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NITRATE REMOVAL FROM DRINKING WATER

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INTRODUCTION

The two principal sources of nitrate contamination of water sources are fertilizers and septic tank wastes. Thus, the most vulnerable water supplies to nitrate contamination are ground waters in agricultural areas and in areas having large numbers of septic tanks.

ALTERNATIVES TO TREATMENT

Solutions to the nitrate contamination problem in ground water are several with treatment being just one of the potential remedies. Good engineering practice requires that all alternatives to treatment be explored for their feasibility and cost effectiveness in comparison to treatment. Because most small communities have limited resourses, treatment will very likely be selected as a last resort approach to the problem.

Three alternatives to treatment are:

(1) development of another water supply;

(2) blending of two or more water supplies; and

(3) connecting to approved water supply.

Each alternative has advantages and disadvantages depending on the conditions and circumstances in each community (Fig. 1).

Obviously, the most simple approach is the development of a new water supply, such as drilling a new well. This solution assumes that a nitrate free water source exists in the area. With advanced drilling techniques, water can be drawn from specific strata or the contaminated source can be sealed off. The major disadvantage is the potential for the water quality to change with pumping and time.

FIGURE 1. ALTERNATIVES TO TREATMENT

ALTERNATIVE	ADVANTAGES	DISADVANTAGES
Development of a new water supply.	Less expensive Short time implementation.	Modifications to distribution system. Water quality may change.
Blending of two or more water supplies.	Less expensive. Short time implementation.	Extensive modifications may be required for blending.
Connect to an approved water supply.	Less expensive. Short time implementation. Few modifications.	No control over water supply. Dependent on another utility.

Another approach is to blend water from different sources to achieve a nitrate concentration in the blended water below the Maximum Contaminant Level (MCL) of 10 mg/L (as N). This solution assumes that a good source of water exists for blending with the high nitrate water. Modifications to the distribution system will be required to provide mixing; modifications that could be very expensive.

A third solution is to obtain water from a neighboring community. This solution results in the community giving up control over its drinking water and becoming dependent on another community or utility. Some communities may not be willing to relinquish this control and thus would be willing to pay the higher cost of developing a new supply or providing treatment. Although each alternative seems to be a straightforward simple approach to the problem, each solution has certain disadvantages from either an economic, engineering, or political viewpoint. In the final analysis, each solution may be more expensive than treatment or unacceptable.

TREATMENT METHODS

Several treatment techniques have been studied for the removal of nitrate from drinking water: (1) chemical reduction[1-3]; (2) biological denitrification;[4-5] (3) ion exchange;[6-8] and (4) reverse osmosis[9-10] (Fig. 2). Of these methods only the latter two, ion exchange and reverse osmosis, are considered feasible and practical for full-scale treatment of drinking water. Electrodialysis is very similar to reverse osmosis and is also effective for nitrate removal.[11] Neither conventional coagulation nor lime softening are effective removal methods because nitrate is very soluble in water.

FIGURE 2. TREATMENT METHODS FOR NITRATE REMOVAL

TREATMENT METHOD	EFFECTIVENESS
Chemical coagulation	Not effective
Lime Softening	Not effective
Chemical reduction	Has potential, but not practical
Biological denitrification	Has potential, but not accepted
Ion exchange	Effective
Reverse osmosis	Effective, but costly
Electrodialysis	Effective, but costly

Several chemicals have been investigated for reducing nitrate to nitrogen gas. Of the various chemicals studied, only ferrous iron has been determined to be economically attractive. The process requires a catalyst, copper, for denitrification however and the process must take place in an alkaline solution. Other drawbacks to this process are that only about 70 percent of the nitrate is reduced and large amounts of ferrous iron are required, eight moles of iron per mole of nitrate.

Biological denitrification has been studied for the purification of wastewater and drinking water. The process requires the use of denitrifying organisms in a filter bed to reduce the nitrate to nitrogen gas. The process also requires an organic energy source for the bacteria, such as methanol or ethanol, to be added to the water because most groundwaters are low in organic content. In general, the water utility industry has not accepted this process because of several reasons: (1) the need to add an organic material to water that is generally free of organics; (2) the process requires careful control; (3) the need to develop a large bacterial population in water that is generally free of organisms; and (4) the system will be out of service if the biological mass is lost. As long as other alternatives exist for nitrate removal, this process will probably be given very little serious consideration for drinking water treatment, particularly in small communities.

Currently, ion exchange treatment is the only treatment method being used on a full scale level to remove nitrate from drinking water. In 1974, a full scale plant was constructed by the Garden City Park Water District, Nassua County, New York to treat ground water containing 20-30 mg/L of nitrate-nitrogen.[6] The plant was designed to treat 0.08 m^3/S (1200 gpm) and to lower the nitrate-nitrogen level to less than 2 mg/L.

The Garden City Park facility is a different ion-exchange process that employs a continuously regenerated ion-exchange process in a closed loop. This process is used in industrial applications but uncommon in drinking water treatment. The major advantage of this system is that the resin material is continuously regenerated; large slugs of brine solution for disposal are thus avoided. Greater efficiency of the media for nitrate capacity is also projected.

As of September, 1979, the system was operating successfully, although not on a full time basis. Because most small communities cannot afford such an elaborate system, the more common fixed bed system would have greater application. The Garden City Park system, however, has demonstrated that ion exchange technology will work for nitrate removal. The economics, removal efficiency, chemical usage, and so forth will vary with the quality of water and, therefore, the operation of the Garden City Park plant cannot be universally projected to other locations. For example, the most significant factor of the water is the sulfate concentration because up to about a total dissolved solid (TDS) concentration of 3000 mg/L, sulfate is preferred over nitrate. High sulfate water, therefore, is more costly to treat than low sulfate water because the sulfate competes with nitrate and thus lowers the nitrate removal efficiency.

The Garden City Park ground water is low in sulfate (30-40 mg/L) and therefore the ion exchange system is relatively efficient for nitrate removal. To evalute the influence of higher sulfate water, the Drinking Water Research Division, USEPA funded a research project in McFarland, California that has a ground water containing near 20 mg/L of nitrate-nitrogen and about 300 mg/L of sulfate. The project is investigating the effectiveness and efficiency of ion exchange and reverse osmosis treatment. The project is about 50 percent completed (Jan. 1980) and is scheduled for completion by December, 1980.

Two other treatment methods, reverse osmosis and electrodialysis, will remove nitrate, but these methods are used primarily for treating high TDS and salt water. The nitrate removal efficiency by reverse osmosis varies with the type of membrane; a wide rejection range of 60-95 present is reported.[9-10] Neither method would probably be selected solely for nitrate removal because of their high cost. If the water has several other contaminants or is high in TDS, the techniques may be practical and economical, however.

EQUIPMENT AVAILABILITY

Ion exchange, reverse osmosis, and electrodialysis equipment are readily available from a variety of equipment manufacturers. Because the efficiency of ion exchange treatment for nitrate removal is dependent on the water quality, pilot-plant studies on the specific water are recommended for developing design and operational data. Once these data are established, most water treatment equipment manufacturers can easily specify the size of anion exchange beds and other ancillary equipment.

Reverse osmosis and electrodialysis equipment is also readily available from a large number of manufacturers and pilot studies are not necessary as long as the water quality is known.

TREATMENT COSTS

Of the three most effective and practical methods, ion exchange, reverse osmosis and electrodialysis, the former, ion exchange, is the most economical for low TDS water. Because the equipment for ion exchange nitrate removal is similar to ion exchange softening equipment, and even activated alumina fluoride removal equipment, the construction costs for all three processes should be comparable. A recent EPA publication[12] on the costs of water treatment process, developed by Culp, Wesner, Culp, Consulting Engineers, Santa Ana, California, confirms this as shown in Table 1 and Fig. 3. In assending order of total construction costs up to about 1 mgd, the costs of four comparable processes are (1) activated alumina for fluoride removal; (2) ion exchange softening; (3) ion exchange nitrate removal and (4) reverse osmosis. The costs for the first three processes differ by only a small amount, while reverse osmosis costs are about 2-3 times more than the other methods.

The principal difference in the construction costs for ion exchange softening and nitrate removal is the media expense. An example to illustrate this difference is shown in Table 2 that provides a breakdown in the construction costs of 1136 m^3/d (0.3 mgd) plant. All of the cost categories shown are approximately equal, except for one, the ion exchange media. The anion resin for nitrate removal cost about three times more than that cation resin for the softening process.

Operating cost data for the various processes are compared in Table 3 and Fig. 4. These data are total costs for maintenance materials, energy and labor and exclude the cost of regeneration and brine disposal. These data indicate that the operation costs for ion exchange nitrate removal are about 5-30 percent higher than ion exchange softening and reverse osmosis treatment is 2-5 times more costly than ion exchange.

TABLE 1. CONSTRUCTION COSTS - WATER TREATMENT SYSTEMS[12]

Plant Capacity gpd	CONSTRUCTION COSTS - $			
	Ion Exchange Softening	Activated Alumina Fluoride Removal	Ion Exchange Nitrate Removal	Reverse Osmosis
50,000	60,500	50,000	65,000	78,000
100,000	68,000	58,000	74,000	131,000
250,000	85,000	72,000	98,000	245,000
500,000	106,000	92,000	129,000	430,000
750,000	131,000	110,000	170,000	625,000
1,000,000	150,000	130,000	221,000	776,000

Fig. 3. Construction Costs - Ion Exchange Softening, Activated Alumina Fluoride Removal, Ion Exchange Nitrate Removal and Reverse Osmosis[12]

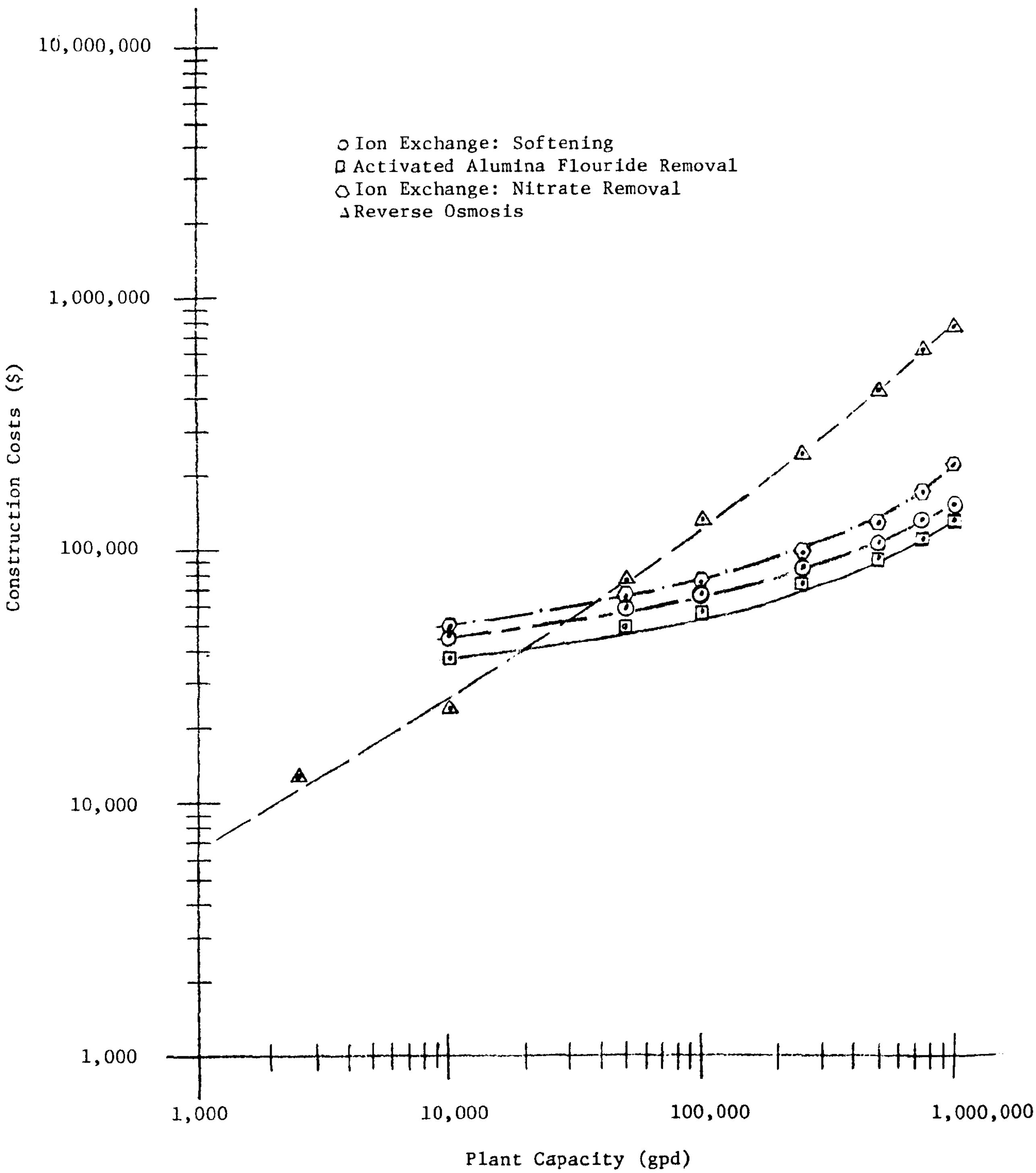


TABLE 2. CONSTURCTION COST - ION EXCHANGE PLANTS FOR SOFTENING AND NITRATE REMOVAL[12]

Cost Category	CONSTRUCTION COST - $ Ion Exchange Softening 280,000 gpd	Ion Exchange Nitrate Removal 270,000 gpd
Site work	640	110
Manufactured Equipment		
Equipment	16,000	16,500
Media	6,790	21,860
Concrete	1,400	490
Steel	2,170	680
Labor	7,430	5,990
Pipe and valves	12,600	12,440
Electrical & instrumentation	21,600	21,460
Housing	8,900	8,900
Subtotal	77,270	88,430
Miscellaneous & Contingency	11,590	13,260
TOTAL	88,860	101,690

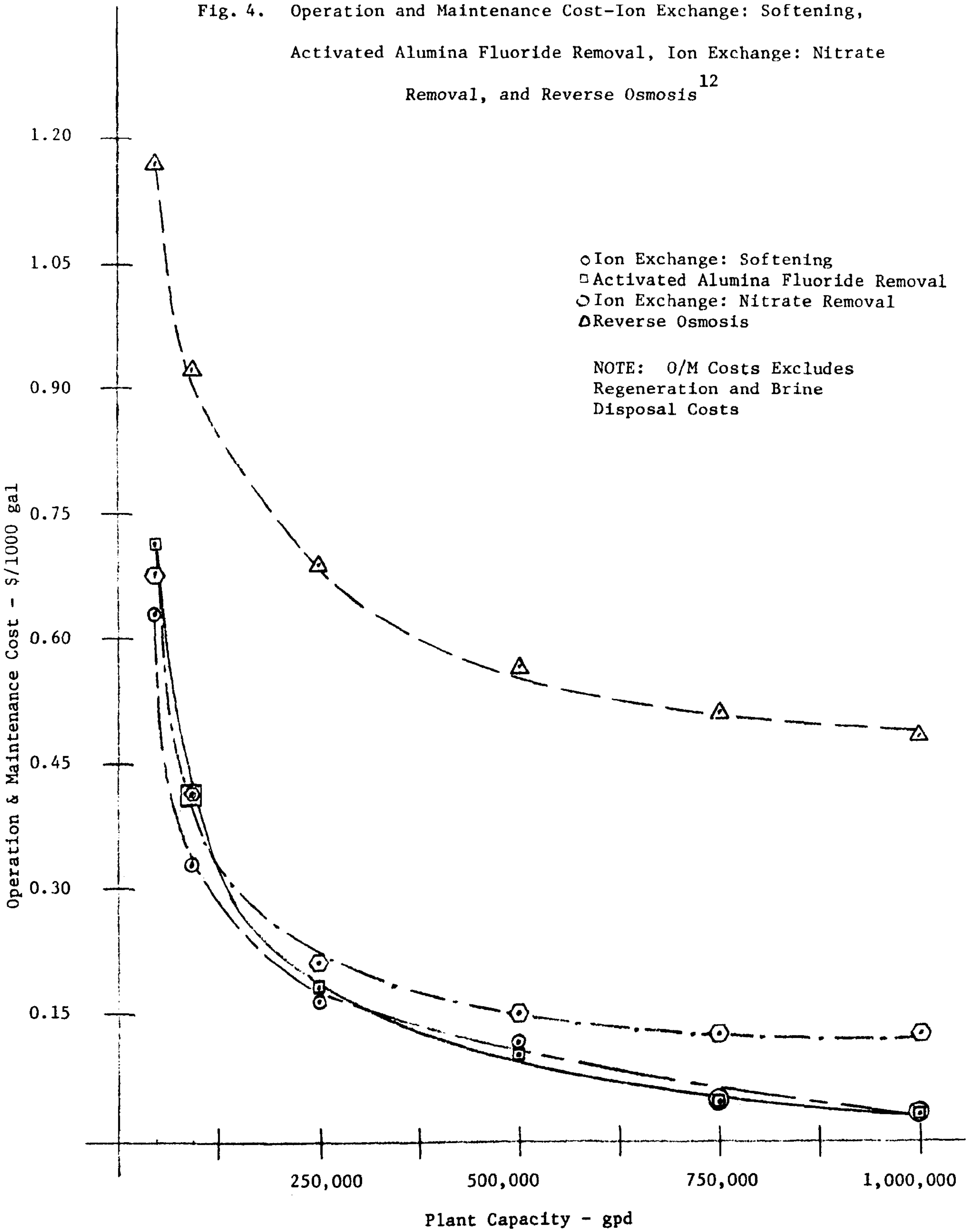
TABLE 3. OPERATION AND MAINTENANCE COST - WATER TREATMENT SYSTEMS[12]

	YEARLY O/M COST - $ and (¢/1000 gal)			
Plant Capacity (gpd)	Ion Exchange Softening	Activated Alumina Fluoride Removal	Ion Exchange Nitrate Removal	Reverse Osmosis
50,000	11,500 (63)	13,000 (71)	12,400 (68)	21,300 (117)
100,000	12,200 (33)	15,000 (41)	15,000 (41)	33,500 (92)
250,000	15,500 (17)	16,000 (18)	20,000 (22)	63,000 (69)
500,000	19,800 (11)	18,000 (10)	26,900 (15)	104,000 (57)
750,000	23,000 (8)	20,800 (8)	34,800 (13)	142,000 (52)
1,000,000	25,300 (7)	23,700 (6)	46,000 (13)	180,000 (49)

*Costs Include - Maintenance Material, Energy, and Labor

Costs Exclude - Regeneration, Brine Disposal

Fig. 4. Operation and Maintenance Cost-Ion Exchange: Softening, Activated Alumina Fluoride Removal, Ion Exchange: Nitrate Removal, and Reverse Osmosis[12]



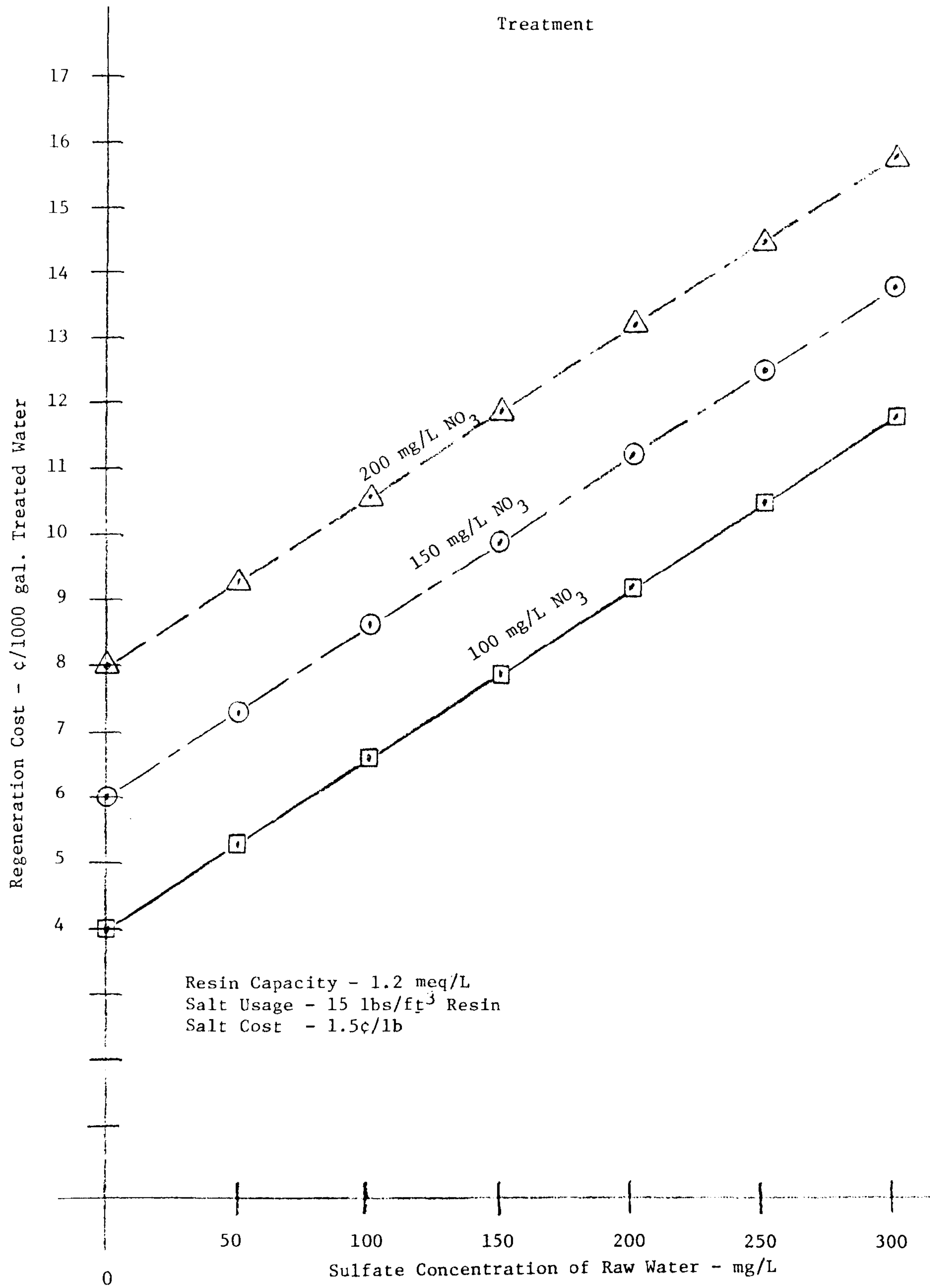
Regeneration and brine disposal costs will increase the costs and are dependent on the efficiency of each process. For ion exchange, regeneration costs are a function of the quality of the water and in particular the total amount of sulfate, nitrate, and other anions in the water. Because sulfate is more preferred than nitrate, the regeneration costs for nitrate ion exchange are primarily dependent on the amount of sulfate in the raw water.

To evaluate the effect of sulfate on the regneration costs for ion exchange nitrate removal, cost data were developed assuming: (1) 100 percent efficiency in removal of sulfate and nitrate; (2) a capacity of 1.2 meq/ml of resin; (3) 240 kg of salt per cubic meter of resin (15 lbs/cu. ft.) for regeneration; and (4) 1.5¢/lb of salt. These data given in Fig. 5 show that the sulfate concentration can increase regeneration cost substantially; the costs will double as the sulfate concentration increases from 50 to 250 mg/L. Increases in salt usage and salt costs will also increase these costs. The data from Fig. 5 also show that the regeneration costs are a major portion of the operating costs that can amount to 40-50 percent of the total costs. Including regeneration costs in the total operating costs for ion exchange treatment also narrows the gap between this treatment method and reverse osmosis.

SUMMARY

Currently, ion exchange treatment is the most economically and practical method for nitrate removal from groundwater. The construction costs for ion exchange nitrate removal are slightly higher than those of an ion exchange softening plant because of the higher cost of the anion

Fig. 5. Regeneration Costs - Nitrate Removal by Ion Exchange Treatment



resin. Excluding regeneration and brine disposal, operating costs are about 20-40 percent higher for nitrate removal than for softening. The regeneration costs are a very significant portion of the total cost, 30-50 percent. Regeneration costs are directly dependent on the total amount of nitrate and sulfate in the water.

Reverse osmosis and electrodialysis are effective, but more costly methods for nitrate removal. The methods become more competative with ion exchange when the sulfate and TDS concentrations are high. These methods are also advantageous when the drinking water has a multiple contaminant problem that cannot be solved·by anion ion exchange treatment alone.

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