in significant quantities, or when radioactivity levels reach a certain point, the bed is considered exhausted. The bed is then either regenerated or the ion exchange resins are discarded and replaced with new resins. The quantity of spent ion-exchange resins produced by a nuclear plant depends on the specific plant characteristics (corrosion problems, formation of neutron activation products, radiochemically produced compounds, etc.) and operating procedures (regeneration or replacement frequency) at the plant. Whatever the quantities of spent ion-exchange resins generated by a particular nuclear plant are, the disposal of spent resin requires specialized handling and shipping procedures. Generally, the spent ion-exchange resins are transferred in a slurry form to some type of container which is then dewatered and shipped to a commercial burial facility.

In recent years, burial space allocations and increased costs have caused the nuclear industry to review available options to reduce the volume of spent ion exchange resins that must be packaged, shipped, and buried. One available option which has been evaluated by Aerojet and TVA is incineration of the spent resins and solidification of the resultant ash. Due to the chemical nature and potentially high curie content of spent ion-exchange resins, the nuclear industry has moved with extra caution in the utilization of this option. Despite the concerns associated with the incineration of spent ion exchange resins, the process provides many benefits including a reasonable volume reduction factor and attractive waste disposal cost savings. In November 1981, Aerojet finished an extensive ion exchange resin incineration test program which was closely monitored by TVA. The resultant data from the test program provided insight into the resin incineration process and the resultant product. The data verified that incineration of spent ion exchange resins is a feasible means of reducing the overall volume of radwaste requiring disposal. However, care must be exercised in the basic process used for incineration of resins, the cleanup of the resultant off-gas and the disposal of the scrub solution generated by the off-gas cleanup system. This paper will discuss in further detail the subject of spent resin incineration.

## CHARACTERIZATION OF SPENT RESINS

One of the more difficult aspects of incinerating spent resins is obtaining a thorough definition of the resin wastes. During 1979, in an effort to define "typical" spent resins for the nuclear industry, radioactive resin samples were collected by Aerojet from the Oconee, Brunswick, Browns Ferry, Surry, Hatch, and Arkansas Nuclear One nuclear power plants. These resin samples represented bead and powdered resins, fresh and salt water plants, BWRs and PWRs, and plant services from condensate polishing to fuel pool cleanup. These resin samples were transported to the Georgia Institute of Technology, where radiological analyses were conducted on each waste sample. Elemental analyses were performed by Zethus Research Company. The results of these analylses are summarized.

Elemental Analyses

| Element | Wt. Percent Fresh Water Plant | Wt. Percent Salt Water Plant |
|---|---|---|
| C | 60.30 | 51.85 |
| H | 7.54 | 5.66 |
| N | 2.68 | 1.23 |
| S | 2.80 | 7.38 |
| Cl | 0.12 | 1.64 |
| P | 0.014 | 0.013 |
| B | 0.0033 | 0.0057 |
| O | 9.48 | 14.20 |
| Li | 0.0001 | - |
| Na | 0.039 | 2.50 |
| Mg | 0.039 | 0.046 |
| Ca | 0.113 | 0.060 |
| Fe | 1.55 | 0.23 |
| Cr | 0.0063 | 0.11 |
| Ni | 0.0065 | 0.041 |
| Moisture | 5.57 | 7.09 |
| Dirt | 5.60 | 6.40 |
| Hexane Solubles | 0.442 | 0.076 |

Radiological Analyses

| Service | Isotopes | Specific Activity (μCi/g) |
|---|---|---|
| Condensate Polishing | Cs-134, Cs-137, Zn-65, Mn-54, Co-58, Co-60 | $4.55 \times 10^{-4}$ |
| Turbine Bldg Sump | Cs-134, Cs-137, Zn-65, Mn-54, Co-60 | $1.15 \times 10^{-3}$ |
| Multiple | Cs-134, Cs-137, Zn-65, Cr-51, Mn-54, Fe-59, Co-58, Co-60 | 5.082 |
| Multiple | Cs-134, Cs-137, Zn-65, Mn-54, Co-58, Co-60 | 0.191 |
| Multiple | Cs-134, Cs-137, Zn-65, Cr-51, Mn-54, Co-58, Co-60, Ag-110, Zr-95, Nb-95 | 0.942 |
| Radwaste | Cs-134, Cs-137, Mn-54, Co-58, Co-60 | 1.969 |
| Condensate Polishing | Zn-65, Cr-51, Mn-54, Fe-59, Co-58, Co-60 | 0.021 |
| Radwaste + Fuel Pool | Zn-65, Cr-51, Mn-54, Fe-59, Co-58, Co-60, Nb-95 | 0.181 |

A review of the sulfur concentration in the elemental analysis of the fresh water resins indicated that although the nuclear plant operators at the sites stated that a cation to anion ratio of at least 1:1 was being utilized at their plants, the samples received and analyzed indicated that a higher percentage of anion resin was present. This was attributed to the fact that resins tend to segregate as they settle. To demonstrate this discrepancy, a sample of "as purchased" resins with *a 1:1 cation* to anion ratio was analyzed. The results of this analysis are summarized as follows:

| Element | Anion Resin | Cation Resin |
|---|---|---|
| C | 79.70 | 53.23 |
| H | 8.75 | 4.71 |
| N | 5.35 | 0.06 |
| S | 0.09 | 16.82 |
| O | 6.11 | 25.18 |
| Ash | 0.12 | 0.06 |
| Heating Value, Btu/lb | 15,350 | 9,210 |

Based on the data obtained from the utilities surveyed, an average cation to anion ratio of 1.2:1 was being used. This ratio was then used to calculate a "typical" spent resin composition for a fresh water plant site. This "typical" composition, summarized below, was then utilized for the development of a process to incinerate the spent resins produced at nuclear power plants.

| Element or Components | Percent wt. (Totally Dry Basis)[a] |
|---|---|
| C | 59.20 |
| H | 5.91 |
| N | 2.14 |
| S | 8.84 |
| Cl | 0.13 |
| Fe | 1.72 |
| Na | 0.04 |
| Dirt | 6.20 |

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[a] Based on composition data for virgin resins given on p.11 of Ref. (1) and the compositions of spent resin sample numbers 1, 8, 10, 11, and 12 given on p. 8 of Ref. (1).

Reference: (1) Anderson, R. E., et. al., "Fluidized Bed Incineration of Spent Ion-Exchange Resins", Final IR&D Report 8681-03, March 1982, Aerojet Energy Conversion Company.

## CURRENT METHOD OF HANDLING SPENT RESINS

For typical ion exchange resin systems employed in nuclear plants, removal of the spent resins from the ion exchange vessel requires generation of a resin-water slurry and the transfer of this slurry from the vessel to a spent resin storage tank and finally to a shipping container. The transfer of spent ion exchange resins by slurry involves the theory of solid-liquid mixtures (slurries). Slurries are generally classified as either homogeneous or heterogeneous and the ability to move resins is dependent on particle size, flow velocity, and other parameters. It should be noted that the handling of spent resin slurries is complex and requires considerable amounts of slurry water in the transfer operation. Once the spent resins are transferred to the shipping container dewatering of the slurry is initiated. The dewatering process involves the removal of free water from the shipping container by suction pumps. The shipping container has filter elements located at various levels within the container through which the slurry water is removed, leaving behind the spent resins. Once the spent resins have been dewatered to meet burial site requirements, the container is sealed and shipped to the burial site for disposal.

## RESIN INCINERATION

Any incineration system designed to process spent resins should have several important design features, including a reliable method of preparing the resin stream for injection into the incinerator, a well-controlled feed system, an efficient process for scrubbing the gases produced during the combustion process, and the inclusion of a drying process that totally removes the water from the scrub solutions allowing for immobilization of the dry salts in a solidification media.

At Aerojet, where a fluidized bed process is utilized for incineration, a series of sub-scale and full-scale tests demonstrated the ability of fluidized bed incineration system to process spent resins. The first series of tests were conducted with a 4-inch diameter bench scale incinerator. These tests demonstrated the feasibility of bed and off-gas chemistry control. A series of 49 tests totalling 66 hours of operation were conducted, with the following conclusions:

1. Resin incineration in a fluidized bed was shown to be technically feasible in a bench-scale apparatus.
2. It would be feasible to incorporate a scavenging process in the system to capture the $SO_X$ leaving the incinerator.
3. CO emissions during resin incineration would be comparable to those produced in a coal-fired fluidized bed combustor.

The next series of tests, which further defined both the bed and off-gas chemistry and the type of resin feed system needed for the full-scale incineration tests, were performed on a 12-inch diameter prototype incinerator system. Six test runs, totalling 216 hours, were completed. The tests included resin incineration without caustic addition (no in-bed scavenging of $SO_X$), incineration of precausticized resin feed, and resin incineration with separate caustic injection. Both new and spent resins were burned, with three types of bed material being evaluated (alumina, zircon, and $Na_2SO_4$). The following conclusions were reached:

1. The process demonstrated good combustion characteristics with low emissions, including a CO concentration of 200 PPM, a $NO_X$ concentration of 150 PPM, and a hydrocarbon concentration of 100 PPM.
2. The addition of $Na_2CO_3$ effectively scavenged the $SO_X$ in the incinerator.
3. Bed defluidization occurred under certain conditions.
4. The resin feed system was adequate for feeding the slurry to the incinerator.

An extended duration test was then performed utilizing the 12-inch diameter incinerator. Two test runs, totalling 101 hours, were completed, during which spent bead resin, new powdex resin and doped powdex resin were incinerated. The composition of the resins utilized for this test are summarized as follows:

| Element | Spent Bead Resin Wt. Percent | Spent Powdered Resin Wt. Percent |
|---|---|---|
| C | 53.70 | 50.20 |
| H | 5.75 | 5.56 |
| N | 1.60 | 1.31 |
| S | 8.11 | 10.19 |
| Cl | 0.63 | 0.18 |
| Fe | 0.37 | 6.28 |
| Na | 0.13 | 0.011 |
| Dirt | 15.20 | 10.70 |

The following conclusions were reached from these tests:

1. Bed defluidization problems could be eliminated by deleting in-bed scavenging of $SO_X$ and by utilizing an inert bed in the incinerator.
2. The combustion efficiency of the process was excellent with concentrations of 100 PPM of CO, 125 PPM of $NO_X$ and no detectable hydrocarbons in the exhaust.
3. The venturi scrubber achieved an efficiency of approximately 99.7 percent in capturing acid gases in the off-gas system.
4. Approximately 90 percent of the sulfur and 100 percent of the chlorine in the resins reach the scrubber as $SO_X$ and HCl, respectively.
5. An active pH control system must be added to the scrub loop to maintain an efficient clean-up capability for the $SO_X$ and HCl.

The final series of demonstration tests for resins incineration were performed on a 30-inch diameter full-scale incinerator. Three tests were conducted totalling 203 hours of operation. The following summarizes the composition of the resins burned during these tests:

| Element | Spent Bead Resin Wt. Percent | Spent Powdered Resin Wt. Percent |
|---|---|---|
| C | 50.30 | 57.79 |
| H | 5.15 | 5.25 |
| N | 3.77 | 4.37 |
| S | 7.75 | 8.60 |
| Cl | 0.50 | 0.04 |
| Fe | 0.27 | 1.24 |
| Na | 0.16 | 0.06 |
| Dirt | 14.20 | 2.27 |

The following conclusions were reached from this series of tests:

1. The resin slurry feed system could successfully operate at resin concentrations up to 19 weight percent (dry weight basis) and at quantities up to 30 gph (42 lbs/hr dry resins).
2. The system could successfully incinerate large quantities of resins while simultaneously drying liquid wastes or scrub solutions in the fluid bed dryer.
3. The off-gas cleanup system reduced $SO_X$ concentrations from 1100-1700 PPM at exit of the incinerator to 0.01-0.05 PPM at the inlet of the charcoal absorber.

4. Large quantities of $Na_2SO_4$ scrub solutions are generated during the incineration of resins if the $SO_X$ is captured in the liquid scrub loop.

5. Reasonable volume reduction factors could be achieved if the scrub solutions were concentrated or totally dried prior to immobilization.

6. The off-gas cleanup system, as designed, would be effective in prohibiting $SO_X$ poisoning of the charcoal absorber and acid corrosion of the off-gas system components.

## COMPARISON OF CURRENT METHOD VERSUS INCINERATION

For the purposes of this paper, this section compares the out-the-door totals of a resin dewatering process utilizing high integrity containers (HICs) versus a resin incineration process after drying the scrub solutions and immobilizing the dry sodium sulfate salts and ash in either polymer or bitumen.

Two resin quantities which are believed to bound the volumes to be expected from a typical PWR with regenerable condensate demineralizers are analyzed: 1,000 $ft^3$/yr and 5,000 $ft^3$/yr. For both cases, it was assumed that there is a 1:1 ratio of cation:anion bead resins, the resins are dewatered (50 weight percent resin dry weight basis), the resin density is 60 lbs/$ft^3$, there is a sulfur content of 18 percent in the cations and 0 percent in the anions, and there is an ash content of 10 percent for both the anions and cations.

After incineration of the resins and the subsequent drying of the incinerator scrub solutions, the total dry product yield is 14,981 lbs/yr (3,000 lbs. ash, 11,981 lbs. $Na_2SO_4$ salts) for the 1000 $ft^3$/yr case and 74,906 lbs/yr (15,000 lbs ash, 59,906 lbs $Na_2SO_4$ salts) for the 5,000 $ft^3$/yr case. This dry product is then immobilized with either polymer or bitumen prior to shipment and disposal.

Table I summarizes the annual resin disposal costs for the cases analyzed. Table II summarizes the assumptions utilized in the economic analysis.

### TABLE I
### ANNUAL RESIN DISPOSAL COSTS

Conventional w/HICs

| | 100 $ft^3$/yr | 5000 $ft^3$/yr |
|---|---|---|
| a. Number of Containers | 8 HICs | 40 HICs |
| b. Container Cost | $ 40,000 | $200,000 |
| c. Labor Cost | $ 8,000 | $ 40,000 |
| d. Binder Cost | - | - |
| e. Shipment to Barnwell | $ 10,950 | $ 54,725 |
| f. Weight Surcharge | $ 4,000 | $ 20,000 |
| g. Cask Handling | $ 4,000 | $ 20,000 |
| h. Curie Surcharge | $ 40,000 | $200,000 |
| i. Burial Cost | $ 68,150 | $340,675 |
| Total | $175,100 | $875,400 |

VR W/Polymer Solidification

| | 1000 $ft^3$/yr | 5000 $ft^3$/yr |
|---|---|---|
| a. Number of Containers | 30 Drums | 150 Drums |
| b. Container Cost | $ 2,250 | $ 11,250 |
| c. Labor Cost | $ 2,400 | $ 12,000 |
| d. Binder Cost | $ 7,800 | $ 39,000 |
| e. Shipment to Barnwell | $ 5,475 | $ 26,000 |
| f. Weight Surcharge | - | - |
| g. Cask Handling | $ 2,000 | $ 9,500 |
| h. Curie Surcharge | $ 24,000 | $114,000 |
| i. Burial Cost | $ 26,075 | $130,350 |
| | $ 70,000 | $342,100 |

VR w/Bitumen Solidification

| | 1000 $ft^3$/yr | 5000 $ft^3$/yr |
|---|---|---|
| a. Number of Containers | 36 Drums | 179 Drums |
| b. Container Cost | $ 1,150 | $ 5,725 |
| c. Labor Cost | $ 2,875 | $ 14,325 |
| d. Binder Cost | $ 1,100 | $ 5,525 |
| e. Shipment to Barnwell | $ 6,850 | $ 31,450 |
| f. Weight Surcharge | - | - |
| g. Cask Handling | $ 2,500 | $ 11,500 |
| h. Curie Surcharge | $ 30,000 | $138,000 |
| i. Burial Cost | $ 25,875 | $128,600 |
| | $ 70,350 | $335,125 |

### TABLE II
### ECONOMIC ANALYSIS ASSUMPTIONS

1. Loading per Container

   Dewatered Resin - 150 $ft^3$ HIC
   83 percent Full (125 $ft^3$)

   Incinerated Resin - Polymer
   500 lbs Salt/Ash per 55-gallon drum

   Incinerated Resin - Bitumen
   420 lbs Salt/Ash per 55-gallon drum

2. Container Cost

   150 $ft^3$ HIC - $5,000 each
   55-gallon drum (polymer) - $75.00 ea. (7.35 $ft^3$)
   55-gallon drum (bitumen) - $32.00 ea. (7.35 $ft^3$)

3. Binder Requirements + Cost

   Resin Salt/Ash in Polymer - 200 lbs. Binder per 55-gallon drum at $1.30 per pound

   Resin Salt/Ash in Bitumen - 280 lbs. Binder per 55-gallon drum at $0.11 per pound

4. Labor Cost

   150 $ft^3$ HIC - $1,000 ea.
   55-gallon drum - $80.00 ea.

5. Shipment Cost

   1 - 150 $ft^3$ HIC/Shipment x $1368/Shipment
   8 - 55 gallon drums/Shipment x $1368/Shipment