



Project Summary

Nitrate Removal from Drinking Water in Glendale, Arizona

Dennis Clifford, Chieh-Chien Lin, Liou-Liang Horng, and Joan Boegel

A 15-month pilot-scale study of nitrate removal from drinking water by ion exchange (IX), reverse osmosis (RO), and electrodialysis (ED) was carried out in Glendale, Arizona, where 10 of 31 drinking water wells had been shut down because of excess nitrates. The raw water contained 18 to 25 mg/L $\text{NO}_3\text{-N}$, 43 mg/L sulfate, and 530 mg/L total dissolved solids (TDS). The experiments were carried out using the University of Houston/U.S. Environmental Protection Agency (UH/EPA) Mobile Drinking Water Treatment Research Facility (Mobile Inorganics Pilot Plant).

All three processes could readily reduce the nitrate level far below the maximum contaminant level (MCL) of 10 mg/L $\text{NO}_3\text{-N}$. However, anion exchange with chloride-form, strong-base resins was studied in the greatest detail because of the simplicity and low cost of this method. Based on these studies, the rough capital-plus-operating costs estimated for the production of 1000 gal (3.8 m^3) of 7.0 mg/L $\text{NO}_3\text{-N}$ product water in a 1.0-mgd (160- m^3/hr) plant with bypass blending are \$0.30 for IX, \$0.85 for ED, and \$1.00 for RO. IX, however, produces a high-chloride product water with about 500 mg/L TDS, whereas the product waters from RO or ED would contain only about 180 mg/L TDS. Also, the disposal of the IX wastewater containing excess NaCl, NaNO_3 , and Na_2SO_4 is potentially a bigger problem than disposal of RO or ED brine. None of the costs presented include the cost of disposal of the resulting wastewaters.

For the desalting processes, the polyamide RO membrane performed better than cellulose triacetate on the basis of nitrate rejection—94% compared with 76%, respectively. However,

ED performed better than either RO membrane by producing 96% nitrate rejection at 76% recovery.

Various flow rates, commercial resins, and sulfate concentrations were tried during the IX exhaustion tests. Of these, only the sulfate concentration was important: As it increased, the time to nitrate breakthrough was sharply reduced, and the size of the nitrate elution peak sharply increased. Nitrate always broke through before sulfate; but fortunately, nitrate breakthrough was usually signaled by a significant pH rise in the effluent as a result of simultaneous carbonate elution. When a completely regenerated resin was used, a run was complete when the effluent pH rose to become equal to the influent pH.

Regeneration of the nitrate-laden resin was studied extensively using complete regeneration, partial regeneration, and regenerant reuse. For complete regeneration, (i.e., the removal of more than 95% of the sorbed nitrate), the more dilute the regenerant, the more efficient it was. For example, 0.25 N NaCl required 3.0 equiv. Cl^- /equiv. resin, whereas 1.0 N NaCl required 180% of this value. Partial regeneration (i.e., the removal of 50% to 60% of the adsorbed nitrate followed by thorough mixing of the resin bed and high-nitrate-leakage exhaustion) consumed 37% less NaCl than the most efficient complete regeneration. Regenerant reuse and counterflow regeneration were not effective in these studies, but more research is warranted. IX regenerant brine disposal remains an unsolved problem that needs further study.

This Project Summary was developed by EPA's Water Engineering Research Laboratory, Cincinnati, OH, to

announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

In March 1981, the University of Houston, U.S. Environmental Protection Agency (UH/EPA) Mobile Drinking Water Treatment Research Facility was moved to Glendale, Arizona, a suburb of Phoenix. A 15-month project was initiated to study nitrate removal from well water containing 530 mg/L total dissolved solids (TDS). The specific objective of the Glendale, Arizona, work was to compare the following on the basis of technical feasibility and process economics: reverse osmosis (RO), electrodialysis (ED), and strong-base, chloride-form anion exchange for the removal of nitrate from Glendale's Well No. 1. For ion exchange (IX), the objectives were (a) to evaluate the effects of resin type, sulfate concentration, and flow rate on the exhaustion process, (b) to evaluate the effects of NaCl concentration, regeneration level, flow direction, and spent regenerant reuse on the regeneration process, (c) to optimize the design of a single-bed, chloride-IX process using complete regeneration, and (d) to optimize the design of a single-bed, chloride-IX process using partial regeneration.

Several previous studies in the United States and Europe have demonstrated the technical feasibility and low-cost of IX with chloride-form resins. Thus emphasis has been placed on the IX process, particularly in regard to detecting nitrate breakthrough and improving the efficiency of regeneration. Not included in this study, but nonetheless important, is establishing an environmentally sound means of disposal for the spent regenerant brine containing NaCl and NaNO₃.

Experimental Procedures

Water Analysis

Table 1 presents a complete analysis of the raw water from Glendale Well No. 1. The data represent a single sample taken during the first week of the study from a 120,000-gal (454 m³) elevated storage tank isolated from the distribution system. The NO₃-N concentration was later found to vary from 18.3 to 25.5 mg during the 15-month study. Standard Methods were used in most cases, but nitrate was determined using

Table 1. Raw Water Analysis for Glendale, Arizona, Well No. 1

Analysis	Concentration (mg/L)
pH	8.0
Conductivity (microSiemens)	820.
Silt density index (SDI)	5.6
Total dissolved solids	532.
Silica (SiO ₂)	23.1
Anions:	
Total alkalinity (as CaCO ₃)	102.
Nitrate-N	19.2
Fluoride	0.52
Chloride	122.
Sulfate	42.5
Bicarbonate	124.
Cations:	
Total hardness (as CaCO ₃)	198.
Calcium	43.0
Magnesium	28.0
Sodium (by difference)	76.0
Iron	0.26

a low-range Hach* field-test kit based on the cadmium reduction method. The accuracy of the Hach method was assured by frequent standardizations and was verified in EPA quality assurance surveys. The method of standard additions was occasionally used to ensure the accuracy of the analyses.

Desalting Tests

The RO system was made up of two single-pass, hollow-fiber modules—one with cellulose triacetate membranes (Dowex, RO-4K) and the other with polyamide membranes (DuPont B9). Only one single-pass module was operated during each test, which lasted at least 100 hr at 50% to 75% conversion to determine the rejection of the various ions in the feed. Before actual system operation, Dow or DuPont used their respective computer programs to determine the optimum pH, pretreatment requirements, and estimated percentage of rejections. These programs made use of the complete chemical analysis of the raw water including its temperature. Sulfuric acid (to reduce pH to 6.7) and sodium hexametaphosphate (SHMP, 10 mg/L) were added to the feed water as called for by the computer projections to prevent CaCO₃ scaling. The pretreated feedwater was filtered through a deep-bed filter containing AG media (granular aluminosilicate) and then

*Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

through a 10- μ cartridge filter before passage through the RO module. Because the water was stored in an outside tank and passed through outside lines in the Arizona sun, summer feed water temperatures reached 45°C. Hence the first RO test with the DuPont module was performed by passing the feedwater through an ice bath to reduce the feedwater temperature to 31 \pm 4°C. The Dow RO test was deferred until March, when the weather was cooler.

The ED tests were performed using an Ionics Aquamite I reversible current ED unit with internal brine recycling to achieve up to 80% recovery. To comply with the manufacturers' recommendation, the raw water (pH 8.1) was not pH-adjusted, nor was an antiscalant added. Pressurized raw water was passed through the standard granular activated carbon (GAC) filter and 10-micron cartridge filter before entering the ED stack, which contained 200 pairs of cation/anion membranes. The dechlorinating activated carbon filter was used, but it was unnecessary since the feedwater contained no chlorine.

IX Tests

The IX tests were performed using nonpretreated raw water in either 10-in.-diameter columns containing 47 L of resin or 8-in.-diameter columns containing 24.3 L resin. The resin bed depth was approximately 3 ft (0.91 m). Backwashing of the exhausted columns was accomplished using raw water and line pressure. Regenerations were performed using technical grade NaCl typically pumped downflow through the resin after lowering the water level in the columns to 1-in. above the resin. A few upflow (countercurrent) regenerations were done, but they were without much success because of the poor flow distribution. Waste brines from the IX, RO, and ED systems were discharged to the city sewer system.

Complete, partial, reuse, cocurrent, and countercurrent regenerations were studied in detail by monitoring 30 pilot-scale exhaustion/regeneration cycles. The efficiency of each regeneration was calculated in terms of the gram equivalents of chloride (equiv. Cl⁻) required to remove 1 gram equiv. of nitrate (equiv. NO₃⁻) from the raw water or spent resin. Various salt (NaCl) concentrations between 0.25 and 3.0 N were used for the regenerations.

Complete regenerations were achieved by pumping a considerable

excess of salt down (cocurrent) through the exhausted resin. To calculate the regeneration efficiency, the chloride required to elute approximately 95% of the nitrate during a complete regeneration was determined by integration of the area under the nitrate elution curve.

Each partial downflow regeneration was achieved by pumping a less-than-sufficient amount of salt down through the spent resin bed and following that with a displacement rinse using feedwater. Upflow partial regenerations were also studied.

Results

Desalting Results

The ED and RO test results are presented in Table 2, which shows that nitrate rejection by the ED membranes is highest at 96%. This fact and the minimum ED pretreatment requirements make ED the process of choice for achieving a combination of nitrate removal and desalting in the test water. Several additional factors should be kept in mind, however. The RO tests were made with single modules, but in actual practice, reject staging would be used to achieve greater water recovery with similar nitrate rejection. Also, it is doubtful that both acid and SHMP addition would be required for RO pretreatment. In fact, during the DuPont RO test, the acid addition pump failed and the feedwater pH was unadjusted for 4 days without apparent membrane fouling or change in nitrate rejection. A final plus for RO is that rapid advances are being made in RO membrane technology. A small community's choice of IX, RO, or ED will also be influenced by the simplicity of the equipment and its ability to withstand frequent start/stop cycles. Such design variables could not be evaluated in these 3- to 4-day continuous tests.

Overview of IX Exhaustion Results

Nineteen of the thirty IX exhaustion runs were monitored for nitrate breakthrough (see Table 3). Typical breakthrough curves for nitrate and other anions are presented in Figure 1, which shows that up to 400 bed volumes (BV) could be treated before nitrate broke through and reached the 10-mg/L MCL. Following breakthrough, a nitrate peak resulted in which the effluent concentration exceeded that of the influent by as much as 50%, depending on the sul-

Table 2. Desalting Results

Description	ED	Hollow Fiber Polyamide RO	Hollow Fiber Cellulose Triacetate RO
Nitrate rejection, %	96.	94.	76.
Sulfate rejection, %	97.	98.	98.
Chloride rejection, %	88.	95.	--
Bicarbonate rejection, %	93.	95.	95.
TDS rejection, %	92.	95.	83.
Feedwater pH	8.1	6.7-8.1	6.7
Product pH	5.9	5.6	6.0
SHMP antiscalant, mg/L	0.0	10.0	10.0
Product water flow, L/min	1.2	4.6	11.1
Operating pressure, psig	45.	350.	280.
Water recovery, %	76.	50.	74.
Maximum allowable temp., °C	45.	35.	30.
Operating temperature, °C	28-32	27-35	18-26

Table 3. Summary of IX Exhaustion Runs

Run No.	BV to NO ₃ -N MCL	Comments
1	422	Type 1 (ASB-1) resin, C ₀ * = 18.6 mg/L
2	410	Type 2 (ASB-2) resin, C ₀ = 21.5 mg/L
3	410	ASB-2, low flow rate, C ₀ = 22 mg/L
4	345	Isoporous Type 1 (Dowex 11), C ₀ = 25.5 mg/L
5	245	ASB-2, Feed SO ₄ ⁻ = 140 mg/L
6	177	ASB-2 Feed SO ₄ ⁻ = 310 mg/L
7-16		Exhaustion only for complete regeneration studies
17	346	Partial (1/1) regeneration [†] , leakage [§] = 11 mg/L
18	323	Partial (1/1) regeneration, leakage = 15 mg/L
19	320	Partial (0.64/1) regeneration, leakage > 25 mg/L
20	338	Partial (1/1) regeneration, leakage = 15 mg/L
21	322	Partial (1/1) regeneration, leakage = 16 mg/L
22	30	Upflow partial regeneration failed
23	0	Upflow partial regeneration failed
24	420	Complete regeneration, 0.25 N
25	410	Complete regeneration, 0.25 N
26	330	Partial (1/1) regeneration, leakage = 17 mg/L
27	340	Partial (1/1) regeneration, leakage = 16 mg/L
28	370	Partial (2/1) regeneration, leakage = 12 mg/L
30	115	Partial (1/1) regeneration, feed SO ₄ ⁻ = 404 mg/L

*C₀ = concentration of NO₃-N in feedwater; mg/L N = mg/L NO₃-N.

[†] = Partial (1/1) regeneration = partial regeneration with 1 equiv. Cl⁻/equiv. resin.

[§] = Leakage values are NO₃-N concentrations at approximately 10 bed volumes after start of run.

fate concentration. Also evident in Figure 1 is the fact that when the effluent pH rose to become equal to the influent pH, nitrate was beginning to breakthrough. Subsequent analysis showed that this pH increase was due to the simultaneous elution of carbonate with nitrate.

During the course of the 28 exhaustion/regeneration tests, the nitrate capacity of the type 2 resin used did not decrease measurably. This long-term stability may be expected for any typical styrene-divinylbenzene, strong-base anion resin used on the Glendale water or any other non-fouling groundwater.

Effect of Resin-Type

Based on prior laboratory studies with simulated nitrate-contaminated groundwaters, little variation in nitrate removal performance was expected as a result of the type of strong-based resin used. This prediction was verified by comparing the performances of three different styrene divinyl-benzene resins: Ionac ASB-1 (a type 1 gel), Ionac ASB-2 (a type 2 gel), and Dowex 11 (a

type 1 isoporous resin). Resins with higher capacity produced longer runs to nitrate breakthrough, but after capacity was taken into account, no significant differences existed in exhaustion performances as a result of the kind of resin used. The type 2 gel resin was used for the subsequent 25 exhaustion/regeneration runs because of its high capacity and slightly greater preference for nitrate compared with chloride.

Effect of Sulfate Concentration

Increasing the sulfate concentration of the Glendale groundwater from 42.5 to 310 mg/L by spiking shortened the run length to nitrate breakthrough from 400 down to 180 BV. The earlier nitrate breakthrough was due to two factors—the increasing concentration of ions in the spiked feedwater and the resin's tendency to prefer sulfate to nitrate in dilute solution. However, in one run the sulfate/nitrate preference was inverted to favor nitrate when the ionic strength was increased to the point (0.030 N) where sulfate was less preferred than nitrate and broke through earlier. This

run demonstrated the well-known concept of selectivity reversal, in which divalent ions become less preferred than monovalent ions as ionic strength increases.

IX Regeneration Results

Sulfate Elution

Regardless of the regeneration method used, sulfate was much easier to strip from the resin than nitrate. This effect was evident in all the regeneration elution curves, which are typified by Figure 2. The most preferred ion during exhaustion (divalent sulfate) is the first to be stripped from the resin during regeneration because of the selectivity reversal that occurs in high ionic strength salt solution.

Complete Regenerations

Although the elution of sulfate is considerably easier than that of nitrate, the elution of both anions becomes much less efficient as the regenerant NaCl concentration is increased (Figure 3). Two reasons are proposed for the ineffi-

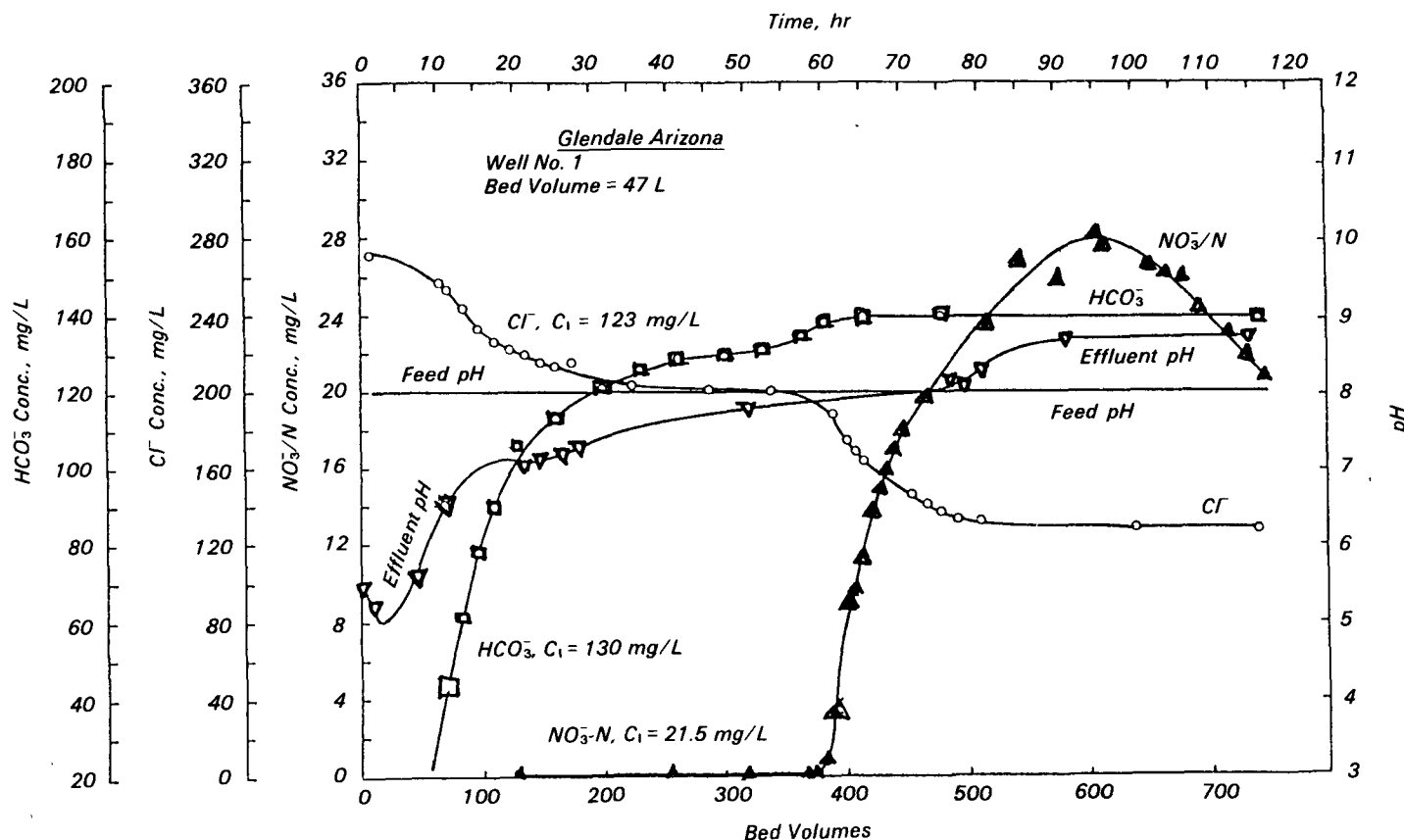


Figure 1. Breakthrough curves for nitrate and other anions following complete regeneration of strong-base (ASB-2) resin in the chloride form.

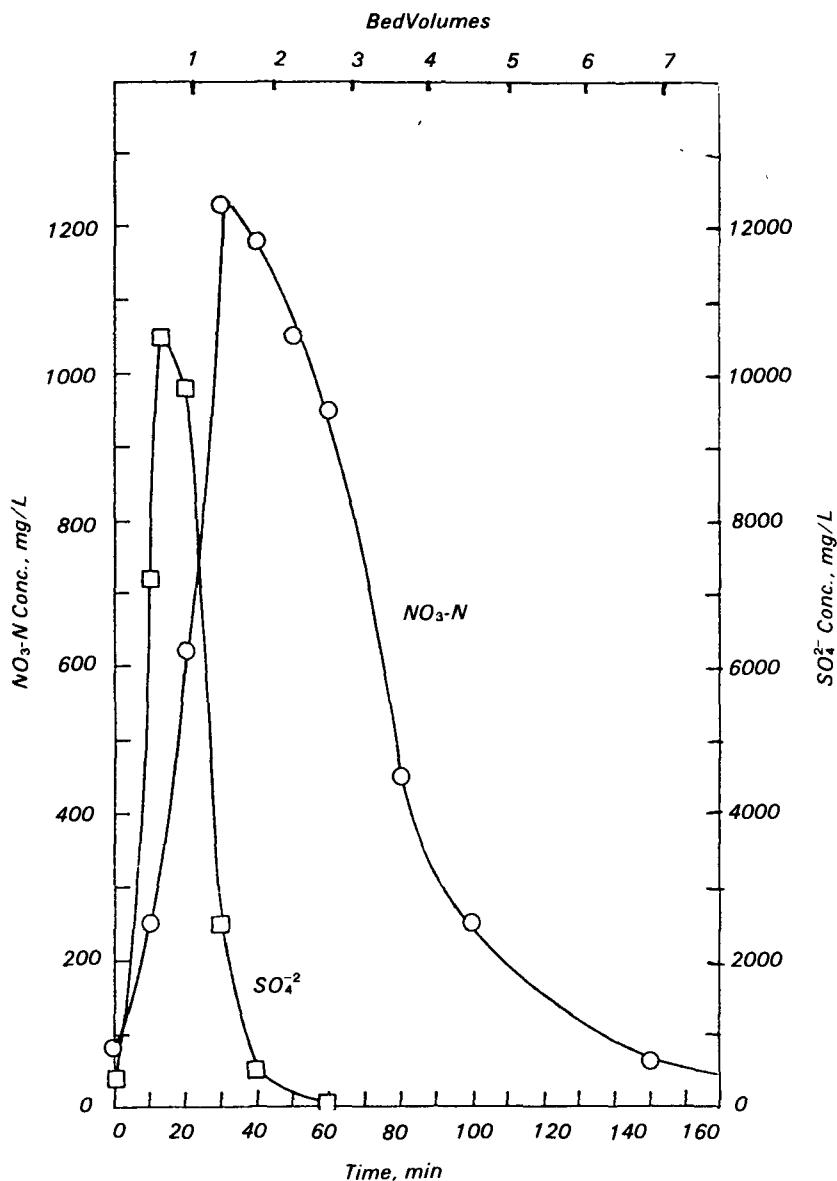


Figure 2. Typical elution of nitrate and sulfate from ASB-2 resin during a complete regeneration with 0.5 N NaCl in a cocurrent fashion.

ciency of concentrated regenerant solutions: (1) inefficient mass transfer at high concentration, and (2) the tendency for the resin to release divalent ions like sulfate at increasing ionic strength. Although dilute regenerants more efficiently use chloride to elute nitrate, they yield greater wastewater volume and increase the required regeneration time.

Reuse of Regenerant

Attempts were made to conserve salt by reusing the spent regenerant during

a roughing regeneration before a second polishing regeneration with fresh NaCl. Dilute (0.5 N) spent regenerants reused in this manner did elute 20% to 50% of the nitrate on the resin, but the subsequent polishing regeneration with fresh NaCl was very inefficient. In fact, it took as long for the polishing regenerant to elute the remaining nitrate from the column as a single-step regeneration would have taken. Thus no net salt savings were realized when reusing spent regenerant to achieve complete regeneration. Partial regeneration was

not attempted using spent brine, but it probably would have been more successful and it deserves further study.

Partial Regeneration

Prior laboratory studies indicated that the amount of salt required for regeneration is substantially reduced when the resin is only partially (e.g., 50%) regenerated. This regeneration procedure is efficient because it avoids the inefficient tail of the nitrate elution curve (see Figure 2). The disadvantage of partial regeneration is that it yields significant and potentially excessive nitrate leakage on subsequent exhaustion of the nitrate-contaminated resin. The partial regeneration experiments in Glendale produced four significant conclusions: (1) Complete mixing of the resin bed is required to avoid excessive nitrate leaking following cocurrent regeneration, (2) counterflow partial regeneration is not nearly as efficient as cocurrent, (3) the amount of salt required is significantly greater than that calculated using another published methodology, and (4) unlike complete regeneration, there is no significant difference in the efficiency of partial regeneration with salt concentrations in the range of 0.25 to 1.0 N (1.5% to 6%) NaCl.

Partial Regeneration Level

Partial regeneration levels from 0.64 to 2.0 equiv. Cl⁻/equiv. resin were tested in Glendale. Figure 4 compares the Glendale nitrate breakthrough curves following complete and partial regenerations with 1.0 N salt. Clearly, a regeneration level of 0.64 equiv. of salt/equiv. resin is insufficient to produce a reasonable run length, but a regeneration level of 1.0 or higher may be acceptable if the excessive nitrate leakage is disregarded during the initial 75 BV of effluent.

Extensive backwashing of the partially regenerated bed was used in an attempt to eliminate the initial high-nitrate leakage. This step was not successful, however (Figure 4). The successful elimination of excessive leakage is apparent in Figure 5, where the performance of a partially regenerated but unmixed bed is compared with that of a well-mixed homogeneous bed. The experiments for eliminations of leakage (Figure 6) were performed in small laboratory columns using simulated Glendale water. Following exhaustion and partial regeneration with 1.0 equiv. Cl⁻/equiv. resin, the unmixed bed was simply exhausted again. By contrast, the

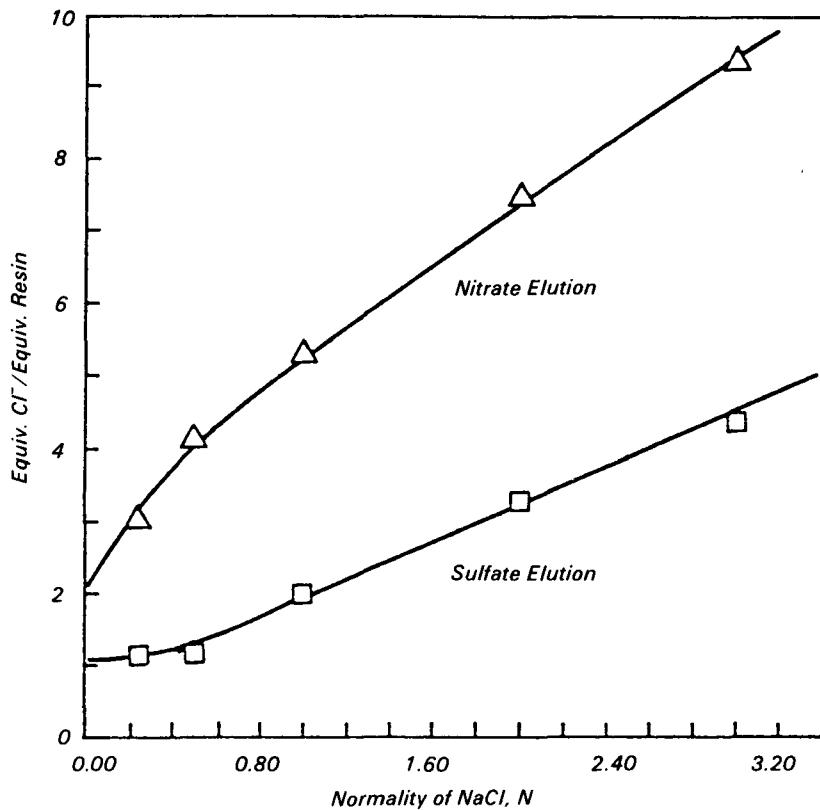


Figure 3. Inefficiency of nitrate and sulfate elution from exhausted ASB-2 resin as a function of regenerant concentration.

resin in the other column was removed, manually mixed, and placed back into the column before the exhaustion run shown. Thorough mixing clearly eliminates the excess nitrate leakage at the beginning of an exhaustion following a cocurrent (downflow) partial regeneration. No amount of conventional backwashing will achieve this mixing because the resin bed remains classified with the largest resin beads on top and the smallest on the bottom.

Comparison of Complete and Partial Regeneration

After it was confirmed that the early excess nitrate leakage could be eliminated by efficiently mixing the resin following a partial regeneration, the method became quite attractive. The experimental data for 1.0 equiv. Cl^- /equiv. resin showed the partial regeneration to be more efficient than complete regeneration, even with the dilute 0.25 N regenerant. For this reason, a detailed comparison was made of the methods. Although 1.0 equiv. Cl^- /equiv. resin was the partial regeneration level used in most of the pilot runs, a careful examination of the nitrate effluent histories led to the conclusion that slightly more chloride would be needed to keep nitrate under the maximum desirable

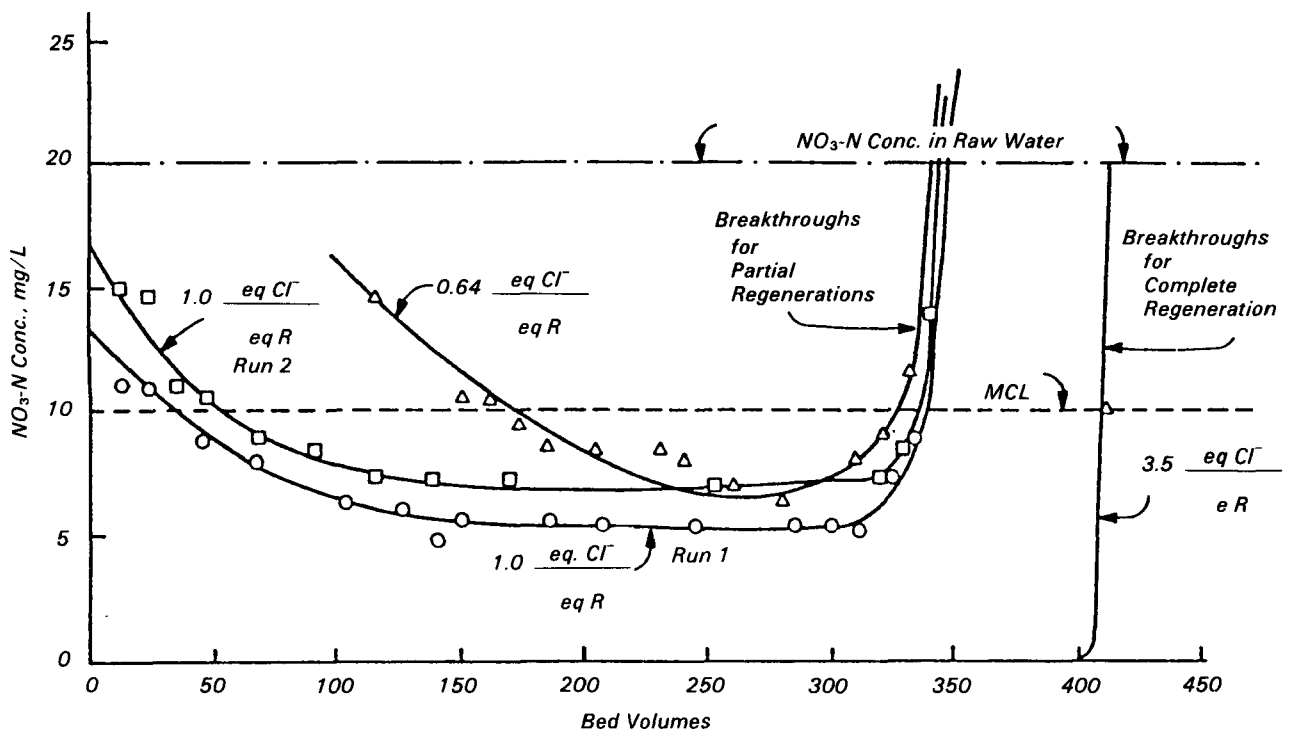


Figure 4. Nitrate breakthrough curves for completely and partially regenerated beds of ASB-2 resin.

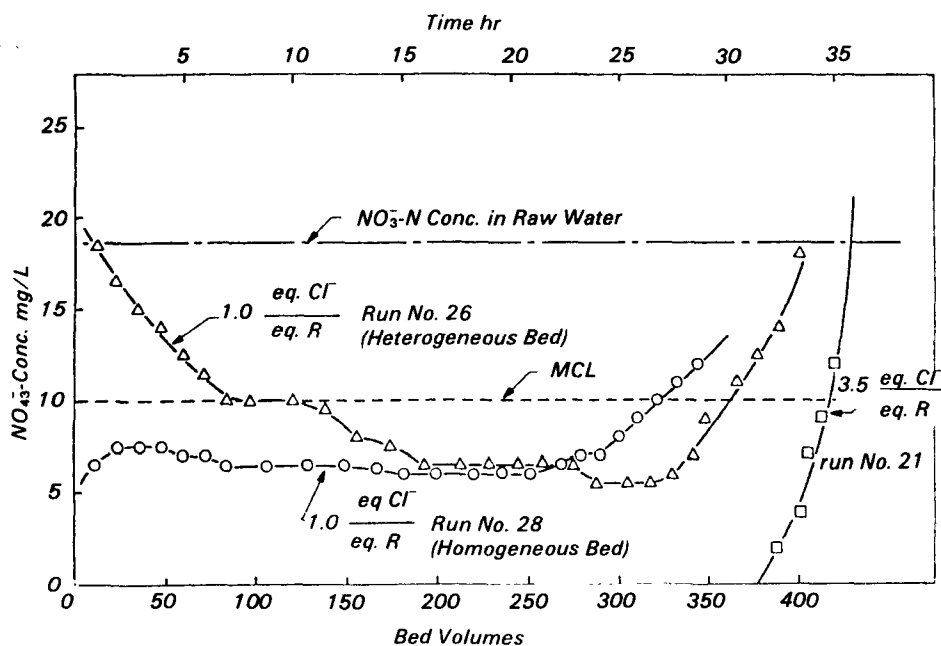


Figure 5. Nitrate breakthrough curves following complete regeneration (3.5 equiv. Cl^- /equiv. resin) and partial regeneration (1.0 equiv. Cl^- /equiv. resin) with and without resin mixing. Column feed is simulated Glendale water. Resin is ASB-2.

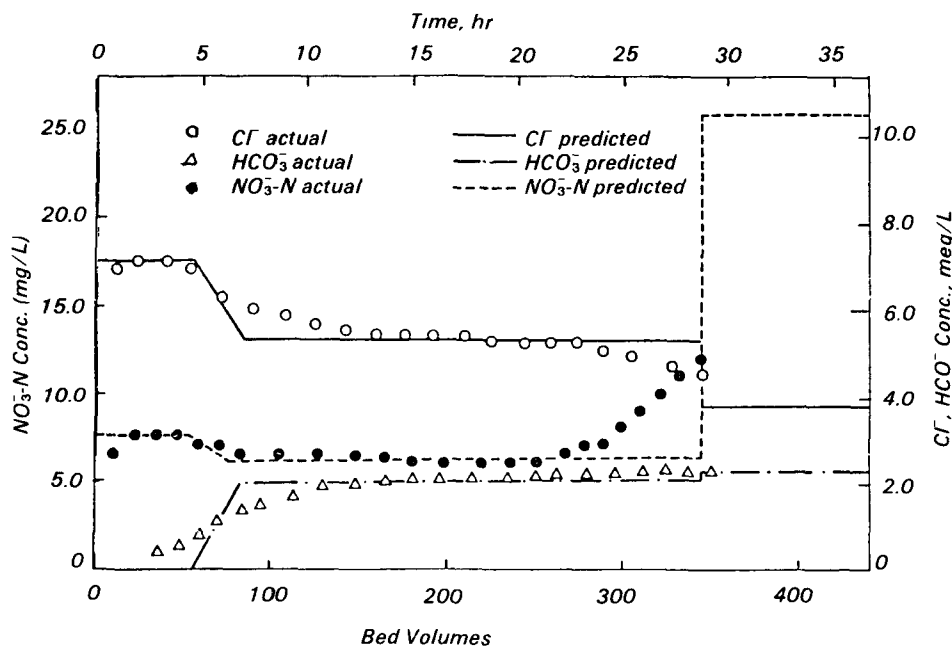


Figure 6. A comparison of predicted and actual concentration histories for ions emanating from a partially regenerated bed receiving simulated Glendale water feed. Resin is ASB-2.

leakage of 7.0 mg/L $\text{NO}_3\text{-N}$. Estimates indicated that a level of 1.2 equiv. Cl^- /equiv. of spent resin would consistently produce 330 BV of acceptable effluent. Thus this value was used in the com-

parison that produced the following advantages of partial regeneration: (1) it is more efficient in terms of equiv. Cl^- required/equiv. nitrate removed (4.84 compared with 6.65); (2) it produces

much less wastewater (1.1% compared with 3.0%); and (3) for a 1.0-mgd ($3.78 \times 10^6\text{-L/day}$) plant, it uses 890 lb less salt/day (404 kg/day) (i.e., 37%) for regeneration. Finally, although partial regeneration requires a complete mixing of resin, it eliminates the need for bypass blending with its attendant complexities.

Treatment Cost Comparison

Low TDS groundwaters (e.g., 500 mg/L) are logical candidates for IX treatment to remove nitrate, particularly if sulfate concentration is not excessive (less than 300 mg/L). However, for nitrate removal from waters containing more than 1000 mg/L TDS, the membrane processes may be the only reasonable alternatives. In this case, ED would tend to be preferred over RO. Rough cost estimates for these processes are listed in Table 4; they include amortized capital, labor, chemicals, resin and membrane replacement, and energy. None of the costs presented include the cost of disposal of resulting wastewaters.

Conclusions

Pilot studies at Glendale, Arizona, have demonstrated the technical feasibility of three processes—RO, ED, and IX—for reducing nitrate concentration of well water from the 20-mg/L $\text{NO}_3\text{-N}$ range to well below the 10-mg/L MCL.

If it is assumed that the pilot-scale findings can be put into commercial practice, the IX process is significantly cheaper than either RO or ED when wastewater disposal costs are not considered.

With the use of commercially available strong-base anion resin, about 410 BV of Glendale water could be treated for complete nitrate removal before nitrate breakthrough, which was signaled by a significant pH change as a result of carbonate elution from the resin.

When the columns were run beyond nitrate breakthrough, chromatographic elution of nitrate by the most preferred ion (sulfate) was always observed. The nitrate peak typically reached 125% of the influent nitrate concentration. However, when the feed was spiked with sulfate, nitrate peaks were observed to approach 300% of the influent concentration. Other studies have shown that special nitrate-selective IX resins can eliminate this peaking problem.

The sulfate concentration of the feedwater was much more important in determining the BV to nitrate break-

Table 4. Approximate Costs for Nitrate Removal by IX, ED, and RO*

Process	\$/1000 gal	\$/m ³	Product Water TDS (mg/L)
Single-bed chlorine-form IX	0.3	0.08	500
ED	0.85	0.22	185
RO (aramid membrane)	1.00	0.26	185

*Assumptions: Feedwater = 500 mg/L TDS, 21 mg/L NO₃-N, 50 mg/L SO₄⁻. Bypass flow = 30% of blended product flow. Desalting process = 90% overall TDS rejection. NO₃-N = 7 mg/L in blended product.

through than was the flow rate or kind of commercial resin used. When sulfate concentration was increased from 43 to 310 mg/L, the BV to nitrate breakthrough decreased from 410 to 180.

Cocurrent complete regeneration (i.e., the removal of more than 95% of the sorbed nitrate) required 3 to 9 times the stoichiometric amount of chloride, with dilute regenerants being far more efficient than concentrated ones.

Cocurrent partial regeneration (i.e., the removal of 50% to 60% of the sorbed nitrate) required 1.0 to 1.2 times the stoichiometric amount of chloride and was not influenced by the regenerant concentration. Complete mixing of the resin bed is mandatory following partial regeneration to reduce the NO₃-N leakage to about 7 mg/L.

A comparison of the optimum complete and partial regeneration indicates that partial regeneration consumes 37% less salt and is therefore preferred if significant nitrate leakage can be tolerated.

Recommendations

Laboratory- and pilot-scale studies should be carried out using the recently developed, nitrate-selective, styrene-

DVB strong-base anion resins. The latter are based on greater charge separation distance to reduce the sulfate preference and greater hydrophobicity to increase the nitrate affinity.

Further research and development should be carried out on regeneration

efficiency, spent regenerant disposal, and nitrate breakthrough detection—the key issues in nitrate removal by chloride IX, an effective and relatively inexpensive process.

Partial regeneration should be further studied on a laboratory scale using background waters containing various levels of sulfate, bicarbonate, and chloride. The effects of sulfate concentration on NaCl efficiency and pH detection of nitrate breakthrough should be examined in these tests using conventional and nitrate-selective resins.

The full report was submitted in fulfillment of Cooperative Agreement No. CR-807939 by the University of Houston-University Park under the sponsorship of the U.S. Environmental Protection Agency.

Dennis Clifford, Chieh-Chien Lin, Liou-Liang Horng, and Joan Boegel are with the University of Houston-University Park, Houston, TX 77004.

Thomas Sorg is the EPA Project Officer (see below).

The complete report, entitled "Nitrate Removal from Drinking Water in Glendale, Arizona," (Order No. PB 87-129 284/AS; Cost: \$18.95, subject to change) will be available only from:

*National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650*

*The EPA Project Officer can be contacted at:
Water Engineering Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268*

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

BULK RATE
POSTAGE & FEES PAID
EPA
PERMIT No G-35

Official Business
Penalty for Private Use \$300
EPA/600/S2-86/107

0000329 PS
U S ENVIR PROTECTION AGENCY
REGION 5 LIBRARY
230 S DEARBORN STREET
CHICAGO IL 60604