NITRATE REMOVAL BY ION EXCHANGE

PRESENTED AT THE NJ SECTION OF AMERICAN WATER WORKS
ASSOCIATION ON MARCH 25, 1992

The presence of nitrates in either ground or surface water can cause a serious problem in young infants. The nitrates, which are reduced or converted to nitrites, combine with hemoglobin in the blood, making it impossible for the hemoglobin to carry oxygen. Infants are then vulnerable to methemoglobinemia, or the blue-baby syndrome, which is associated with oxygen starvation. The National Interim Primary Drinking Water Regulation (MCL) for nitrate-N is 10 mg/L, which is equivalent to 45 mg/L nitrates.

Origin of Nitrates in Water

The main sources by which nitrates enter the sources of public water supplies are rainfall (NOX), sewage, industrial effluents, and leachables from agricultural soils. Two of our nitrate removal systems are installed in plants treating surface waters, and four are treating groundwaters. They are located in Pennsylvania, Massachusetts, Long Island, Delaware, Ohio, Iowa, and Wisconsin; which shows that nitrate contamination is spread over a wide area.

Methods of Reducing Nitrates

The simplest and most economical method of reducing nitrates is to blend water of high nitrate concentration with another supply of lower concentration, if feasible, to meet the 10 mg/L nitrate-N limit.

Biological denitrification takes advantage of naturally occurring microorganisms to reduce the nitrates to nitrogen. This method, however, has not been found to be feasible so far.

Nitrate removal by reverse osmosis and electrodialysis may be practical for high TDS waters, say over 500-700 mg/L, to produce a water that meets both the nitrate and the National Secondary Drinking Water Regulations for sulfates, chlorides, and total dissolved solids.

Nitrate removal by ion exchange is the most widely used method for nitrate reduction. It is a comparatively simple process, easily adapted to automation, and requires a minimum of skilled attention.

The equipment required for nitrate removal is very similar to that used in water softening by ion exchange, including regeneration with salt. The only difference is that anion resin is used in place of cation exchange resin and that anions are exchanged instead of cations.

There are two types of ion exchange system designs: cocurrent and countercurrent respectively.

In cocurrent or conventional regeneration, both the dilute brine (6-10%) and service flow are in the same direction, or downflow.

In countercurrent regeneration, the brine is injected upflow and the service flow is downflow. With countercurrent regeneration, the resin in the service end of the exchanger or at the bottom, is almost totally regenerated. Therefore, the leakage of nitrates would be very low, even at low regeneration levels, and would not be affected by variations of nitrate concentration in the water being treated.

Resin Selectivity

Before discussing the types of nitrate removal systems, we should examine the selectivity of the various ions in the ion exchange reaction, Figure 1.

The most common anions in water are bicarbonates (alkalinity), chlorides, sulfates, and nitrates. In the ion exchange process using conventional strong-base anion resin, the alkalinity, nitrates, and sulfates are all exchanged for chlorides at the beginning of the service run. After approximately one-fourth to one-third of the run, the alkalinity begins to increase until it reaches and slightly exceeds the raw water alkalinity, and continues to do so until the end of the run. From 75% to 98% of the nitrates are removed during the service or exhaustion run, depending upon the design of the ion exchange system (cocurrent vs. countercurrent), and the regeneration level; usually 7-1/2 lb/cu.ft. to 15 lb/cu.ft. All the sulfates are removed during the exhausion cycle. The chlorides are not involved in the ion exchange process, although we have found that chlorides in excess of 50 mg/L slightly depress the exchange capacity. In line with this, the attached expected analysis sheet shows the chemical characteristics of the raw water, ion exchanger effluents during an exhaustion run, and the blended water quality (Figure 2).

Nitrate Leakage and Exchange Capacity

Figure 3 shows the nitrate leakage at various regeneration levels for both cocurrently and countercurrently regenerated systems.

With the cocurrent systems, higher quantities of brine (15 lb/cu.ft.), are required in order to minimize the nitrate leakage, especially at the beginning of the service run. With higher leakages, less raw water can be blended with the exchanger effluent in order to produce less than 10 mg/L nitrate-N in the blended effluent.

For example, at a 10 lb./cu.ft. salt regeneration level, the leakage is 21%. At the 15 lb./cu.ft. salt regeneration level, the nitrate leakage is 7%. Interestingly with the countercurrent regenerated systems, the nitrate leakage at only 7 lb./cu.ft. of salt is 3%.

With the countercurrent regenerated systems, much lower regeneration levels can be used because the nitrate leakage is always low, regardless of the amount of brine applied, and consequently, it is more efficient because more raw water can be blended with the exchanger effluent.

Figure 4 shows the exchange capacity at various regeneration levels for both the countercurrent and cocurrent regenerated systems.

As with most ion exchange processes, the higher the regeneration level, the lower the chemical efficiency. For nitrate removal cocurrent systems, the suggested rating is 15 lbs. of salt/cu.ft. for an exchange capacity of 20 kgr/cu.ft. or 0.75 lb. of salt/kgr exchange capacity. For countercurrent regenerated systems, the suggested rating is 7.5 lbs. of salt/cu.ft. for an exchange capacity of 15 kgr/cu.ft., or a brine efficiency of 0.50 lb. of salt/kgr ion exchange capacity.

Therefore, not only is the countercurrent regenerated system much more efficient, the leakages are always very low, which permits the blending of more raw water to the ion exchanger treated water.

Equipment Design

Generally equipment consists of a closed pressure vessel containing a bed of anion exchange resin supported by a graded gravel bed.

Figure 7 shows the internal distributors for a countercurrent regenerated system. All the distributors are constructed of Schedule 80 PVC except the regenerant collector, which is constructed of Schedule 40, 316 stainless steel.

Figure 8 shows a flow diagram illustrating the basic equipment components covering a complete system operating in the countercurrent regeneration mode.

Additional information and details are included in the H&T nitrate removal bulletin.

Regeneration Sequence

Figure 5 shows the regeneration sequence for both types of systems.

The countercurrent exchangers are backwashed approximately every 20 or so regenerations in order to minimize bed disruption. The interface collector is backwashed every time to remove any suspended solids in the upper portion of the resin bed.

With the countercurrent system, the brine and slow rinse are upflow, accompanied by downflow blocking water at the same rate. This does not allow resin movement during the regeneration step, which is necessary for maximum efficiency. Both the upflow brine injection and slow rinse steps use treated or nitrate-free water.

The last step, or fast rinse, is very short, just to insure that all the traces of brine have been rinsed free.

The cocurrent regenerated ion exchanger regeneration sequence has the standard backwash and brine injection, slow rinse, and fast rinse, all downflow. Slightly more water is required for the regeneration cycle with the cocurrent system because of the brine dilution which occurs in the freeboard area of the tank and which requires longer rinsing to remove the final traces of brine.

The **Comparison of Nitrate Removal Systems** (Figure 6) shows a comparison of both cocurrent and countercurrent regenerated nitrate removal systems on a capacity of 1.6 MGD, and treating a water containing 15 mg/L nitrate-N and 34 mg/L sulfate.

System A, countercurrently regenerated, and System C, cocurrently regenerated, are designed to produce the same capacity and reduce the nitrate-N to 5 mg/L. For additional comparison System B is a countercurrently regenerated system, but the nitrates are reduced to only 7.5 mg/L, which is still well below the 10 mg/L MCL.

This chart shows that with System A, less water can be treated or more water bypassed to achieve the 5 mg/L nitrate- N level in the blended water. In addition, the salt consumption for System A is 2,894 lbs./day in contrast to 4,728 lbs./day with System C. This will result in a yearly savings of some $27,000 based on continuous operation and a salt cost of $0.04/lb. Other advantages of System A are the lower waste water volume and the total dissolved solids in the waste water.

The equipment cost for System A would be approximately 5-10% higher than System C because more resin is needed due to the lower regeneration level (7.5 lb./cu.ft. vs 15 lb./cu.ft.) and consequently slightly lower exchange capacity. Also, the system modifications for countercurrent regeneration are slightly more expensive.

Waste Disposal

The chemical composition of the waste is shown on Figure 5. As expected, there is a much larger quantity of excess salt in the cocurrent regenerated system. This is also reflected in the total dissolved solids of the overall waste shown in Figure 6.

The most common methods of disposal of the waste are:

a. Sending is to a sanitary sewer system with or without equalization.

b. Collecting the concentrated portion of the wastes for off-site disposal.

c. Sending the wastes to an evaporation pond, location and climate permitting.

d. Collecting, equalizing, and gradually dispersing it to a surface supply, if regulations permit.

Summarizing, ion exchange is a viable method for the removal of nitrates from most groundwater or surface supplies. The countercurrent regeneration method is superior to the cocurrent method in that:

a. It is much more efficient.

b. Nitrate-N leakage is low during the entire run, usually averaging less than 0.5 mg/L.

c. There is less total dissolved solids in the waste water because regeneration levels are lower.
d. Nitrate leakage remains low regardless of variation in nitrate concentrations in the raw water.

FIGURE 1

TYPICAL EXHAUSTION RUN CHARACTERISTICS

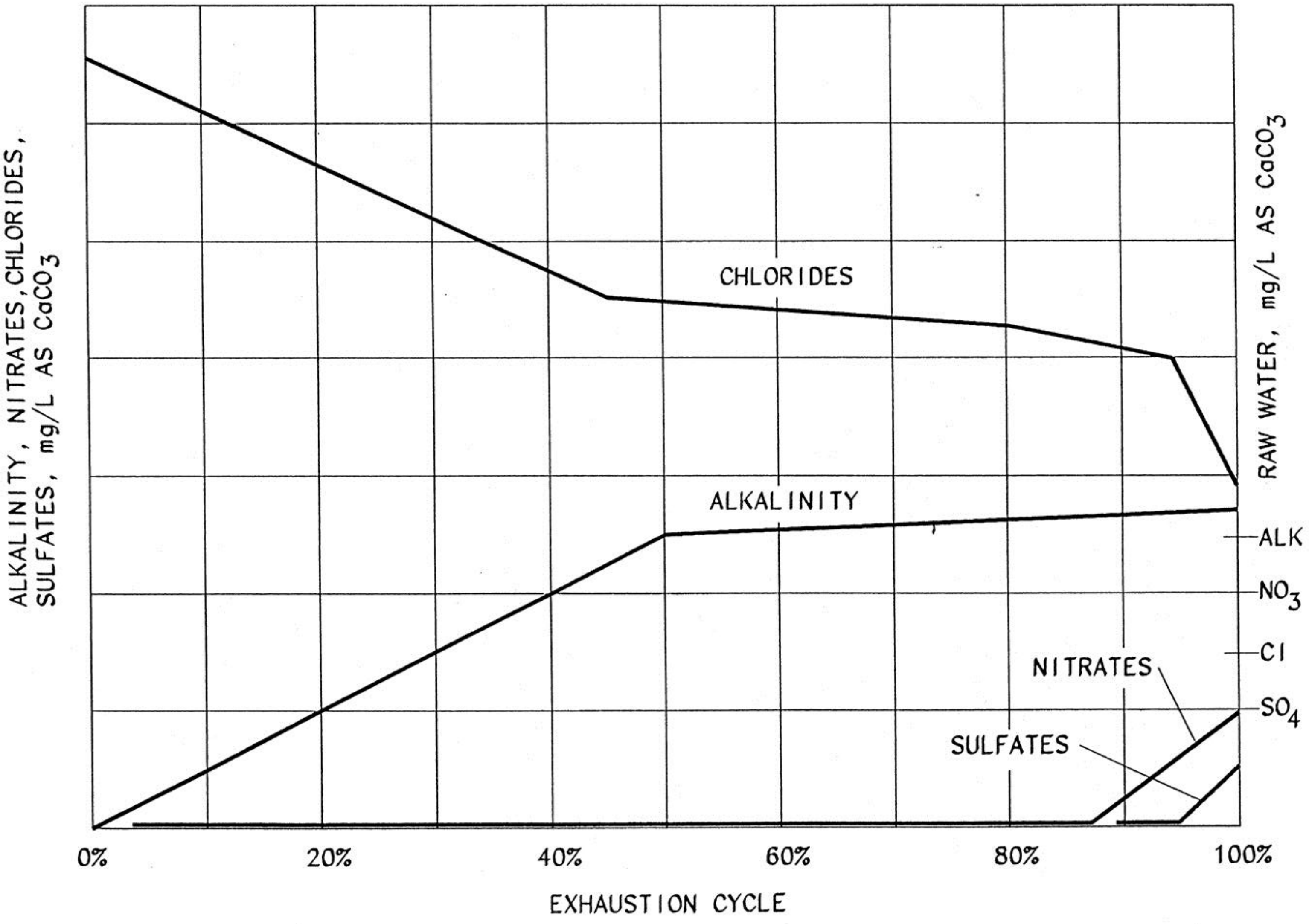

FIGURE 1

FIGURE 2

Expected Analysis After Treatment

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Manufacturers of Water Treating Plants

CLAYTON, NEW JERSEY

FIGURE 2

For: Countercurrent Regenerated System

Column #1 See Remarks below Column #4

Column #2 Column #5

Column #3 Column #6

CONSTITUENTS		1	2	3	4	5	6
	P.P.M.						
pH							
Turbidity	SiO_2						
Color							
Chlorine	Cl						
Cations	$CaCO_3$						
Ca	$CaCO_3$	300	300	300	300	300	300
Mg	$CaCO_3$	27	27	27	27	27	27
Na (calculated)	$CaCO_3$	25	25	25	25	25	25
H^+ (calculated)	$CaCO_3$						
Total Cations	$CaCO_3$	352	352	352	352	352	352
Anions	$CaCO_3$						
Hydroxide	$CaCO_3$						
Carbonates	$CaCO_3$						
Bicarbonates	$CaCO_3$	228	3	200	260	154	177
Sulfates	$CaCO_3$	35	0	0	0	0	10
Chlorides	$CaCO_3$	35	347	150	90	196	146
Nitrates	$CaCO_3$	54	2	2	2	2	19
Total Anions	$CaCO_3$	352	352	352	352	352	352
Total Hardness	$CaCO_3$						
M. O. Alk	$CaCO_3$						
Iron Total	Fe						
Manganese	Mn						
Silica	SiO_2						
Nitrates	N	15	<0.5	<0.5	<0.5	<0.5	5

CHEMICALS REQUIRED PER 1000 GALLONS AND APPROXIMATE OPERATING COST

CHEMICAL	LB./1000	CENTS/LB.	CENTS/1000. GAL

Remarks: Column #1: Raw
Column #2: Unit effl., beginning of run
Column #3: Unit effl., middle of run
Column #4: Unit effl., end of run
Column #5: Unit effl., ave. blend of 3 units
Column #6: Final blended effl.

FIGURE 3

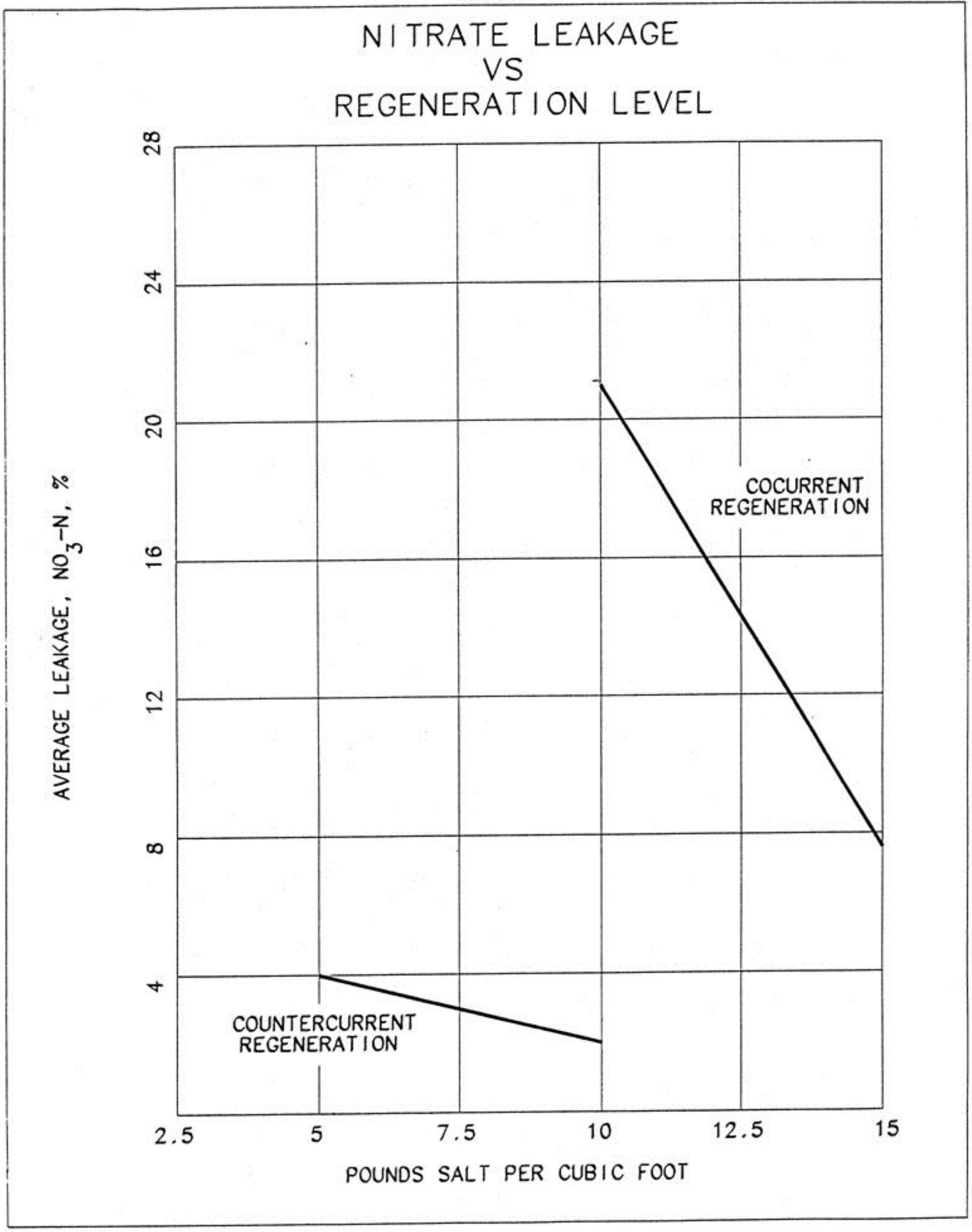
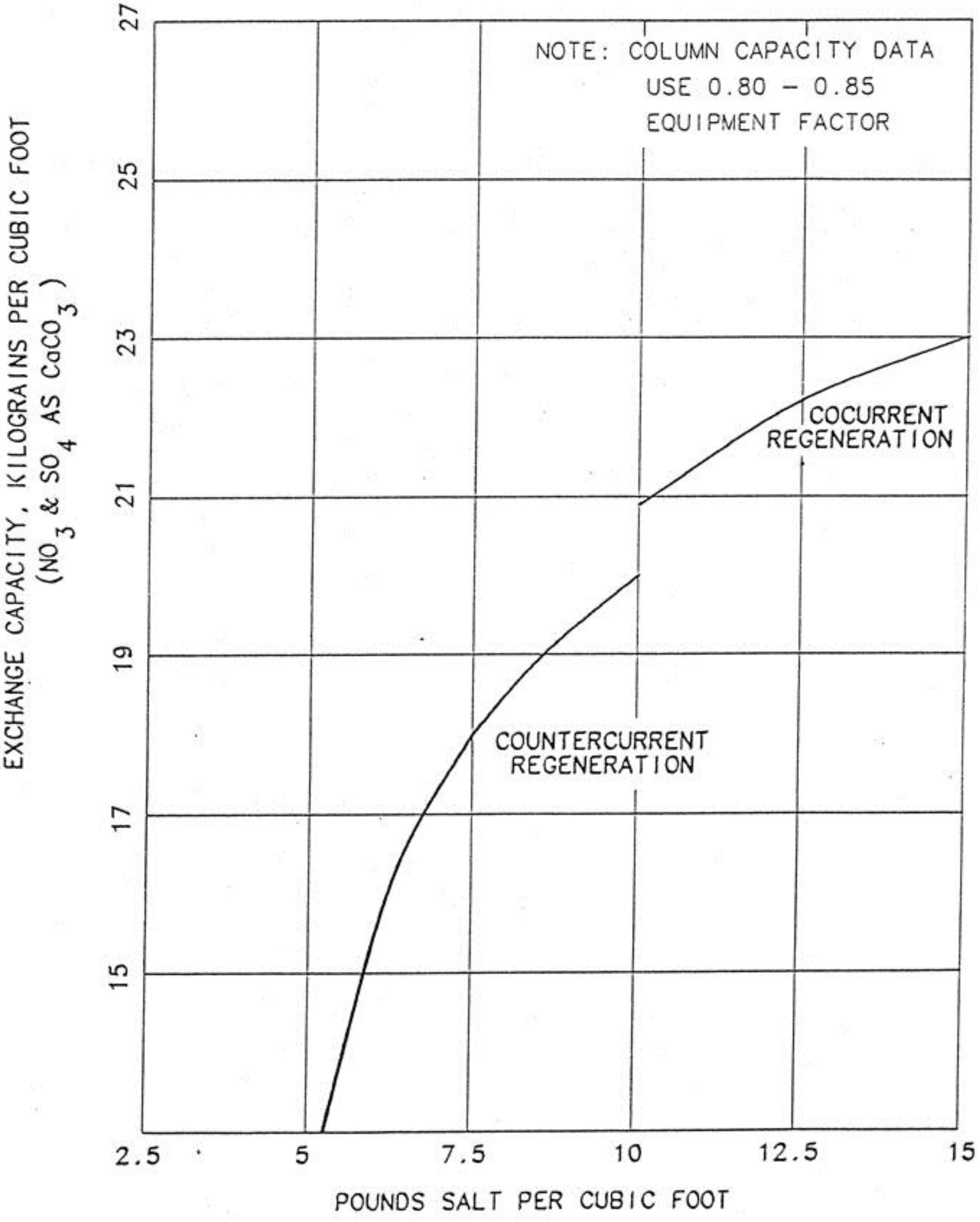

NITRATE LEAKAGE
VS
REGENERATION LEVEL
AVERAGE LEAKAGE, NO_3-N, %
28
24
20
16
12
8
4
2.5
5
7.5
10
12.5
15
POUNDS SALT PER CUBIC FOOT
COCURRENT REGENERATION
COUNTERCURRENT REGENERATION

FIGURE 4

REGENERATION LEVEL
VS
EXCHANGE CAPACITY



NOTE: COLUMN CAPACITY DATA USE 0.80 – 0.85 EQUIPMENT FACTOR

FIGURE 5

COUNTERCURRENT REGENERATION SEQUENCE (SYSTEM A)

	Function	Gallons
1.	Service	-
2.	20th regeneration backwash	(1,275)
3.	Regeneration collector backwash	1,000
4.	Brine injection	1,500 1,500
5.	Slow rinse	1,600 1,440
6.	Fast rinse	1,000
		Total gallons – 8,040

COCURRENT REGENERATION SEQUENCE (SYSTEM C)

	Function	Gallons
1.	Service	-
2.	Backwash	1,275
3.	Brine injection	1,500
4.	Slow rinse	540
5.	Fast rinse	5,800
		Total gallons – 9,115

REGENERATION WASTE CHARACTERISTICS

	System A	System C
Sodium chloride (NaCl), lbs	600	1,225
Sodium sulfate (Na_2SO_4), lbs	170	185
Sodium nitrqate ($NaNO_3$), lbs	315	340
Sodium bicarbonate ($NaHCO_3$), lbs	170	185

FIGURE 6

COMPARISON OF NITRATE REMOVAL SYSTEMS

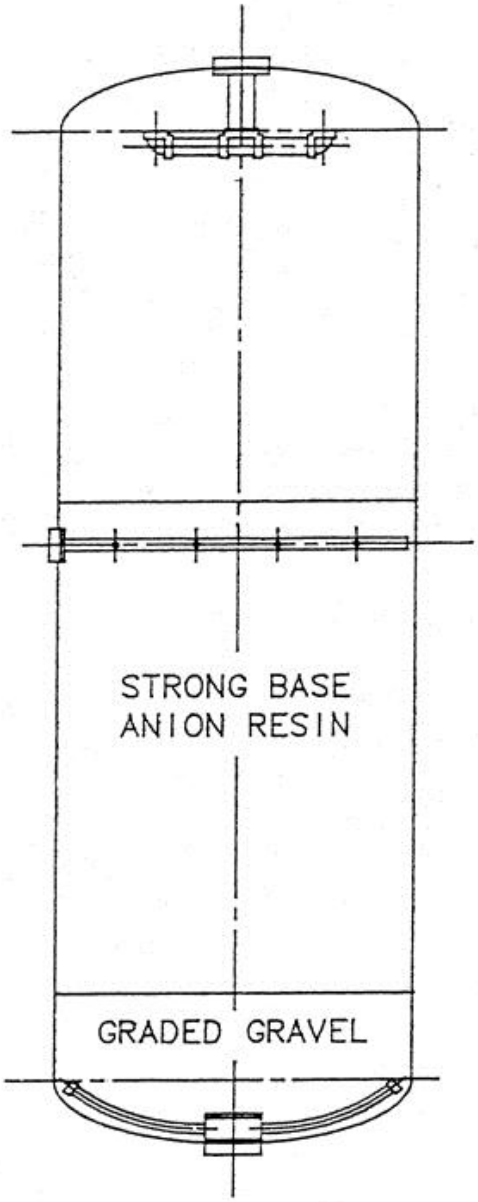
Type System	Nitrate Reduction NO3N, mg/L	No. & Diam of Exchangers	Ion Exch Resin, Cu.Ft.	Flow Rate, GPM		Run Length Hrs.	Lb Salt / 1,000 gal Blend	Lb Salt / Day	Salt Cost $ / Yr	Gal Waste Water/Day	Waste Water TDS, mg/L
				Ion Exch, Effluent	Raw Blend						
A. Countercurrent	15 to 5	3 – 6’	157	770	350	26.5	1.8	2,894	42,250	21,800	18,500
B. Countercurrent	15 to 7.5	3 – 5’	110	600	520	24.0	1.4	1,250	32,850	15,300	18,500
C. Cocurrent	15 to 5	3 – 6’	116	840	280	26.5	2.9	4,720	69,000	24,760	25,500

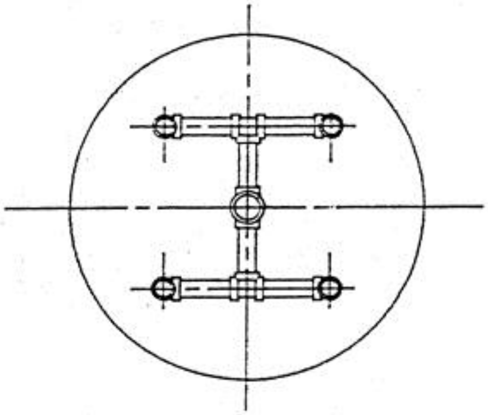
FIGURE 6

HUNGERFORD & TERRY Inc.
CLAYTON, N.J.

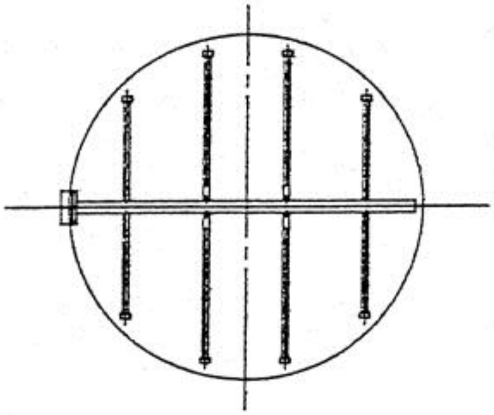
MADE BY ____
DATE ____
SCALE ____
CHECKED ____
APPROVED ____

TITLE **COUNTERCURRENT REGENERATED ANION EXCHANGER**

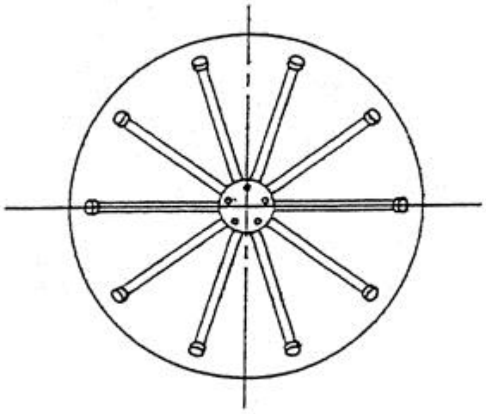




INLET



REGENERANT COLLECTOR



UNDERDRAIN

				SK FIGURE 7
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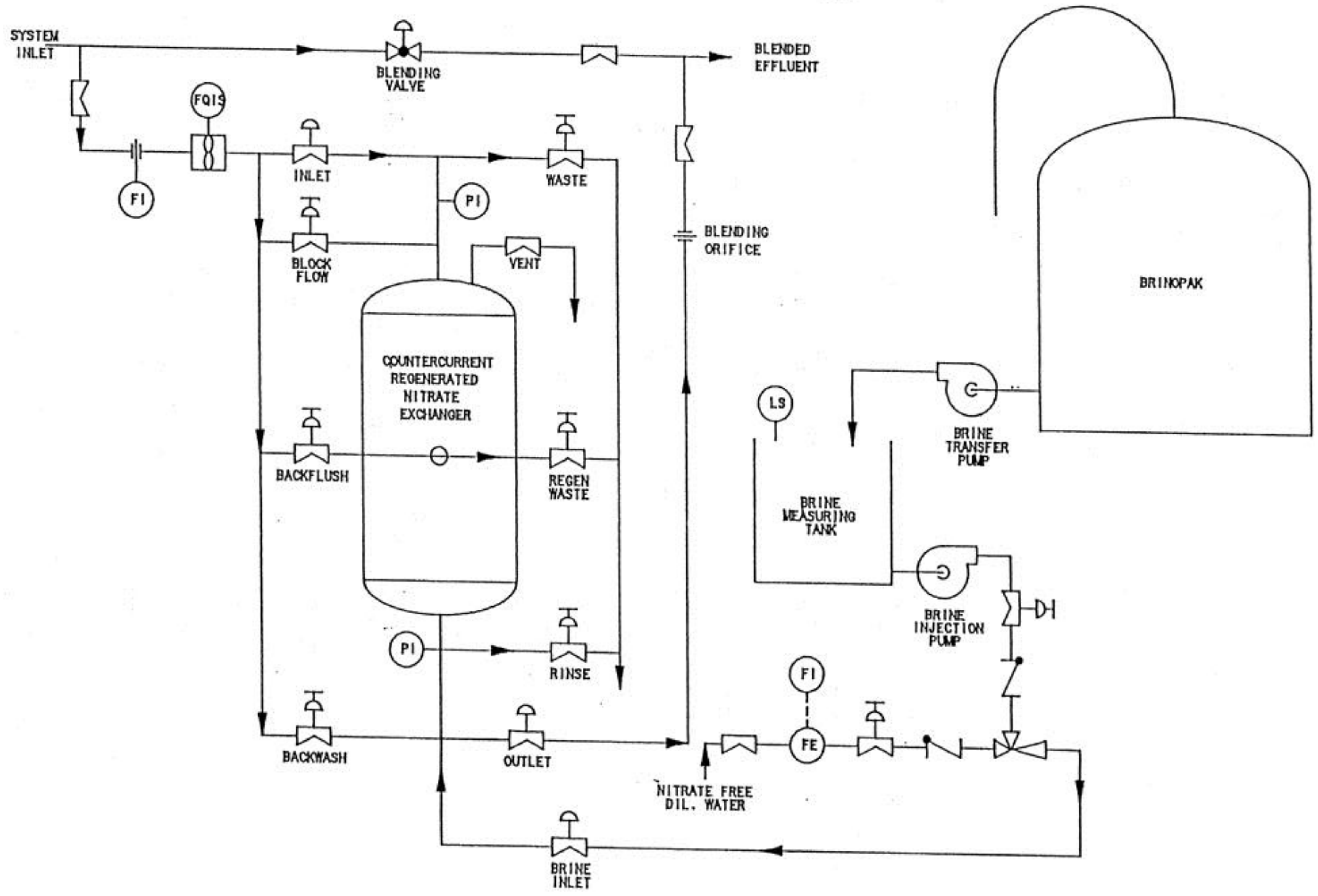
FLOW DIAGRAM
COUNTERCURRENT REGENERATED NITRATE REMOVAL SYSTEM



NITATE1.2D