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Hanford Waste Treatment Process

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Appendix D - UNIVERSITY HONORS PROGRAM
SENIOR PROJECT - APPROVAL

Name: Stephen R. Kennedy

College: Engineering Department: Chemical Engineering

Faculty Mentor: Dr. Jack Watson

PROJECT TITLE: Separations of Nuclear Waste at the DOE Hanford Site

I have reviewed this completed senior honors thesis with this student and certify that it is a project commensurate with honors level undergraduate research in this field.

Signed: Jack S. Watson, Faculty Mentor

Date: 6-2-97

Comments (Optional):

Hanford Waste Treatment Process

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Chemical Engineering 490 Design Project

Honors Seminar

May 22, 1997

Abstract

The Department of Energy has a large reserve of highly radioactive waste sludge located at the Hanford facility. The storage tanks that hold this material are approaching the end of their expected life cycles. The potential of disaster such as leakage or explosion is increasing with every passing year. This report presents the preliminary design of a system to process a large volume of this sludge to low-level waste.

The processing of this waste requires leaching with 3 M sodium hydroxide before entering the system. The system design includes using the ion exchange resin Crystal Silicotitinate to remove the radioactive cesium ions from the waste stream. The high level waste radioactive ions are taken away to be stored in a safer waste facility. The rest of the waste sludge can then be treated by acidification, crystallization, and electrochemical reduction to re-claim most of the sodium which is recycled and used as leaching solution. This design will process 25,000 gal/hr of solution and has an expected annual operating cost of $164 million. The major expense is the annual waste disposal cost of $6.1 billion. The current design has a life cycle of three years. It is recommendation that a lower flowrate that will increase the life cycle of the plant and allow the cost to be incurred over a greater number of years be investigated.

Table of Contents

List of Figures

List of Tables

Appendices

Introduction

Beginning in the mid-1940's, the United States Department of Energy (DOE), in the midst of the nuclear arms race of the Cold War, began storing spent nuclear fuel and nuclear waste at it's Hanford site in Richmond, Washington. This 560 square mile site along the Columbia River houses 177 underground high-level waste tanks each capable of 50,000 gallons to 1,000,000 gallons capacity (ENR October 23, '95, 16). Of these tanks, 149 are single-shelled (constructed from 1944-1969) and the remaining 28 are double-shelled (built after 1970). The double-shelled tanks are composed of 1.5 feet thick reinforced concrete with two inner steel liners. They are covered with six to eight feet of soil (Seltzer, 5). All told, the site contains 80% of the United States spent nuclear fuel from arms production totaling 227,000 cubic meters or 60,000,000 gallons of high level radioactive waste (Babad et. al., 427).

The Hanford site also houses 2300 tons of spent fuel rods, which are still "hot", in underwater steel casks in two basins 37.5 meters long and 20 meters wide (Illman, 30). It costs the taxpayers $35 million per year to monitor these basins (ENR August 28, '95, 17).

Many instances of release have been reported at the Hanford site. Many of the single-shelled tanks have leaked, although none of the double-shelled tanks have. The basins containing the spent fuel rods have leaked on several occasions and are considered by many experts to be seismically unsafe. For instance, the K-East basin spilled 15,000,000 gallons of water in the late 1970's and 94,000 gallons in 1993 (Civil Engineering October '95, 12). It is not believed that any of this contamination reached ground water.

In addition, several safety concerns have been expressed by community members and federal inspectors regarding this DOE site. Some of the tanks are suspected to be seismically unsafe. In 1992, the "Red Team", a group of technical experts from various consulting firms and national laboratories found that many tanks do not have proper monitoring systems. The team also found 3000 pieces of equipment out of service, including pumps, compressors, and ventilation systems (Illman, 23). Some of the older single-shelled tanks have high hydrogen levels and must be "burped" (a process for releasing hydrogen from the tank in order to prevent pressure build up and thus explosion).

The Hanford site has also become a great economic liability. Besides the $35 million listed earlier to monitor the basins, much more money is needed to monitor the tanks. Maintenance costs on the equipment are astronomical. Taxpayers have been estimated to have paid $7.5 billion since 1989. This money did not go to cleanup processes but rather to meet compliance standards of the endless federal and state regulations. Senator Frank Murkowski (Alaska) called Hanford, "...the largest civil works project in human history."

The Department of Energy realized that it must act to correct this situation before it gets worse or before a disaster occurs. A request was made by DOE for contractors to submit estimates for cleanup of the Hanford site so that a contract could be issued. As of 1995, four teams were bidding on the project: 1)Fluor-Daniel is leading the team of Lockheed-Martin, Rust Federal Services, Babcock & Wilcox, Duke Energy and Services and Numerated & International Technology Corporation; 2) Bechtel Corporation is leading the team including Westinghouse, British Nuclear Fuel Limited, Computer

Sciences Corporation and Johnson Controls; 3) Raytheon is spearheading the team of CH2M Hill Incorporated, ICF Kaiser, Tenneco Boeing Information Services and Seimans Power Corporation; finally 4) TRW and Parsons Corporation are allegedly organizing a team (ENR Jan. 15, '96, 15).

In lieu of these developments, the consulting firm of Binkley, Kennedy & Luttrell are attempting to undertake the cleanup of one of the waste tanks at the Hanford site. The team came up with a conceptual design and cost estimate (capital and operating costs) for recycling caustic leach solutions in one of these waste tanks. The facility can process 25,000 gallons per hour of caustic solutions that have been used to "leach" alumina and smaller concentrations of other components from the precipitates. Below is an estimate of the composition of the tank being treated:

Component	Concentration
Sodium hydroxide	3M (minus NaOH consumed in converting aluminum to aluminate)
Sodium aluminate	Saturated
Sodium nitrate	0.05M
Sodium nitrite	0.01M
Sodium phosphate	0.01M
Cesium nitrate	10-6M

Other salt concentrations can be assumed negligible.

The plant is designed to remove cesium from the leach liquor to a level sufficient enough to allow the remaining dissolved components to be incorporated in a low-level waste which can be handled without shielding. As much sodium as practical is removed from the solution, converted to sodium hydroxide and recycled to the beginning of the process. This will aid in cost savings.

In addition, a discussion of nuclear regulatory policy is also contained in this paper. Several sources are cited as references for this project. I would especially like to thank my partners, Brandon Binkley and Billy Luttrell, and my advisor for this project, Dr. Jack Watson. Without these people, none of this project would have been possible.

Nuclear Regulatory Policy

When the Cold War began in the mid 1940's, the United States paid much more attention to getting ahead in the nuclear arms race than it did in exploring the environmental repercussions of doing so. Gradually, scientists and the public began expressing concerns about the safe storage of spent nuclear fuel and the byproducts of nuclear power and weapons production. What followed was a series of Congressional regulations that became a bit more stringent with each new promulgation. This gradual trend gave technology the opportunity to advance (cleanup methods) and also allowed the enormous cost of cleanup to be spread out over a longer period of time.

The Atomic Energy Act of 1946 was the first Congressional regulation dealing with atomic energy. This statute established the Atomic Energy Commission (AEC), which was to conduct research and development on the peaceful applications of fissionable and radioactive materials.

The Atomic Energy Act of 1954 stressed domestic and international uses of the atom and also provided for the control of source material and by-product material (radioactive substances). It is the primary source of federal authority for regulating nuclear materials. In *Northern States Power Co. v. Minnesota*, 405 US 1035 (1972), the Supreme Court decided that the federal government has the right to regulate control and operation of nuclear materials, including disposal of nuclear wastes (Herzik 54).

The Price-Anderson Act originally passed in 1957 amended the Atomic Energy Act by encouraging financial responsibility of nuclear plant owners. Plant owners who obtain sufficient liability insurance according to the act's guidelines were shielded from unlimited tort recoveries. The Act was amended in 1966 to prohibit participating nuclear entities from assessing legal defenses of governmental immunity and contributory negligence. Further Amendments in 1988 limited liability to $560 million in the event of an extraordinary nuclear occurrence. Punitive damages cannot be awarded for a nuclear incident or precautionary evacuation. The Price-Anderson Act does not clearly provide the same liability dollar limit protection to transporters and storers of radioactive wastes as it does to nuclear producers. Therefore, all transporters and storers of nuclear waste obtain insurance which will be able to cover all costs of an accidental spill (because of high risk, this is very expensive). Insurance companies will rarely insure against claims for punitive damages, civil fines and penalties (Herzik 55).

The National Environmental Policy Act of 1969 (NEPA) stated its purpose as, "to prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man." (Murray 159). NEPA created the Council of Environmental Quality (CEQ), an advisory group reporting to the President. This Act also established the Environmental Impact Statement, which must accompany any federal action that may significantly affect the environment. An EIS is a large document that describes alternatives, potential environmental, economic, and social effects, includes public comments and agency answers and reports the findings of hearing boards. The Environmental Protection Agency was also created to regulate air and water standards, establish limits on pollution and control radioactive materials. The EPA provides for public participation through meetings, hearings and advisory group reviews (Murray 159). The Energy Reorganization Act of 1974 divided the jurisdiction of the Atomic Energy Commission between two agencies, the Energy Research and Development Administration (ERDA) and the Nuclear Regulatory Commission (NRC). The Energy

Reorganization Act of 1977 replaced the ERDA (Murray 159).

The Nuclear Regulatory Commission has jurisdiction over reactor construction and operation. It also licenses and regulates the possession, use, transportation, handling and disposal of radioactive materials. Agreement states accept authority to control radioactive wastes under NRC guidelines. Title 10 Energy, contains 1400 pages of regulations on radiation standards and reactors (Murray 160).

The Department of Transportation (DOT) provides rules on the transportation of radioactive materials, and the Federal Emergency Management Agency (FEMA) prepares plans for emergency response to radioactive releases.

In 1983, the Department of Energy issued the Defense Waste Management Plan. This plan called for the construction of waste treatment and disposal facilities, the construction of new storage facilities, and a safer transportation system for nuclear wasted (Herzik 128). It was produced in response to Congressional pressures for the Department of Energy to provide a direction for nuclear waste cleanup.

The U.S. Environmental Protection Agency has been charged with enforcing the clean-up provisions of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) and its amendments contained in the Superfund Amendment and Reauthorization Act of 1986. Should a nuclear spill occur during transportation, the EPA and its state counterpart will spearhead the cleanup effort (Herzik 56).

In 1988, Congress included language about environmental contamination in the Defense Authorization Act. In 1989, Department of Energy (DOE) Secretary, James Watkins, stated that environmental protection and assurance of safety and health took precedence over production. "Tiger Teams", groups of DOE and contractor experts were sent to inspect facilities across the nation. These teams assessed compliance with rules and laws and prepared reports for corrective action. The teams inspected 35 major facilities and issued 8715 findings. This study led to the establishment of an Environmental Safety and Health Progress Assessment Program to implement findings (Murray 142).

A key conclusion of the study was that safety concerns existed at many of the facilities. A total of 111 U.S. inactive sites were identified and a date of 2019 was set as a goal date for cleanup. To accomplish the time frame, DOE created the Office of Environmental Restoration and Waste Management (EM). Many issues and challenges face this program: 1) Coordination with the EPA Superfund program (EPA has identified 25 radioactively contaminated sites, along with sites with soil contamination due to natural radionuclides); 2) What degree cleanup is feasible (can't make totally clean for technological, economic and social reasons); 3) The need for new technologies (robotics and new separation technologies); 4) Requirements for environmentally trained personnel (takes time and money to retrain employees in nuclear cleanup field); 5) Must convince the public that this expensive project with little visible signs of a product deserves support and must be done; 6) Establishing priorities for cleanup (most of the content is unknown, and studies must be performed to see which areas are in need for quickest cleanup; 7) Deciding on the applicability of the concepts of ALARA (as low as reasonably achievable) and BRC (below regulatory concern); 8) Finding sites for disposal facilities that will accommodate decontamination and decommissioning waste; 9) Need to manage effectively (comprehensive management system is needed for entire nationwide process). (Murray 143)

Concerns about the possibility of having no place to dispose of low-level radioactive wastes led the states to seek control of waste management. This led to the Low-Level Radioactive Waste Policy Act of 1980. The legislation says, "Each state is responsible for providing for the availability of capacity either within or outside the state for disposal of low-level radioactive waste generated within its borders (excluding defense or other federal wastes). Low-level radioactive waste can be most safely and effectively managed on a regional basis." (Murray 160) This act created compacts among several states. Compacts decide what facilities are needed and which state will serve as the host and for how long.

Then, in 1985 Congress passed the Low-Level Radioactive Waste Policy Amendments Act. It called for keeping three commercial disposal sites open through 1992 due to the longer-than-anticipated time necessary for the states to form compacts. It also set volume limits on the wastes that could be sent to these sites. The Act called for deadlines on ratifying compacts, selecting host states, developing plans, submitting license applications and providing for disposal. The Department of Energy was able to allocate additional storage capacity to reactors in cases of emergency, and the Nuclear Regulatory Commission could authorize emergency access to the existing sites (Murray 161).

Establishing low-level waste storage facilities by the deadline of 1996 has been slow for a number of reasons: 1) each project must develop its own selection process for a disposal site; 2) a survey of a complete host state for potential sites involves the collection and analysis of enormous amounts of data; 3) the processes of site characterization and interpretation of data are long and involved; 4) the application for a license is a many volume document; 5) the regulatory review of the application is thorough and extensive; and 6) lawsuits initiated by potential host communities or intervening groups delay action (Murray 162). This lack of storage facilities has added great expense to generators who now have to store wastes on site.

In 1982, Congress passed the Nuclear Waste Policy Act for the management of high-level radioactive waste and spent fuel. It contained input from industry, government, and environmentalists and a timetable for action by the Department of Energy leading to underground disposal of high-level waste.

The Act was designed to regulate primarily commercial waste materials, but provides for defense waste disposal upon Presidential approval. A nuclear waste fund was setup to pay for disposal, with money coming from the waste generators themselves, who in turn charge their electricity customers. The fee was established at 1/10 cent/kilowatt hour (Murray 162).

Following passage of the law, DOE established the Office of Civilian Radioactive Waste Management (OCRWM). Guidelines were issued for the process to select suitable sites for a repository, a Mission Plan was developed, and geological surveys were begun. Nine sites were identified as potentially acceptable, and this number was further reduced to three sites in 1987: Hanford, Washington, Yucca Mountain, Nevada and Deaf Smith County, Texas (Murray 163). After the passage of the Nuclear Waste Policy Amendments Act of 1987, Yucca Mountain would be the only site characterized.

It was decided to use a Monitored Retrievable Storage (MRS) system, and studies were conducted on how to best implement it. A limit on storage capacity of the facility was set at 10,000 tons. A license must be granted by the Nuclear Regulatory Commission before the MRS can be built. This is the legal device that prevents the MRS from becoming a permanent storage facility (Murray 163).

The 1987 Act added a number of special features: A Nuclear Waste Review Board in the National Academy of Sciences was created; spent fuel must be shipped in NRC-approved packages, with state and local authorities notified of the shipments; authority was given for continued studies of the sub-sea-bed disposal option; no further crystalline rock studies were allowed; and DOE is to submit a study for the needs of a second repository in the period from 2007 to 2010 (Murray 163).

Progress in characterization of the Yucca Mountain site have been slow due to the efforts of the State of Nevada to halt the project. DOE finally obtained approval to proceed and not be held up by permit requirements. The main concern expressed was regarding pathways on the premises that would allow rapid radionuclide transfer on the site.

A timetable was revised to accept spent fuel from utilities by 1998 and begin waste disposal in 2010. To accept the fuel, DOE must have the Monitored Retrieval Storage facility ready. This in turn depends on the success of the OCRWM to characterized the site efficiently and to avoid legal obstruction. Finally, adequate funding must continue if this project is to reach fruition (Murray 164).

In 1992, Congress passed the Energy Policy Act which was broad in scope, emphasized energy efficiency, research and development on conventional fuels, alternative fuels and uranium enrichment. The law stated that: 1) the EPA would set standards for Yucca Mountain based on findings by the National Academy of Sciences on several specific issues related to radiological protection; 2) the NRC would provide requirements and criteria based on EPA standards, assuming engineered barriers and long-term oversight of the repository by DOE; 3) DOE would report to Congress on the adequacy of plans for disposal of waste from future reactors, and 4) states would have authority over below-regulatory-concern (BRC) wastes, negating NRC policy (Murray 164).

The principle regulation concerning low-level wastes (civilian radioactive wastes) is Part 61 (10 CFR 61) of Title 10 Energy. The legislation is based on research by the NRC and its contractors and must gain approval by industry and the public (Murray 165).

Low-level wastes are further broken down into smaller categories. "Below regulatory concern" (BRC) wastes can be disposed of without any concern of radioactivity. Next, Class A wastes require minimum precautions for disposal. They must not be stored in cardboard containers, must be solidified or mixed with an absorbent so there is no more than one percent liquid, there must be no explosive or combustible material present, containment at low pressure if gaseous, and must receive treatment if biological in origin (Murray 165). Class B wastes must be stable (keep their size and weight despite stresses on the container from soil weight, moisture and radiation) and also have to meet minimum requirements (Murray 165). Class C wastes should be protected so that an inadvertent intruder could not reach the waste by drilling, digging a well, or excavating for a building. Finally, Greater than Class C wastes (GTCC) must be treated as high-level wastes and thus are not cleared for near surface burial. The Department of Energy disposes of these wastes. These classes are based on half-lives and activity of isotopes in the material. Data for the isotopes may be found in 10 CFR 61

(Murray 165).

NRC Regulatory Guides supplement regulations and provide information on issues such as quality assurance, design bases, calculation methods and the form of reporting (Murray 165).

Over 30 pages of regulations govern the storage of high-level radioactive wastes. They are contained in Part 60 of the Code of Federal Regulations Title 10 Energy (10 CFR 60). Some of these important provisions include: 1) Design and operation of the facility should not pose an unreasonable risk to the health and safety of the public (radiation limit is a small fraction of that due to natural background); 2) a multiple barrier approach is to be used, including the waste form, containers, and host rock; 3) performance objectives are set for both the components and the system; 4) a thorough site characterization must be made, with features such as possible flooding regarded as sufficient to disqualify, and features such as geological stability or slow water flow regarded as favorable; 5) repository should be located where there are no attractive resources, far from population centers, and under federal control and should maintain good records and prominent markers; 6) high-level wastes are to be retrievable up to fifty years from the start of operation; 7) waste package must be designed to take account of all possible effects (must be dry and chemically inert); 8) wastes in the package should be safe from water for at least 300 years; and 9) predictions of safety must be made with conservative assumptions and by calculations that take account of uncertainties, using expert opinion (Murray 166).

Accompanying this legislation is 10 CFR 960, which contains the Department of Energy's criteria on characterizing repositories. In lieu of Congress's decision in 1987 to limit the study of Yucca Mountain, the regulations related to selection of several sites for characterization and on the recommendation of one site for use are now irrelevant (Murray 166).

The fact is that nuclear regulatory policy is an area that has evolved over the last fifty years. Over that time, it has tended to be an area where fear from the people make legislation somewhat less scientific than it should be at times. As America heads into the twenty-first century and as our fuel needs continue to grow, the public must learn to look at nuclear power in a different light than it views nuclear weapons. In addition, scientists must continue to work at finding new storage techniques that are safer and cheaper than the facilities current technology permits. Nuclear power is an unlimited source of power. America should take advantage of it, but we must first learn to deal with the problems of waste disposal which come with it.

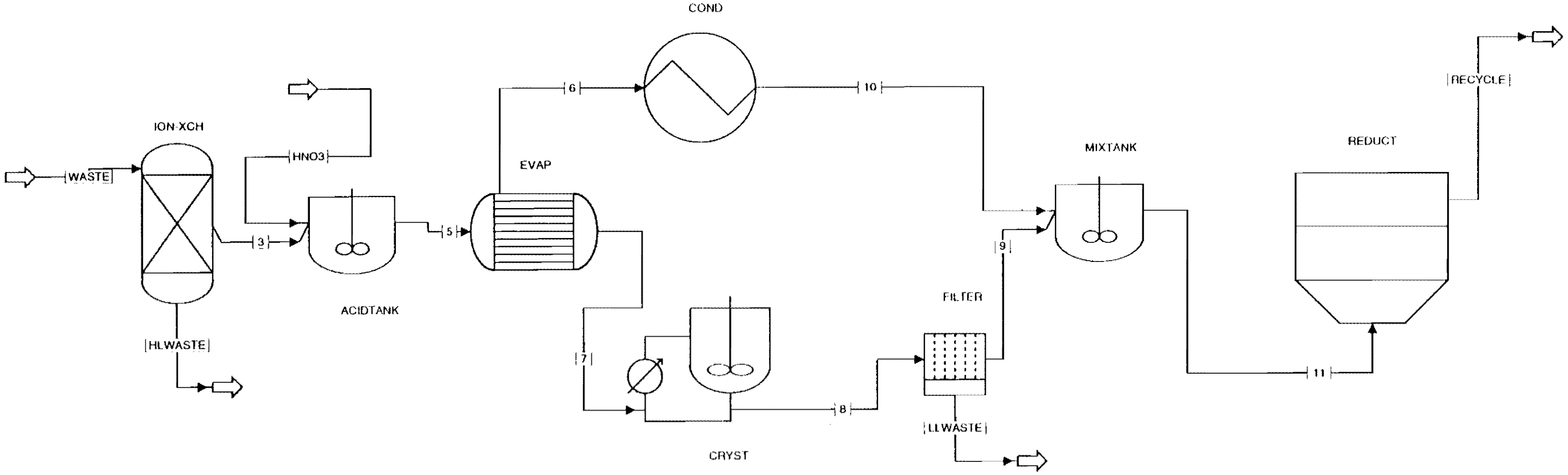
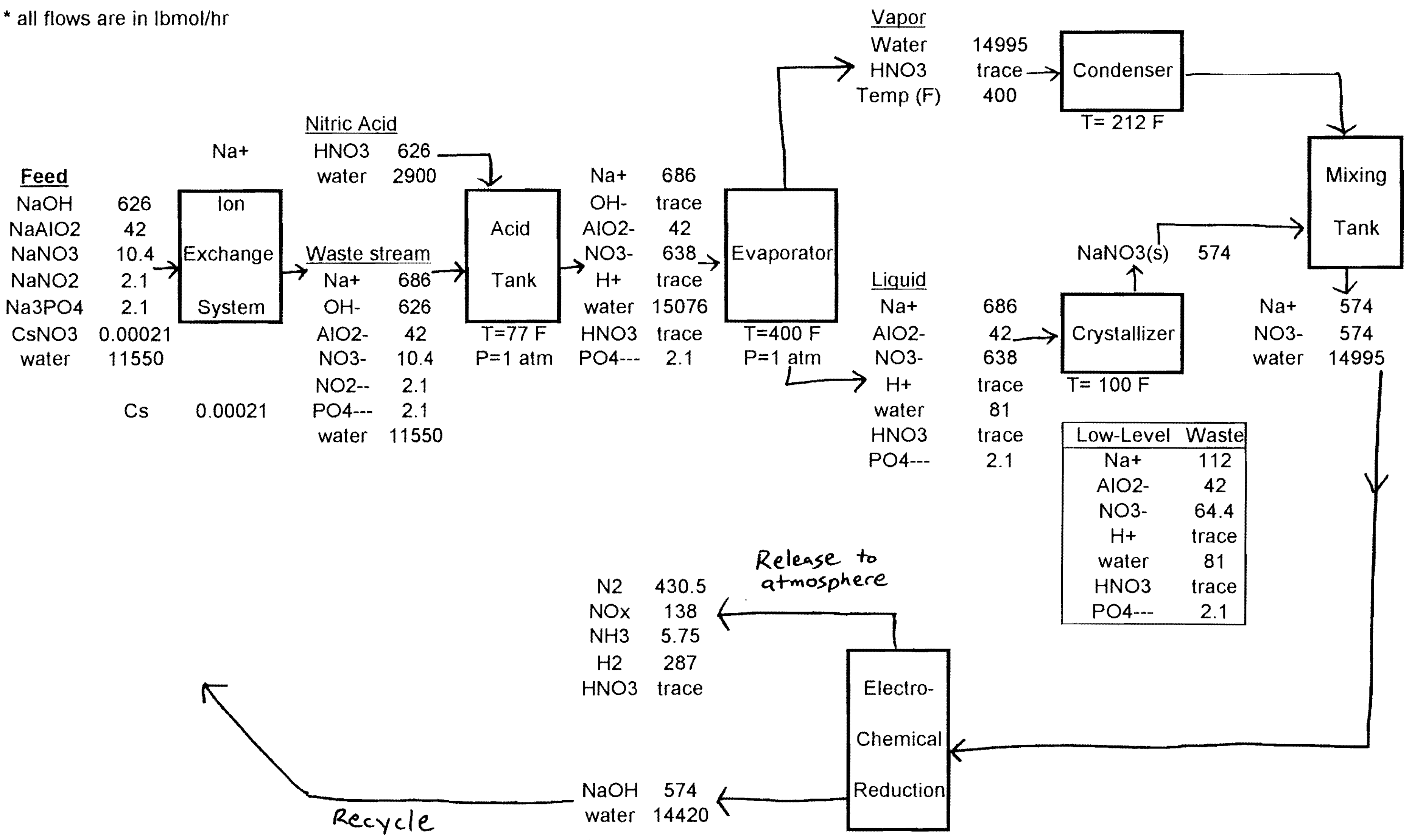


Figure 1: Process Flowsheet

Figures should appear after they are cited in the text.



This seems to be less than 3M. You will need to evaporate some water to recycle as 3M levels

Figure 2: Material Balance

Process Description

The most crucial aspect of the treatment system is to remove the radioactive cesium from the waste stream in a safe manner. The waste must be contained within protective shielding until all of the cesium is removed. A system of ion exchange columns is designed to remove the cesium in the first stage of the process. The composition of the waste stream entering the ion exchange system is shown in Table 1. The ion exchange system pictured in Appendix A is a series of columns packed with Crystal Silicotitinate (CST), a resin that exchanges Cs^+ ions for Na^+ ions according to the following reaction.

$$1)\quad Cs^+ + NaR \text{ <---> } CsR + Na^+$$

The design is a scale up of a laboratory effort presented in the report on ion exchange resin by DOE. The following assumptions are made to scale up the process used in the laboratory experiments.

1.) The 1x10-6 M Cs+ feed solution is equivalent to the 7.5 x 10-5 M test solution.
2.) All of the Cs+ ions (100%) are removed in the ion exchanger.
3.) Only Cs+ ions exchange for the Na+ ions

Assumption 1 allows for the use of the experimental loading curve from the lab experiments to determine the amount of CST required to remove the Cs^+ in the feed. The second and third assumptions allow us to assume that the material balance is the same as the entrance feed with the exception that the cesium nitrate is converted to sodium nitrate.

The next step in the process is to acidify the waste stream with 12 M nitric acid. Acidification converts all of the nitrites to nitrates and destroys the aluminate ions in the solution. The aluminate ions (AlO_2^-) are essentially aluminum ions (Al^{+3}) and four hydroxide ions (OH^-) in water. Hydroxide ions cannot exist in an acidic solution so the aluminate ions are represented in the process and simulation from this point on as aluminum ions. This part of the process is modeled using ASPEN to obtain a representation of the interactions of the acid with the waste stream. The acidifier is modeled using the MIXER module in ASPEN as an agitated tank. The components of the waste stream are broken down into individual ions to account for the interactions of the dissociated species in solution. The ASPEN simulation does not function properly when phosphate ions are incorporated into the waste stream; therefore, phosphate ions are left out of the simulation and are assumed to follow the same path as the aluminum ions. This assumption causes a negligible error since the amount of phosphate ions in the waste stream is small (< 0.02% by molar flow rate).

The acidic waste stream is sent to an evaporator to remove most of the water before the remaining stream undergoes crystallization. The evaporator is modeled in ASPEN using the FLASH2 module. The evaporator, operating at 400 °F and atmospheric pressure (14.7 psig) creates two streams. The vapor stream consists of water and a trace of nitric acid. The liquid stream is predominately sodium and nitrate ions (Na^+ and NO_3^-, respectively) with a small amount of salt ions (Al^{+3}, PO_4^{-3}, etc.) and water. The liquid stream is sent through a crystallizer operating at 100 °F to solidify most of the sodium and nitrate ions as sodium nitrate, $NaNO_3$ (s). The crystallizer is represented in the simulation with the HEATER module operating as a cooler. The crystallized stream is passed through a vacuum filter, modeled in ASPEN with a SEP2 unit, to separate the solids from the liquid waste. The liquid waste is taken away as low-level waste. The total molar flow rate of low-level waste is approximately 300 lbmol/hr; the volumetric flow rate is 50 ft^3/hr.

The solid sodium nitrate from the filtration step is re-dissolved in water so it can be converted by electrochemical reduction to reclaim the sodium from the process. The water to dissolve the sodium nitrate comes from the vapor product of the evaporator. The vapor from the evaporator is condensed at a pressure of 14.7 psig to a temperature of 212°F. The condenser is modeled in ASPEN using a HEATER module as a cooler. The condensed water and the solid sodium nitrate are combined in an agitated tank to produce a 2.2 M solution of sodium nitrate.

The final step in the treatment of the Hanford waste solution is nitrate destruction in an electrochemical cell. In this cell a potential is applied which drives the destruction of nitrates. The laboratory work in the report by Hobbs results in the lead electrode completely destroying the nitrates and producing 75% of the feed in the form of N_2 gas, 24% as NO_x gas, and 1% as NH_3 gas. The following assumptions are made so Hobbs' work could be used to determine material balances in the cell. The detailed calculation are in Appendix B.

1.) The reactions in the process go as those in the report producing the same product streams.
2.) The cell destroys exactly enough water to produce OH- ions that will combine with Na+ to produce sodium hydroxide.

The resulting material flows are summarized in Figure 2. The off gases produced in the nitrate destruction are released into the atmosphere. It is assumed that the NOx emissions do not exceed regulations or that release permission may be purchased.

Equipment Sizing and Costing

Cost estimates are calculated using general correlations from *Perry's Chemical Engineer's Handbook, 4th edition* and *Plant Design and Economics for Chemical Engineer's (Peters and Timmerhaus)*. The Marshall and Swift Equipment Cost Index for the second quarter of 1996 is used to calculate the proper present day cost from equipment prices based in past years. Cost estimates for all of the major equipment items are displayed in Table 2; calculations for the individual items are detailed in Appendix C.

Table 2: Equipment Costs

Equipment Item	**Size**	**Cost**
Ion Exchange Columns	8 @ 16 m^3	$844,800
Shielding/Building	5000 ft^2	$4.3 million
Acid Tank	1000 gallons	$28,000
Evaporator	100,000 ft^2	$1.5 million
Condenser	100,000 ft^2	$1.5 million
Crystallizer	700 tons/day	$804,500
Filter	200 ft^2	$48,600
Mixing Tank	1000 gallons	$28,000
Electrochemical Cell	2100 m^2	$210,000
Total Equipment Cost	---	**$9.3 million**

The ion exchange system is the most capital intensive section of the project. This operation must be carried out in a building shielded by seven feet of reinforced concrete on all sides. The layout of the building and exchange columns is also located in the Appendix. The system consist of two sets of four ion exchange columns in parallel separated by a concrete wall. Each column has a volume of 16m^3 (Diam- 2m, L- 5m), and is packed with 320 kg of CST resin. At a flow rate of 6 column volumes per hour (6 CV/hr) each column will exhibit .02% breakthrough at 70 CV or 12 hrs. and will load to 50% in 280 CV or 47 hours (DOE). The proposed system runs continuously because the layout allows the feed to travel through one side while a column is being changed out on the other. The piping is arranged so that the feed can be pumped through the system in any order necessary. Each column is loaded in 47 hours and one column must be exchanged every 12 hours. The cost for each unit is $105,600 and the total material cost for the facility is approximately $5 million.

The equipment items for the section of the process simulated on ASPEN (from the acid tank to the sodium nitrate solution tank) are sized and cost estimations are made based on the flow rates and compositions of the streams within the simulation. The acid tank and the sodium nitrate solution tank are evaluated as 1000 gallon agitated vessels. The size was chosen arbitrarily and ensures an adequate capacity to handle the flows in the process. The cost of each tank is $28,000. The costs of the evaporator and the condenser are assumed to be essentially the same. Both units handle roughly the same flow rate and perform opposite functions; the evaporator vaporizes the water and the condenser cools it back down. The heating surface is assumed to be 100,000 square feet making the cost of each unit approximately $1.5 million. The cost of the crystallizer is calculated based on a capacity of 700 tons per day resulting in a cost of $805,500. The filter cost, based on a filtering area of 200 square feet, is $48,600.

The projected equipment cost for the electrochemical cell is a rough estimate. The $210,000 price is an estimate based on multiplying the required electrode area of 1400 m^2 by 1.5 and then again by $100 / m^2. The cell consists of one hundred 14 m^2 electrodes in series. The layout and calculations of the cell are in Appendix C.

Fixed capital investment is calculated using a typical percentages table for direct and indirect cost segments. Fixed capital investment amounts to $32.4 million and is summarized in Table 3.

Table 3: Fixed Capital Investment Chart

Component	**Assumed % of Total**	**Cost**
Purchased Equipment	30	$9.3 million
Installation	8	$2.5 million
Instrumentation	4	$1.25 million
Piping	10	$3.1 million
Electrical	4	$1.25 million
Building	7	$2.2 million
Yard Improvements	2	$620,000
Service Facilities	15	$4.65 million
Land	0	0
Engineering and Supervision	7	$2.2 million
Construction Expense	5	$ 1.55 million
Contractor's Fee	2	$620,000
Contingency	10	$3.1 million
Total Fixed-Capital Investment	---	**$32.4 million**

Operating and Material Costs

Operating costs are calculated based on twenty four hours a day, 365 days a year (8766 hrs/yr) of operation. A summary of the operating costs, including material and waste removal costs, is found in Table 4. The calculations for these costs are summarized in Appendix C.

Table 4: Operating, Material, and Waste Removal Costs

Utility/Material	**Usage**	**Annual Cost**
Ion exchange system	730 columns/yr	\$77.1 million
Nitric acid	40,000 lb/hr	\$36.3 million
Sodium hydroxide	2040 lb/hr	\$20.2 million
Steam	4.35 e5 lb/hr	\$12.4 million
Electricity	2.2 e8 kwh	\$17.5 million
Labor	3% of fixed capital invest.	\$522,000
Overhead	50% of labor cost	\$261,000
Total Operating Cost	---	**\$164.3 million**

Low-level waste removal	25,000 m^3/yr	\$248 million
High-level waste removal	11,680 m^3/yr	\$5.84 billion
Total Waste Removal Cost	---	**\$6.1 billion**

The largest operating cost is incurred in the change out of the ion-exchange units. The cost per unit includes the cost of the column and the packing material and amounts to \$105,600. An ion exchange unit is replaced every twelve hours and results in a cost of \$77.1 million. The next major operating expense is the cost of nitric acid for the acidification. The price of nitric acid is \$210 per ton as quoted in the April 14, 1997 issue of *Chemical Market Reporter*. The annual cost of nitric acid amounts to \$36.3 million. Two major utilities costs are incurred in running the plant; 500 psig steam for the evaporator and electricity for electrochemical reduction. The annual steam cost is \$12.4 million while the electricity cost is \$17.5 million. The cost of labor is estimated as three percent of fixed capital investment and comes to \$522,000. Overhead costs are estimated as fifty percent of the labor cost or \$261,000. The total annual operating cost is \$164.3 million.

Waste Disposal Options

Waste disposal is a major cost associated with the operation of the clean salt process. A question arises over whether to design a system to re-claim the sodium as sodium hydroxide and recycled as caustic or to dispose of the sodium with the low-level waste. The low-level waste is incorporated into a glass that contains 50% waste by weight and costs $10,000 per cubic meter to produce. Option 1 is to use electrochemical reduction to convert the sodium nitrate into sodium hydroxide for use as caustic recycle. Option 2 is to dispose of the sodium and nitrate as low-level waste. Calculations for the comparison of the two modes of disposal are given in Appendix C with results summarized in Table 5.

Table 5: Low-level Waste Disposal Comparison

	Option 1 (with NaOH recycle)	**Option 2 (without recycle)**
Volume of low-level waste	25,000 m^3/yr	200,000 m^3/yr
Waste removal cost	$248 million	$1.97 billion
Cost of purchasing NaOH	$20.2 million	$248 million
Cost of electricity for electrochemical cell	$17.5 million	------
Total waste removal cost	**$285.7 million**	**$2.2 billion**

The waste disposal cost under option 2 is considerably higher due to the larger volume of low-level waste; the cost amounts to $1.97 billion annually. The cost of purchasing fresh caustic is included in option 2 because no sodium hydroxide is recycled; this cost is $248 million per year. The total waste disposal cost under option 2 is over $2.2 billion per year.

The low-level waste disposal cost under option 1 is $248 million per year. The total cost under option 1 also includes the cost of the electrochemical reduction unit. The equipment cost for the unit is $210,000. The cost of operating the unit is $17.5 million per year for electricity. A small amount of sodium hydroxide must be purchased under option 1 because the recycle does not contain the needed amount of caustic. Approximately 51 lbmol/hr of sodium hydroxide must be purchased; a cost of $20.2 million per year. The total waste disposal cost under option 1 is $285.7 million; a savings of over $1.9 billion per year compared to option 2. The plant is designed based on option 1 with the electrochemical reduction process and the caustic recycle.

Results Discussion and Analysis

The plant design (See Figure 1: Process Flowsheet) contains several unit operations. First, the caustic sludge is pumped into two sets of four shielded ion exchange columns in series. In this reactor, all of the radioactive cesium is replaced by sodium. Next, the process stream is pumped into an acidifier and mixed with 12 M nitric acid. Most of the hydroxide ions are neutralized and the stream, which is mostly water, and sodium nitrate is piped to an evaporator. The top stream which is almost exclusively water vapor is sent to an evaporator, condensed, and sent to another mixing tank where it will eventually be mixed with another process stream. The bottom stream which is sodium ions, nitrate ions, water, aluminum ions and phosphate ions is pumped into a crystallizer. Inside the crystallizer, the sodium and nitrate ions solidify into sodium nitrate. This stream is then passed through a vacuum filter where solids and liquids are separated. Approximately 300 lbmol/hr or 50 ft3/hr of liquid is disposed of as low level nuclear waste. The sodium nitrate (solid) is redissolved in the mixer with the water from the condenser before it is passed into the electrochemical cell. All of the processes after the ion exchange to the electrochemical cell were modeled and costed using ASPEN. The ion exchanger and the electrochemical cell were sized, modeled and costed by hand. The sodium nitrate solution entering the electrochemical cell is 2.2 M. In the cell, Hobbs' analysis was used to model the destruction of the nitrates. The lead electrode completely converts the nitrates into nitrogen gas, NOx, and ammonia. These off gases produced are released into the atmosphere. The remaining 574 lbmol/hr of sodium hydroxide is recycled as fresh caustic.

All of the equipment for the plant (ion exchange columns, shielding/building, acidifier, evaporator, condenser, crystallizer, filter, mixing tank and electrochemical cell) cost $9.3 million. The total fixed capital of the project, including equipment, land and construction totals $32.4 million. Materials, labor and overhead add an additional $164.3 million to the project and waste disposal contributes an enormous $6.1 billion to the project. The waste cost is assuming that the plant implements the sodium hydroxide recycle, which reduces low-level waste storage costs and cost for purchase of fresh caustic. The total cost of the project sums to $6.3 billion (97% of total cost can be attributed to waste storage).

Conclusions

Unfortunately, there is currently no permanent high-level waste storage facility in the United States. Nonetheless, due to the safety concerns at the Hanford site, a cleanup project must be initiated. A plant similar to the design in this report is very inexpensive compared to the cost of the actual disposal of the nuclear waste materials. Processes similar to the sodium hydroxide recycle must be employed to help reduce costs of new materials and unneeded waste disposal. Perhaps, a similar process to recycle nitric acid as fresh feed could be researched. Also, chemicals such as nitric acid and ammonium hydroxide which will be purchased in massive quantities could be negotiated to lower prices.

Given that the plant, labor and equipment comprise such a small percentage of the total cost of the Hanford cleanup cost, the Department of Energy should not only consider the price of the bids on its cleanup contract, but also the reputation and technological expertise of the company to whom it gives the bid. An avoidable disaster does not need to take place simply because the government was trying to cut a few million dollars from a multi-billion dollar project.

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Appendix A:

Ion Exchange hand Calculations

Ion Exchange Sizing

From Figure 13 - Loading Curve for CST - 38B @ 6 column volumes/hr

pH = 14 $\quad 7.5 \times 10^{-5}$ M Cs

C/C_0	CV
0.005	40
0.01	55
0.02	70
0.05	95
0.1	120
0.2	150
0.3	200
0.4	240
0.5	272

Test Conditions

6 CV/hr

Diameter = 1.5cm > $\frac{\pi D^2 L}{4} = V$

$V = 26.5 cm^3$

11.87 ≈ 12g CST
H = 6cm

$V_{CST} = 10.6 cm^3$

Assumptions:

1) 7.5×10^{-5} M (Test) ≈ 1×10^{6}
2) Assume 100% Cs Removed up to Breakthrough
3) Only Cs^+ ions exchange in unit

1) Volume of Test Vessel

$$V = \frac{\pi D^2 L}{4} = \frac{\pi (1.5)^2 L}{4} = 26.5 cm^3 = 1\ CV$$

$$u = \left(\frac{6CV}{hr}\right) \frac{26.5 cm^3}{CV} = \frac{159 cm^3}{hr} \times \left(\frac{4}{\pi D^2}\right) = 89.9 = \frac{90 cm}{hr} \times \frac{1 hr}{3600 sec} = \frac{.029 m}{s}$$

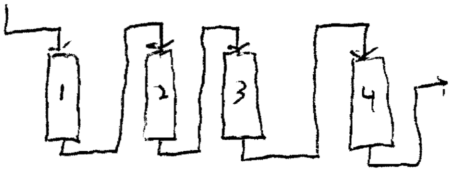
$$G = \rho u = \left(\frac{0.00025 m}{s}\right)\left(\frac{20 kg}{m^3}\right) = \frac{0.005\ kg}{m^2 s}$$

2) From Breakthrough Curve

Starts breaking up at $\frac{C}{C_0} = 0.02 = 70 CV$

Column Considered fully Loaded @ $\frac{C}{C_0} = 0.5 = 280 CV$

So 4 columns in series to get 280CV to fully load



Ion Exchange Sizing

From Breakthrough Curve : cont'd - Size of Vessel

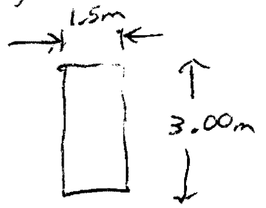
Flow Rate Q in Test = $160 \frac{cm^3}{hr} = 6CV$

In process, Need 6 Column Volumes = $\frac{25{,}000 gal}{hr} \times \frac{3.785 \times 10^{-3} m^3}{gal} = 94.652 m^3$

$6CV = 95 m^3$

$1CV = 15.83 m^3$

$1CV = 16 m^3 = \frac{\pi D^2 L}{4}$



Take $D = 2 m^2 \approx 6.5'$

$L = 5.00 m^2 \approx 16'$

Each Column loads to 0.02 in 70CV

so $\frac{70 CV}{6 CV/hr} = 11.6 \approx 12$ hours

at Steady State, column must be changed every 12 hours

1^{st} column can go $\frac{280}{6} = 46.6 \approx \boxed{47 hrs}$ before 50%

after change = 12 hrs

3) Weight of CST in each Column

$\frac{16 m^3}{unit} \left(\frac{20 kg}{m^3} \right) = 320$ kg CST/unit

4) P-drop Check

* Order of magnitude - rough
Just to see if need to check further

* (5-196) p. 5-53 Perry's 6th Edition

$$\Delta P = \frac{2 f_m G^2 L (1-\varepsilon)^{3-n}}{D_p g_c \rho \Phi_s^{3-n} \varepsilon^3}$$

$\Phi_s = .75$ Avg. for various Types of Sand

McCabe Smith Harriott
50% NaOH @ 80°F

$\varepsilon = 0.5$

$\mu = 70 cp \times \frac{1 \times 10^{-3} \frac{kg}{m \cdot s}}{cp} = 0.7 \frac{kg}{m \cdot s}$

$G = 0.005 \frac{kg}{m^2 s}$

$L = 5 m^3$

Assume small $D_p = 0.05 cm \times \frac{1m}{100cm} = 0.0005 m$

$f_m = 10^5$

$\rho = \frac{20 kg}{m^3}$

$N_{Re} = \frac{D_p G}{\mu} = \frac{D_p (0.005 kg/m^2 s)}{0.07 \frac{kg}{m \cdot s}} = D_p (0.0714) \Rightarrow N_{Re} < 1$

$\therefore n = 1$

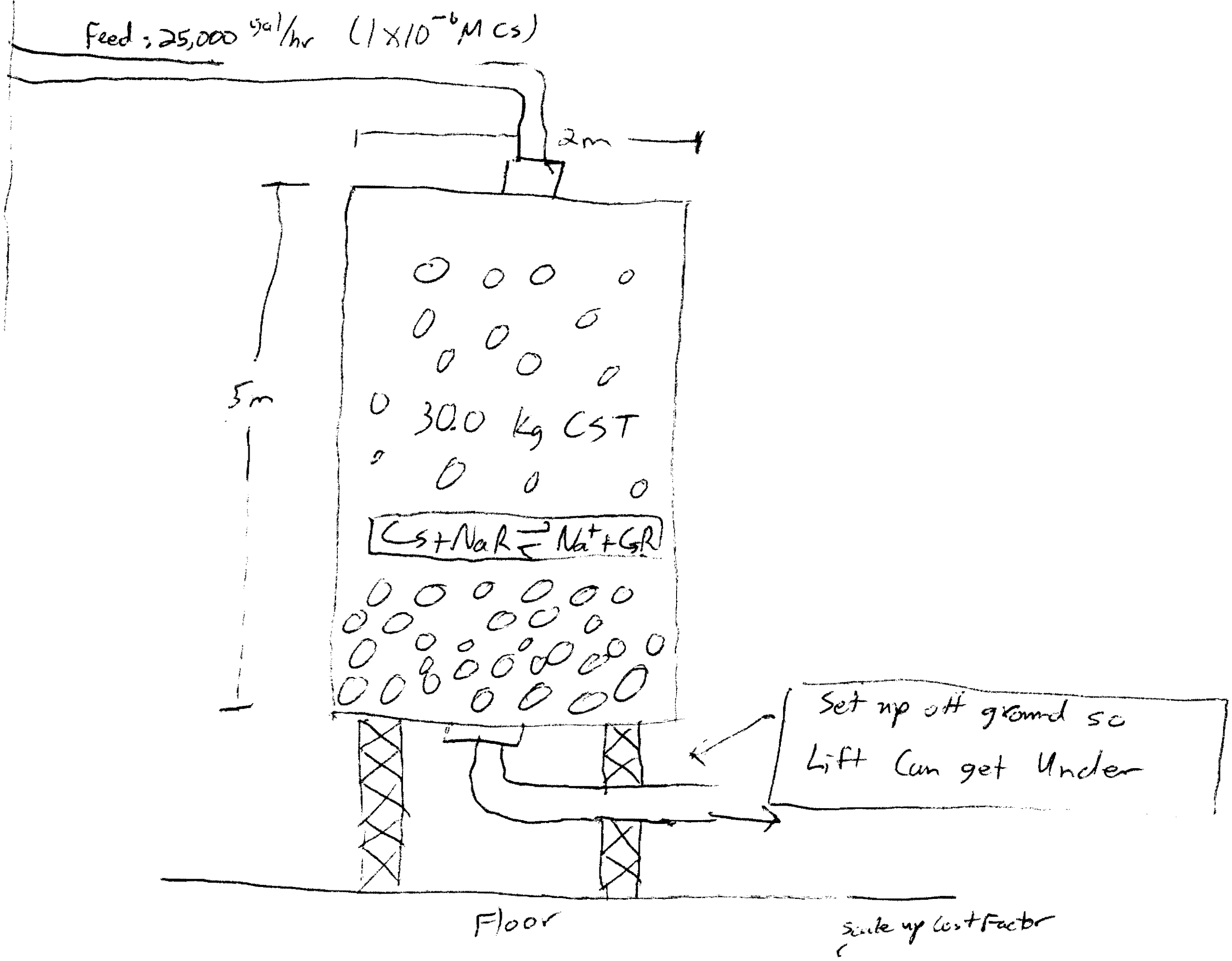
Worst Case $\Delta P = \frac{2(10^5)(005)^2\, 5\,(0.5)^2}{0.005\, g_c\, 20\,(0.75)^3\,(0.5)^3} = \frac{6.25}{0.0007} = \frac{8900\,kg\ m/s}{m^2}$

T fn $8900\,\frac{N}{m^2} \times \frac{1.5\times10^{-4}\,psi}{N/m^2} \approx 1.333\,psi \approx \Delta P$

ΔP is Not Problem

If D_p 0.00005 $\Rightarrow \Delta P = 13$ psi

So P-drop will not be a problem however we run system



scale up Cost Factor

<u>Costs / Unit</u>

1) $320\,\frac{kg}{unit}\left(\frac{\$220}{kg}\right) = \$70,400 \times (1.5) = \boxed{\$105,600/unit}$

2) 8 units (105,600) = Initial Equipment Cost = $\boxed{\$845,000}$

3) Cost of Replacing Units/yr

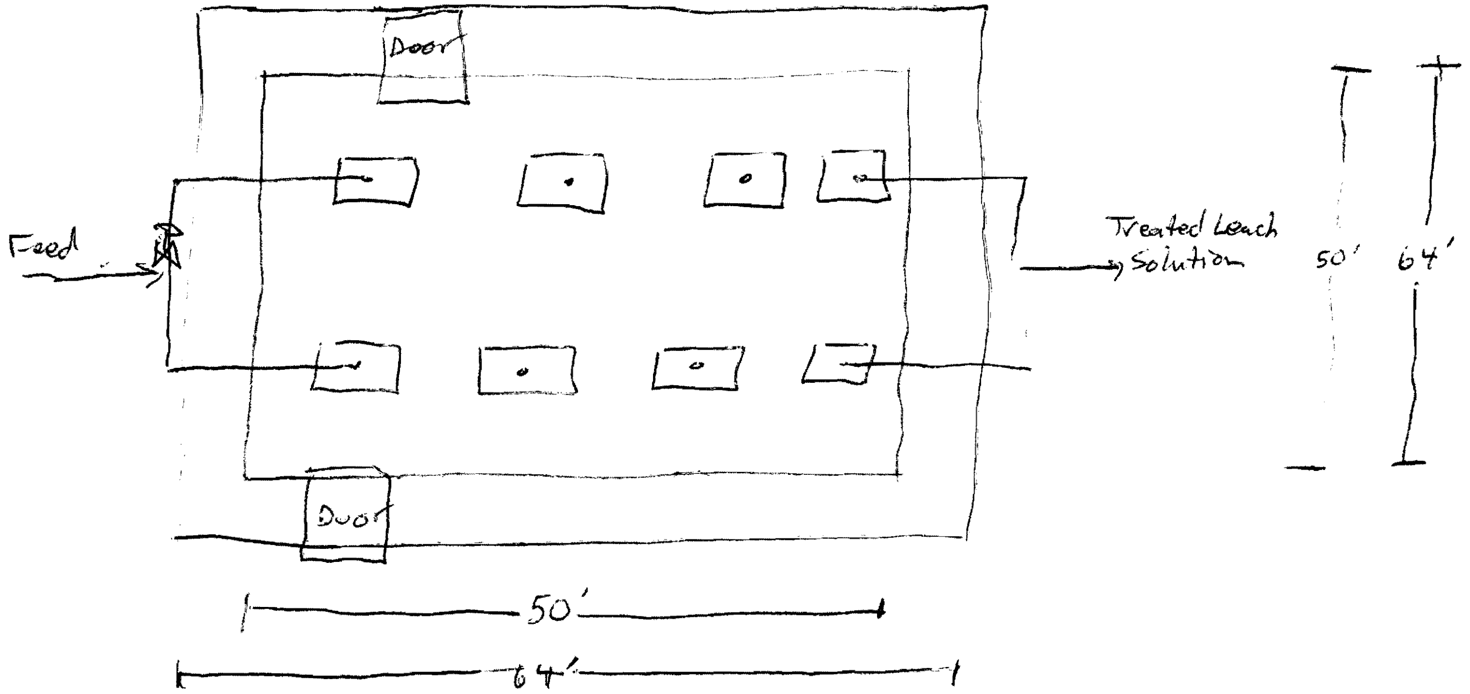
Based on 24 hr day $\frac{2\ units}{day} \times \frac{365\ day}{yr} \times \frac{\$105,600}{unit} = \boxed{\$77,088,000/yr}$

770 units @ \$500,000 (high level waste disposal) = $\boxed{\$365,000,000/yr}$

Ion Exchange Sizing Room

5) Setup 4 (16m^3) Vessels in Series

2-sets - so can change and run one side while performing maintenance on other



Room 50 x 50 x 20 = 50,000 ft^3

Surrounded All Sides Top + Bottom w/ 7' Reinforced Concrete

Concrete Used = (64 X 64 x 34) - (50 x 50 x 20) ≈ 90,000 ft^3

→ [\$400 / yd^3] + (7 x 50 x 20) ≈ 2000 ft^3

92,000 ft^3

Costs: Concrete (92,000 ft^3) (400/yd^3) ($\frac{0.0343 \text{ yd}^3}{3 \text{ ft}^3}$) = \$1,262,240

Machinery - Fan (Motor) = \$ 100,000

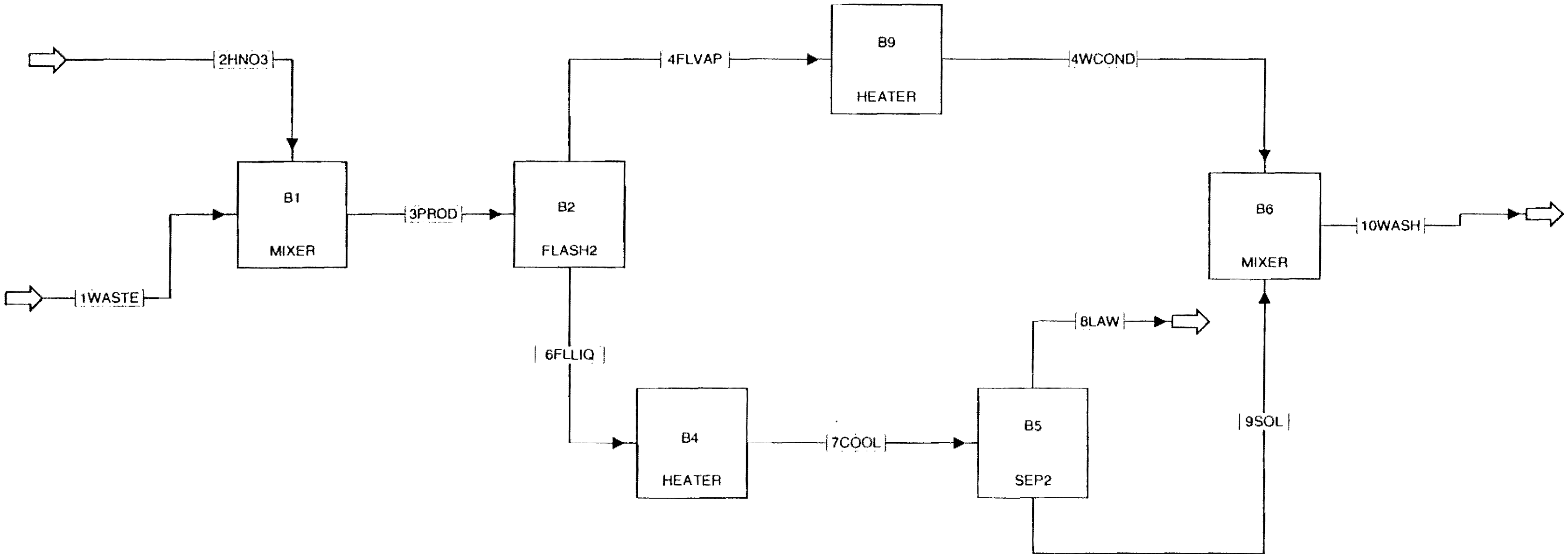
Doors (2) = \$ 1,000,000 = \$ 2,000,000

Ventilation System = 35% Fixed Cost = \$ 900,000

Total Cost of Ion Exchange Building ≈ $\boxed{\$ 4,270,000}$

Appendix B:

ASPEN material balances and flowsheet


2HNO3
1WASTE
B1
MIXER
3PROD
B2
FLASH2
4FLVAP
B9
HEATER
4WCOND
B6
MIXER
10WASH
6FLLIQ
B4
HEATER
7COOL
B5
SEP2
8LAW
9SOL

```
============================================================================
Data file created by ASPEN PLUS Rel. 9.2-1  on  17:06:14 Tue Apr 15, 1997
Run ID: NACH Item: STREAM-SUM Screen: Stream-Sum.Main
C-----------C-----------C----------C----------C----------C----------C-----------

 Display ALLSTREAMS     1WASTE     2HNO3      3PROD      4FLVAP     4WCOND
 Units:           From                        B1         B2         B9
 Format: GEN_E    To    B1         B1         B2         B9         B6
                  Phas LIQUID     LIQUID     LIQUID     VAPOR      LIQUID
 Temperature [F]              77.0       77.0      124.3      400.0      212.0
 Pressure    [PSI]           14.70      14.70      14.70      14.70      14.70
 Vapor Frac                  0.000      0.000      0.000      1.000      0.000
 Mole Flow   [LBMOL/HR  12916.500   4151.406  16442.500  14995.254  14995.254
 Mass Flow   [LB/HR]   236402.703  91690.375 328093.406 270143.688 270143.688
 Volume Flow [CUFT/HR]   3315.258   1190.556   4702.904 9.37619E+6   4516.409
 Enthalpy    [MMBTU/HR  -1564.457   -411.252  -1975.711  -1520.710  -1807.333
 Mole Flow   [LBMOL/HR
   NA+                    686.000              686.000
   OH-                    626.000              < 0.001                 < 0.001
   NO3-                    12.500    625.406   638.500                 < 0.001
   H+                                625.406   < 0.001                 < 0.001
   WATER                11550.000   2900.000 15076.000  14995.254  14995.254
   HNO3                                0.594     trace    < 0.001

 Display ALLSTREAMS     1WASTE     2HNO3      3PROD      4FLVAP     4WCOND
 Units:           From                        B1         B2         B9
 Format: GEN_E    To    B1         B1         B2         B9         B6
                  Phas LIQUID     LIQUID     LIQUID     VAPOR      LIQUID
   AL+3                    42.000               42.000
   NANO3(S)
```

```
Display ALLSTREAMS    6FLLIQ     7COOL      8LAW       9SOL       10WASH
Units:           From B2         B4         B5         B5         B6
Format: GEN_E    To   B4         B5                    B6
                 Phas LIQUID     MIXED      LIQUID     SOLID      LIQUID
Temperature [F]            400.0      100.0      100.0      100.0      181.2
Pressure    [PSI]          14.70      14.70      14.70      14.70      14.70
Vapor Frac                 0.000      0.000      0.000      0.000      0.000
Mole Flow   [LBMOL/HR   1447.246    873.098    298.949    574.149  16143.552
Mass Flow   [LB/HR]    57949.371  57949.371   9149.454  48799.602 318943.312
Volume Flow [CUFT/HR]    437.247    395.986     50.180    345.806   4756.264
Enthalpy    [MMBTU/HR   -128.158   -151.462    -36.244   -115.218  -1922.552
Mole Flow   [LBMOL/HR
  NA+                    686.000    111.851    111.851               574.149
  OH-                    < 0.001    < 0.001    < 0.001               < 0.001
  NO3-                   638.500     64.351     64.351               574.149
  H+                       trace      trace      trace               < 0.001
  WATER                   80.746     80.746     80.746             14995.253
  HNO3                     trace      trace      trace                 trace

Display ALLSTREAMS    6FLLIQ     7COOL      8LAW       9SOL       10WASH
Units:           From B2         B4         B5         B5         B6
Format: GEN_E    To   B4         B5                    B6
                 Phas LIQUID     MIXED      LIQUID     SOLID      LIQUID
  AL+3                    42.000     42.000     42.000
  NANO3(S)                          574.149               574.149
```

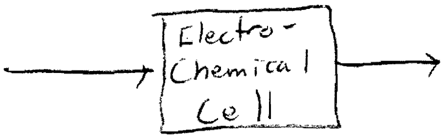
```
Display ALLSTREAMS
Units:           From
Format: GEN_E    To
```

Appendix C:

Electrochemical Cell hand calculations

Electrochemical Cell Material Balance

Feed	lbmol/hr
Na^+	574.149
OH^-	<0.001
NO_3^-	57.149
H^+	<0.001
Water	14,995
HNO_3	trace



Product	lbmol/hr
Na^+ OH^- > NaOH	574
N_2	430.5
NO_x	137.76
NH_3	5.74
H^+	~~[illegible]~~ 574
water	14,421
HNO_3	trace

From Hobbs Report:

Lead electrodes: 100% destruction NO_3^-

Results 75% N_2 24% NO_x 1% NH_3

574 lbmol/hr NO_3^- Feed

Yields: 430.5 lbmol/hr N_2
137.76 " NO_x
5.74 " NH_3

Assumptions

1) Reactions yield exactly as in Hobbs Report

2) Electrochemicall cell Destroys Exactly Enough Water that OH^- can react w/ Na^+ (574 $\frac{lbmol}{\cancel{hr}}$ OH^-)

$$H_2O \rightarrow H^+ + OH^-$$

$$Na^+ + OH^- \longrightarrow NaOH \quad (574\ \frac{lbmol}{hr})$$

(Leaves 574 $\frac{lbmol}{hr}$ H^+)

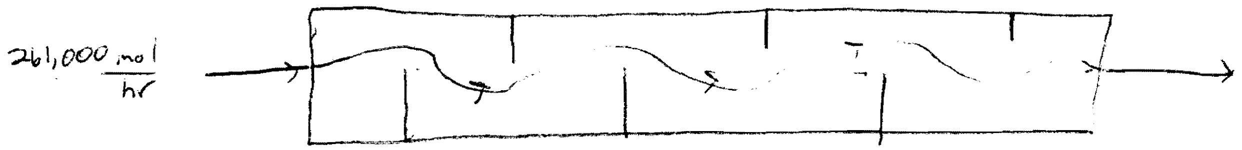
Electrochemical Cell Sizing - Costing

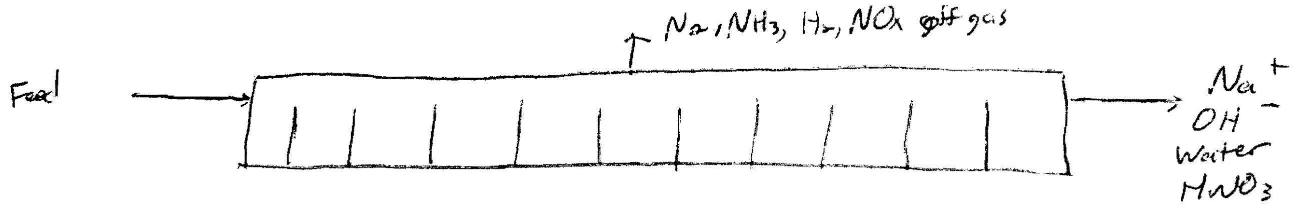
NO_3^- Feed $= 574 \frac{lbmol}{hr}$ Current Density

$$574 \frac{lbmol}{hr} \times \frac{kmol}{2.21\,lbmol} \times \frac{1000\,mol}{1\,kmol} \times \frac{6.022\times10^{23}\,e^-}{mol} \times \frac{1.06\times10^{-19}\,C}{1\,e^-} \times \frac{1\,hr}{3600\,s}$$

$$6{,}994{,}252 \frac{C}{s} \times \frac{1\,A}{1\,C/s} \times \frac{dm^2}{A} \times \frac{1\,m^2}{1\,dm^2} = \boxed{1400\,m^2}$$ Electrode Area

Plates - 100 $14\,m^2$ (3.7m x 3.7m)
(12.3' x 12.3')





Costing

Material Scaling Factor

Equipment $1400\,m^2\,(15) = 2100\,m^2$

$$2100\,m^2 \times \frac{\$100}{m^2} \Longrightarrow \boxed{\$210{,}000}$$

Operational Cost:

Use 3V

$$P = VI$$

$$= 3\,V \times \frac{1\,J/C}{1\,V} \times \left(6{,}994{,}252 \frac{C}{s}\right) = 20{,}982{,}756\ J/sec$$

$$20{,}982{,}756 \frac{J}{s} \times \frac{3600\,s}{hr} \times \frac{24\,hr}{day} \times \frac{2.28\times10^{-7}\,kWhr}{J} \times \frac{\$0.08}{kWhr} = \$17{,}360{,}000/yr$$

$$\boxed{= \$17{,}500{,}000/yr}$$

Appendix D:

Costing hand Calculations

Cost of Mixing Tank (304 Stainless Steel)

Assume 1000 gallon Tank

1996 = 1036.9

1979 = 561

* From Peters and Timmerhaus

* 1979 Cost = $15,000

$$1996\ \text{Cost} = \$15{,}000\left(\frac{1036.9}{561}\right)$$

$$\boxed{= \$27{,}725}$$

- Cost for Acid Tank
- cost for Mixing Tank

Cost of Evaporator and Condenser

Assume the cost of both units is essentially the same

Marshall and Swift Indices

1996 = 1036.9

1960 = 239

- Assume 100,000 ft^2 heating surface

* 1960 cost = \$ 340,000   * from Perry's Handbook (7th Ed.) Pg. 11-41

1996 Cost = \$ 340,000 $\left(\frac{1036.9}{239}\right)$

$$\boxed{\text{Cost} = \$\ 1,480,000}$$

Material is Stainless Steel

Cost of Crystallizer

Flow = 57,950 lb/hr

$= 1.39 \times 10^6$ lbs/day $\left(\frac{1 \text{ ton}}{2000 \text{ lbs}} \right)$

= 700 tons /day

* $180,000 in 1958

Marshall and Swift
1958 = 232
1996 = 1,036.9

Cost in 1996 = 180,000 $\left(\frac{1036.9}{232} \right)$

$$\boxed{\text{Cost} = \$804,500}$$

* from Perry's Handbook (4th ed) p.17-21

Costing of Filter

Marshall + Swift Indices

1996 = 1036.9

1955 = 192

Continuous Vacuum Disk Filter

* Assume Filtering Area is $200 ft^2$

* 1955 cost = \$9000

* From Perry's Handbook (4th Ed) p. 19-71

$$1996\ \text{Cost} = \$9000\left(\frac{1036.9}{192}\right)$$

$$\boxed{1996\ \text{Cost} = \$48{,}600}$$

Operating Cost of Ion Exchange System

- Cost per unit is $ 105,600
- Change out every 12 hours
- 8766 hours per year
- 730 changes per year

$$\boxed{\text{Total Cost} = \$\,77{,}100{,}000\,/\text{yr}}$$

Materials Cost

HNO_3

Amount required $= 626 \frac{\text{lbmol}}{\text{hr}} \left(\frac{63 \text{ lbs}}{1 \text{ lbmol}}\right) = 39,438 \frac{\text{lbs}}{\text{hr}}$

Price of $HNO_3 = \$210/\text{ton} \left(\frac{1 \text{ ton}}{2000 \text{ lbs}}\right) = \$0.105/\text{lb}$

Price from Chemical Market Reporters April 14, 1997

Cost of $HNO_3 = 39,438 \text{ lbs/hr} \left(\frac{\$0.105}{\text{lb}}\right) = \$4141/\text{hr}$

Annual Cost $= \$4141/\text{hr} \left(\frac{8766 \text{ hr}}{\text{yr}}\right) = \boxed{\$36,300,000/\text{yr}}$

NaOH (if recycle is not included)

Amount required $= 626 \frac{\text{lbmol}}{\text{hr}} \left(40 \frac{\text{lbs}}{\text{lbmol}}\right) = 25,040 \text{ lbs/hr}$

Price of NaOH $= \$1.13/\text{lb}$ from Chemical Market Report April 14, 1997

Cost of NaOH $= 25,040 \frac{\text{lbs}}{\text{hr}} \left(\frac{\$1.13}{\text{lb}}\right) = \$28,295/\text{hr}$

Annual Cost $= \$28,295/\text{hr} \left(\frac{8766 \text{ hr}}{\text{yr}}\right) = \boxed{\$248,000,000}$

With recycle (Need to add $51 \frac{\text{lbmol}}{\text{hr}} = 2040 \frac{\text{lbs}}{\text{hr}}$)

$2040 \frac{\text{lbs}}{\text{hr}} \left(\frac{\$1.13}{\text{lb}}\right)\left(\frac{8766 \text{ hr}}{\text{yr}}\right) = \boxed{\$20,200,000/\text{yr}}$

Steam Requirements For Flashes

Heat Duty Required : 3.28×10^{8} BTU/hr

Heating Value of Steam : 754.9871 BTU/lb

Steam Required : 4.34×10^{5} lb/hr

Cost of Steam : \$3.25 / 1000 lb

\$ 3.25×10^{-3}/lb

$$434 \times 10^{5} \text{ lb/hr} \left(\frac{\$.00325}{\text{lb}} \right) = \$1410.50/\text{hr}$$

$$\text{Steam} \quad \frac{\$\,1410.50}{\text{hr}} \times \frac{8766 \text{ hrs}}{1 \text{ yr}} =$$

$$\text{Annual Cost for Steam} = \boxed{\$\,12,364,443}$$

Costs for Labor and Overhead

- Labor Costs are assumed to be 3% of fixed capital investment

- Fixed capital expense = $17,400,000

- Labor Cost = $14,400,000 (0.03)

$$\boxed{= \$522{,}000}$$

- Overhead Costs

- Overhead costs are assumed to be 50% of labor costs

- Overhead cost = ($522,000) (0.50)

$$\boxed{= \$261{,}000}$$

Cost of Waste Removal

- Low Level Waste
- \$10,000 / m^3 in glass
- Glass is 50% waste by weight

Annal Cost W/ Recycle

Volume of waste = 2.83 m^3/hr
(ASPEN stream 8LAW)

Cost of waste removal
$$2.83\ m^3/hr\left(\frac{\$10{,}000}{m^3}\right) = \$28{,}300/hr$$

Annual Cost
$$\$28{,}300/hr \times \frac{5766\ hr}{yr} = \boxed{\$248{,}000{,}000}$$

Electrochemical Cell costs
Equipment Cost = \$210,000

Annual Electricity Cost
$\boxed{\$12{,}000{,}000}$

Cost of NaOH for caustic
$\boxed{\$20{,}200{,}000}$

$\boxed{\text{Total Cost} = \$280{,}200{,}000}$

Cost without Recycle

Volume of waste = 22.43 m^3/hr
(ASPEN stream 6ELLtq)

Cost of waste removal
$$22.43\ m^3/hr\left(\frac{\$10{,}000}{m^3}\right) = \$224{,}300/hr$$

Annual Cost
$$\$224{,}300/hr\left(\frac{8766\ hr}{yr}\right) = \boxed{\$1{,}970{,}000{,}000}$$

Cost of buying fresh NaOH (caustic)
$\boxed{\$248{,}000{,}000}$

$\boxed{\text{Total Cost} = \$2{,}200{,}000{,}000}$

High-Level Waste Removal

- 500,000 m^3 incorporated into glass

- 16 m^3 per cannister, 730 cannisters per year

- $\frac{16 m^3}{\text{cannister}} \times \frac{730 \text{ cannisters}}{\text{yr}} = 11,680 \, m^3/\text{yr}$

- $\$500,000/m^3 \left(\frac{11,680 m^3}{\text{yr}} \right) = \boxed{\$5.84 \text{ billion}}$

Appendix E:

Other hand calculations

Supporting Calculations   Results - Conclusions

730 units/yr

177 - 1 million gallon Tanks → Maximum 177,000,000 gallons

Say Feed solution is 3 to 1; NaOH to waste

177,000,000 gallons (3) = 531,000,000 total gallons to process

$$\frac{531{,}000{,}000 \text{ gallons}}{25{,}000 \text{ gallons/hr}} \times \frac{1 \text{ day}}{24 \text{ hr}} \times \frac{1 \text{ yr}}{365 \text{ days}} = 2.4 \text{ yrs}$$

$$\text{Expected life of Project} = 2.5 \approx \boxed{3 \text{ years}}$$

High level waste volume at End of Project

$$3 \text{ yrs} \times \frac{730 \text{ units}}{1 \text{ yr}} \times \frac{16 \text{ m}^3}{\text{unit}} = \boxed{35{,}000 \text{ m}^3}$$

High-Level Waste Volume

Appendix E - UNIVERSITY HONORS PROGRAM
PLAN FOR INTERNATIONAL STUDY, WORK, AND TRAVEL

Name: Stephen R. Kennedy

College: Engineering Department: Chemical Engineering

Faculty Mentor: ______________________________

BRIEF DESCRIPTION OF PROPOSED INTERNATIONAL EXPERIENCE:

I will be working for Eastman Chemical Company in their Tech Services Division for Europe located in Kirkby, England.

I have discussed the above plan with this student.

Signed: Jack S. Watson faculty mentor

Date: 6-2-97

. . . .

ATTACH COPIES OF: Your travel schedule, addresses of institutions with which you will be affiliated, copies of relevant correspondence from host institutions.

I have met with this student and discussed the plan and attachments describing the proposed international study, work, and travel. The plan is well-conceived, and the student appears to be prepared adequately for this experience.

Signed: ______________________________ Date: ______________

Elizabeth Ousley, Advisor
Center for International Education
G102 Melrose Hall
phone: 974-3177
Email: EOUSLEY@UTK.EDU

Return this completed form to The University Honors Program, F101 Melrose Hall, 974-7875, at least 1 month prior to your departure.