A METHOD TO OPTIMIZE ION EXCHANGE RESIN REPLACEMENT IN PROCESS DEIONIZERS

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A METHOD TO OPTIMIZE ION EXCHANGE RESIN REPLACEMENT IN PROCESS DEIONIZERS

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ABSTRACT

A METHOD TO OPTIMIZE ION EXCHANGE RESIN REPLACEMENT IN PROCESS DEIONIZERS

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A model to predict optimal ion exchange resin replacement time is developed. The model relates capacity decay, regeneration cost and new resin expense to predict the point where regeneration cost savings between old and new resin exceeds the expense of new resin. The model is then applied to a process deanionization cell in water service using data collected over a three year period.

A procedure to apply the model to laboratory column contact experiments is also developed. Four anion exchange resins were tested to determine the capacity decay rates. Scaling the laboratory data to approximate a full-scale process allows recommendation of a replacement resin.

ACKNOWLEDGEMENTS

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CHAPTER I

INTRODUCTION

Water usage in industry has been estimated at 140 billion gallons per day[1], much of which is used for boiler feed, cooling, and process needs. Considering the particular case of boiler feed-water, especially in high temperature and pressure systems, the presence of impurities can lead to disastrous consequences if unaddressed. It is apparent that a large market exists for water purification systems, and that installing, maintaining, and operating such systems will claim a significant portion of a process operating budget and capital expenditure.

Impurities in water consist of suspended solids, dissolved organics and inorganics, and dissolved gases. Removal of these impurities can arbitrarily be divided into two categories: Those that remove non-ionic species, e.g. filtration, carbon treatment, and deaeration; and those that deal with the ionic species, i.e. deanionization and decationization. Today the method of choice for deionization of water uses ion-exchange resins, both for processing ease and overall cost savings. However, convenience comes at a price. The expense of purchasing

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1 Betz Laboratories Inc., Handbook of Industrial Water Conditioning, 8th ed. (Trevose, Privately printed, 1980) 10

new ion-exchange resin can approach several hundred dollars per cubic foot, with a useful life of less than five years (dependent on flow and feed conditions).

This work addresses the issue of predicting resin decay behavior, and maximizing the water quality to cost ratio by optimizing the time of resin replacement in a process cell. The model will be applied to plant data for a deanionization cell and to the comparison of resins evaluated in the laboratory.

CHAPTER II

MODEL THEORY AND DEVELOPMENT

The mechanism of ion exchange simply involves the substitution of acceptable ionic species for all unacceptable species present in the feed. Deionization of industrial water therefore involves two discrete operations, decationization and deanionization. Decationization removes cations (e.g. Ca^{++}, Mg^{++}, Na^{+}) from water releasing H^{+} ions. Deanionization removes anions (e.g. Cl^{-}, SO_4^{-}, $CO_3^{=}$) and releases OH^{-}. The net effect is removal of ionic impurities, with the acidic H^{+} and basic OH^{-} balancing to a near neutral pH. Affixing the reactants to a solid, or resin, allows retention of undesired species while purified water continues downstream.

Ion exchange resins consist of two components: the active sites where the ion exchange reaction occurs, and an inactive matrix providing support. The most common matrix is polystyrene cross-linked with 8 to 10% divinyl benzene (See figure 1).

When a polymer bead is placed into solution, it will swell to a limit determined by the degree of cross-linking. Water fills the resulting voids allowing diffusion of ionic species between polymer chains, exposing all active sites to reaction. This diffusion historically has been referred to as pore diffusion, though there are no physical pores involved in the mechanism. In cases where resin beads are composed of many smaller beads bound together, as macroreticular resin beads are, the diffusion within the small bead is still described as pore diffusion and follows the same mechanism.

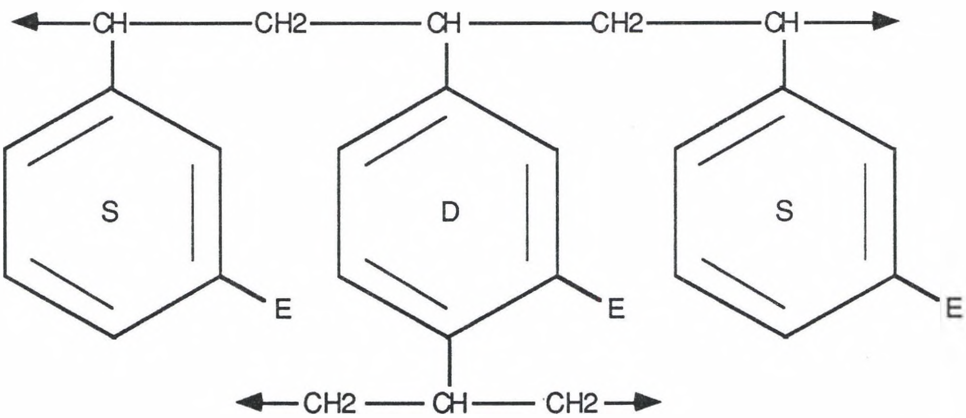

Figure 1. Structure of SDVB polymer. S= styrene, D= divinyl benzene, E= exchange site.

The functional group serving as the exchange site determines the capabilities of the resin, thus a resin can be classified as being one of four types:[2]

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[2] Betz Laboratories Inc., Handbook of Industrial Water Conditioning, 8th ed. (Trevose, Privately printed, 1980) 50

Resin Type		Functional Group
1) Strong Acid	(SA)	HSO_3^-
2) Weak Acid	(WA)	$COOH^-$
3) Strong Base	(SB)	$(CH_3)_3N^+$, $(CH_3)_2NCH_2CH_2OH^+$
4) Weak Base	(WB)	NH_2^+, NRH^+, NR_2^+

Regardless of the resin type, or structure, the mechanism of exchange can be modeled as a catalytic reaction with five steps: diffusion of reactant from bulk solution through Nernst layer to bead surface, diffusion through bead to exchange site, reaction at exchange site, diffusion of product through bead to surface, diffusion from surface to bulk solution (See figure 2).

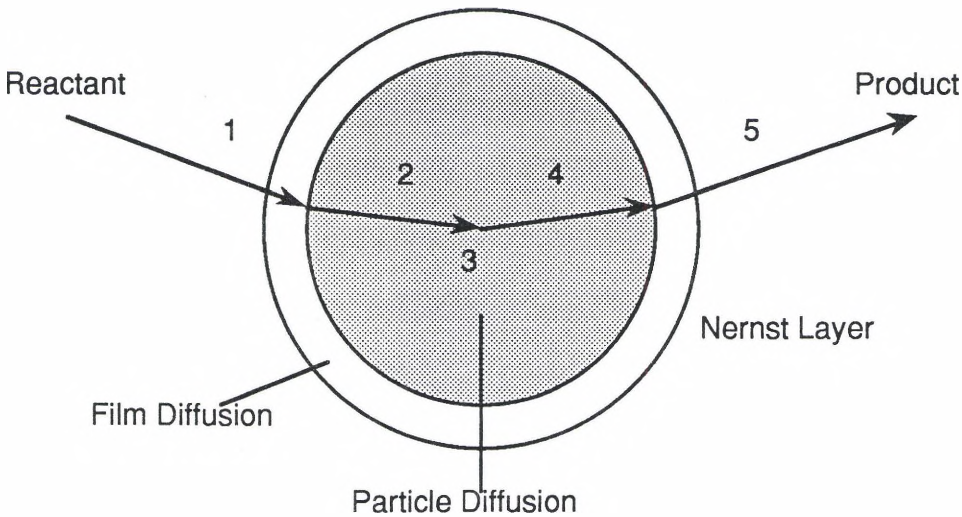

Figure 2 Mechanism of ion exchange for a resin bead. 1) Film diffusion of reactant, 2) Particle diffusion to exchange site, 3) Reaction, 4) Particle diffusion of product, 5) Film diffusion of product.

After exhaustion, the resin is regenerated. Like a catalyst, the resin bead is able to be reused since it was not permanently changed by the reaction. However, over time permanent site deactivation will take place and result in a loss of capacity. Treating this capacity loss as a case of first order decay, the following rate expression can be postulated:[3]

$$-r_c' = -\frac{dC}{dt} = C_o e^{-k_d t}$$

Where:	$-r'_C$	rate of capacity decay
	C	capacity at time t
	C_o	initial capacity at time t_o
	k_d	decay constant
	t	time

Separation and integration yields:

$$C = Ke^{-k_d t}$$

Where:	C	capacity
	K	constant C_o/k_d

As time increases, the resin capacity decreases exponentially.

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3 Octave Levenspiel, Chemical Reactor Omnibook (Corvalis, Oregon State University Press, January 1989) 31.16

Adapting this to a function which relates unit cost of deanionized water to the resin age involves dividing the cost of regeneration by the capacity at current time t.

$$Cost = K'e^{+k_d t}$$

Where:	Cost	regeneration cost/capacity
	K'	regeneration cost/K
	k_d	decay constant

As expected, when time increases, cost increases exponentially. Integration of the water cost as a function of time curve from initial time T_0 to T_1 yields the total amount of money spent on regeneration during the period (See figure 3). If the ion exchange resin were to be replaced at time T_1 with new resin (See figure 4), the difference between the area under the existing resin curve and that of the new resin curve from time T_1 to T_2 gives the regenerant cost savings.

Maximizing the water quality to cost ratio infers that new resin should be purchased at the earliest opportunity for several reasons: First, as capacity decreases, the number of active sites decreases and the ability of the resin to retain ions is impaired. The net result is though the center of the resin bead is not exhausted, anions can slip to the effluent without ever contacting an active site. Second, regenerant usage is higher with lower capacity resins. In addition to

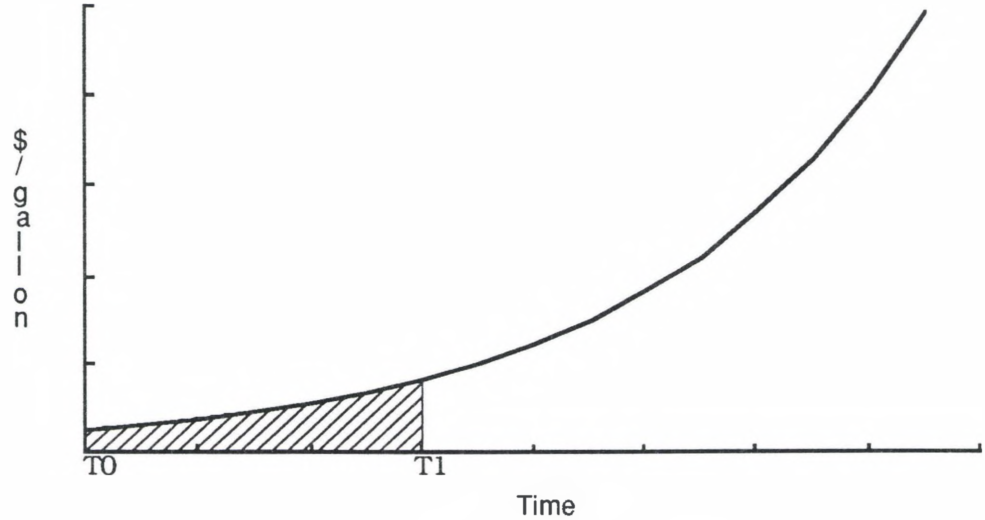

Figure 3. Plot of Deanionized Water Cost as a Function of Time. Shaded region represents total amount spent on regeneration during the period.

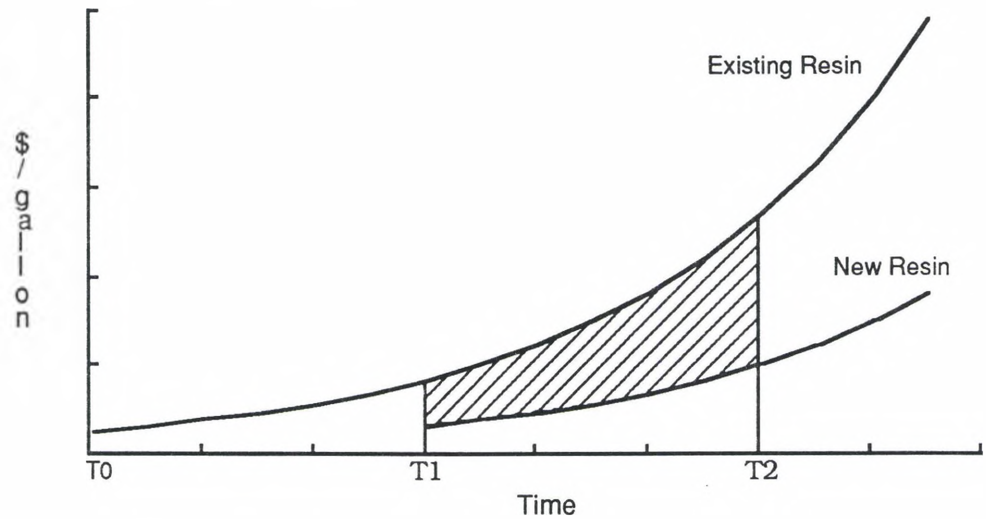

Figure 4. Plot of Deanionized Water Cost as a Function of Time after Resin Replacement at T_1. Shaded region represents the savings in regeneration cost if resin replacement is made at T_1.

regenerant cost, the transporting, handling, and storage of hazardous materials used in regeneration will increase. Finally, with the increase in number of regenerations, the amount of water used for rinsing and back-washing increases as well. This results in higher raw water charges, and an increase in the wastewater bill to dispose of it. Therefore when the cost savings equal the expense of new resin, replacement should occur. Development of an equation relating this optimum replacement time to readily measured parameters is the goal of this study.

The area difference between the curves in figure 4 can be expressed as (refer to appendix A, page 30 for derivation):

$$A = \frac{a_1}{b_1}\left(e^{b_1 T_2} - e^{b_1 T_1}\right) - \frac{a_2}{b_2}\left(e^{b_2 (T_2 - T_1)} - 1\right)$$

Where:	a_1	Resin 1 initial capacity
	b_1	Resin 1 decay coefficient
	a_2	Resin 2 initial capacity
	b_2	Resin 2 decay coefficient
	T_1	Time of resin replacement
	T_2	Life of new resin
	A	Area equalling cost savings

The difficult variable to specify is T_2, the time of replacement of the new resin. This can be defined several ways: First, it can be the amortization period for the capital cost of the new resin. Second, it could be an estimate of the life of the new resin from old plant data, or manufacturers specifications. Finally, it could be assumed that the replacement resin and the existing resin are the same (i.e. identical resin decay coefficients). If this is true, then the life of the new resin will likely be the same as the old, or equal to T_1-T_0. Using this approach and substituting into the area equation above (refer to Appendix A, page 31), and solving for T_1 (taking T_0 to be zero) yields:

$$T = \frac{\ln\left(\sqrt{A\frac{b}{a}} + 1\right)}{b}$$

Where:	T	Optimum replacement time
	A	New resin expense
	a	Resin initial capacity
	b	Resin decay coefficient

This equation will give the optimum time for resin replacement given values for the resin capacity decay coefficients and the new resin expense. Values for the resin capacity decay coefficients can be determined from operational capacity data, or from laboratory testing. Resin expense should include; the cost of new resin, the cost of installation, the cost of disposal for the old resin, the savings from reduced water usage in backwashing the resin and in the rinse water used during regeneration, and the reduction in wastewater charges because of fewer regenerations.

CHAPTER III

APPLICATION TO PLANT DATA

In applying this model to process data, the definition of capacity needs to be clarified. Total capacity refers to the total number of sites available for exchange. Operating capacity is a measure of actual useful performance, determined by total capacity, extent of regeneration, solution composition, flow rates, temperature, resin particle size, etc.[4] Capacity, as used with process data, is of necessity the operating capacity of the system, and is measured by the amount of throughput before exhaustion (i.e. gallons of water processed).

Loss of capacity can be attributed to six major causes:

(1) Physical breakdown of the resin.
(2) Decrosslinking and increased swelling.
(3) Loss of total exchange capacity.
(4) Loss of acidity or basicity of functional groups.
(5) Poisoning (irreversible adsorption) of functional groups due to humic acids, organo-metallics, and natural color bodies.
(6) Fouling due to precipitation of foreign matter on surface or within particle.

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4 Kirk-Othmer, Encyclopedia of Chemical Technology, 2nd ed. Volume 11 (Wiley and sons, 1966), s.v. "A Basic Reference on Ion Exchange", by R.M.Wheaton and A.H.Seamster.

The decay coefficients are therefore a function of these six factors. Due to the difficulty in isolating each factor's contribution to the overall decay, accuracy is best for a system where one factor is dominant. Such a system is the deanionization of water that has been processed through a decationizer (see figure 5).

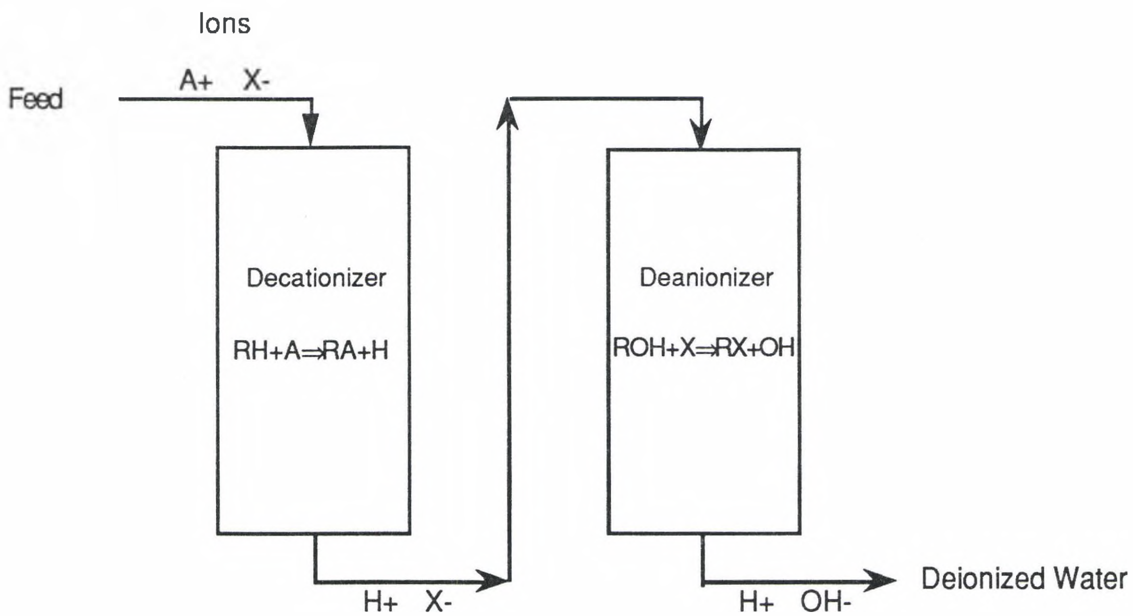

Figure 5. Schematic of deionization process using ion exchange.

Since the raw water encounters the decationizer first, most of the foreign matter responsible for fouling will be retained on the cation resin. This reduces the fouling of the anion resin. When a strong base anion resin is used, the rate of capacity decay due to deactivation of functional groups by oxidation is much greater than physical breakdown and decrosslinking effects. Thus, for a strong base anion resin, the dominant factor in capacity decay is the deactivation of functional groups by oxidation, and the model can be applied successfully.

Data from a process cell consists of the volume of water processed between regenerations. The cost of water produced is the regeneration cost divided by this volume processed. This cost data can be plotted as a function of total throughput to show the capacity decay of the resin. This sample data was collected from a pair of deanionization cells (identified as North and South) operated in parallel downstream of a decationizer (refer to Appendix C for data, constants used, and regression information). The cells use the same strong base type II anion resin, installed at approximately the same time. Data was collected for three years and plotted (See figure 6). Since process data fluctuates with changing feed impurity concentration, flow rate through cell, temperature etc., there was a significant amount of "noise" or random variation in the cost of water produced. This noise can be reduced through time-smoothing the data by averaging over a number of data points (see figure 7).

Fitting the time-smoothed data to an exponential curve-fit involves plotting the logarithm of the cost as a function of throughput, and determining the slope and intercept of the line using linear regression (see figure 8). Substituting the determined values of a, b,

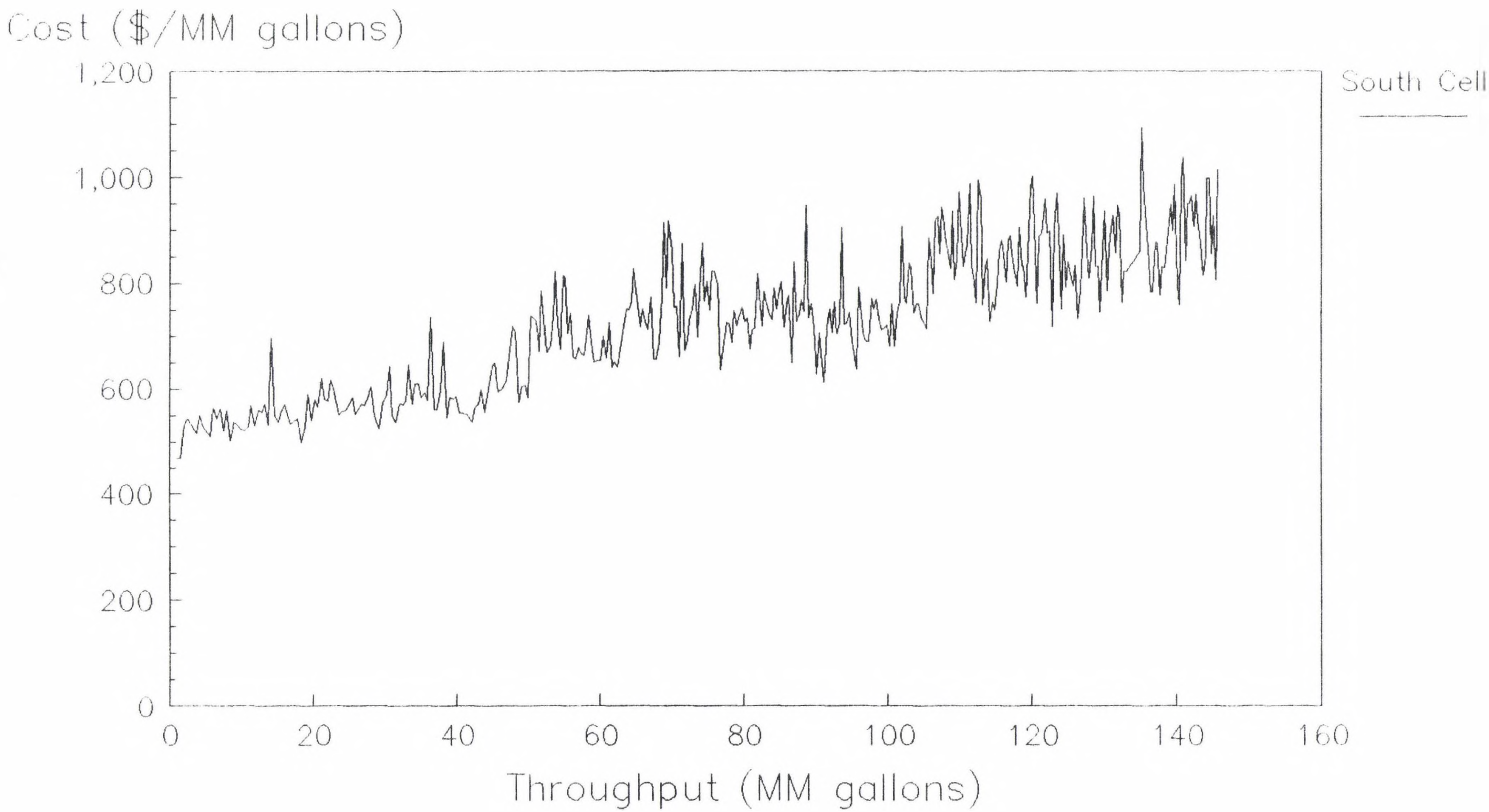

Figure 6. South Cell Water Cost as a Function of Throughput

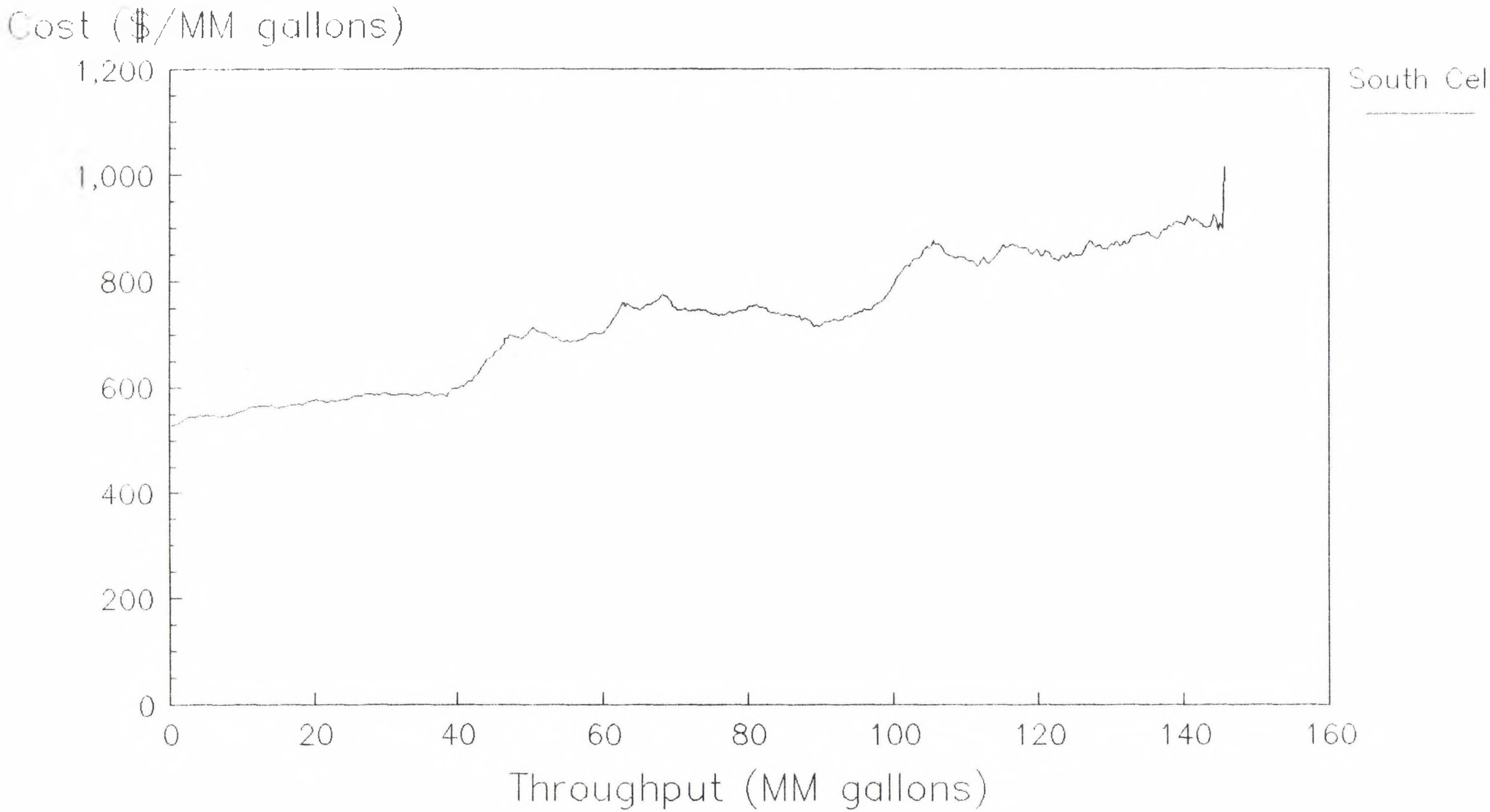

Figure 7. South Cell Water Cost as a Function of Throughput Using 25 Point Time-Smoothing Average

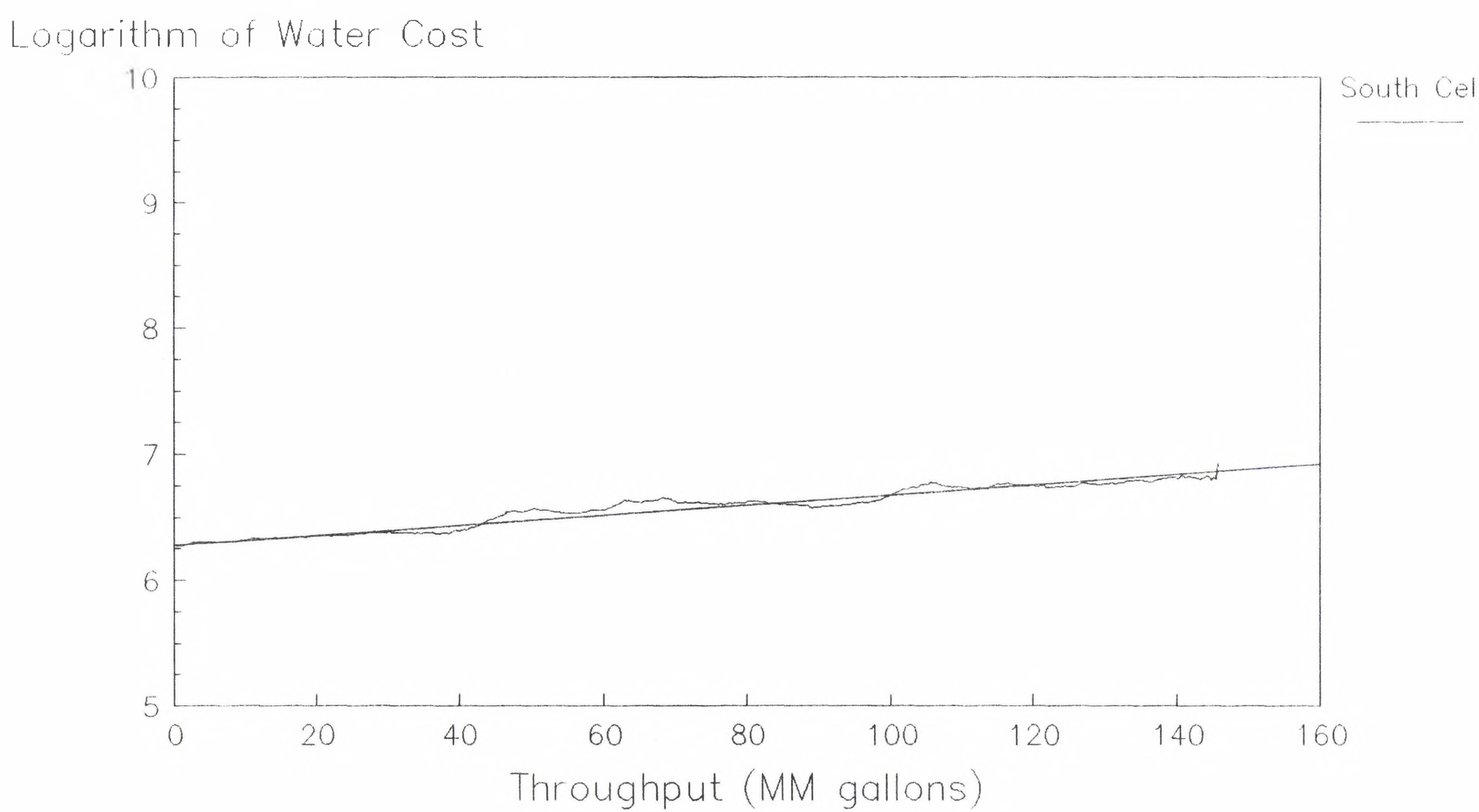

Figure 8. South Cell Logarithm of Water Cost as a Function of Throughput Using 25 Point Time-Smoothing Average with Linear Regression

and the cost of new resin replacement into the derived equation yields the optimum time to change the resin. This replacement time is expressed in gallons of water processed to avoid error due to cell down-time and changes in demand.

$$T = \frac{\ln\left(\sqrt{A\frac{b}{a}} + 1\right)}{b}$$

Where: a_{North} = \$567.98 a_{South} = \$545.03
b_{North} = .004636 b_{South} = .003762
A = \$74,250

T_{North}=124.2 MM gallons T_{South}=143.5 MM gallons

Some variation in the calculated replacement times is expected and could be due to physical differences between the two cells (e.g. sparger differences), or due to a difference in the amount of resin in the cell (i.e. a difference in the small amounts of resin lost due to attrition over time). Comparing these values to the manufacturer's estimate of a minimum useful life of 500,000 gallons per cubic foot (138 MM gallons for the cell) indicates some agreement. The recommendation that new resin be purchased at the calculated times can be justified because of the agreement in replacement time between the two cells, and agreement with the manufacturers recommended replacement time.

CHAPTER IV

APPLICATION TO LABORATORY TESTING

The question of when to change the resin in a process cell can be answered with some degree of certainty as shown. The obvious next question is what replacement resin maximizes the water quality without increasing the amount of money spent on regeneration. Using the model of resin capacity decay, if the decay coefficients and cost of the new resin are known, a logical recommendation can be made. There are several ways to determine this decay behavior: First, plant history of resins used can give an idea of the decay coefficients, however, it is unlikely that process equipment and procedures have not undergone change. Second, manufacturer supplied data can offer some insights, but it may be difficult to compare performance between resins due to different analytical techniques between suppliers. Finally, laboratory column contact experiments can be carried out to determine the decay coefficients.

Laboratory testing was carried out on four different type II anion exchange resins. Samples were placed in a process deanionizer and allowed to undergo process exhaustion and regeneration cycles for a period of four months. The samples were then removed, and placed into one inch diameter chromatography columns. The capacity of the resin was then determined through exhaustion using decationized water similar to that encountered in the process cells. An equal sample of virgin resin was then tested for capacity using the same method (refer to Appendix B for procedure). Plotting the logarithm of the capacity as a function of time permits the determination of the initial capacity coefficient (a) and the decay coefficient (b) for each resin.

Prior to performing the capacity studies on the resin samples, the maximum feed-rate of decationized water to the column was determined. This was necessary since as flow rates increase, there is a shift from ion exchange limited by resin capacity, to ion exchange which is limited by the flow rate of reactant through the bed. This is best expressed in terms of the time-constants of the system, τ. When the time-constant of flow is much greater than the time-constant of adsorption ($\tau_{Flow} >> \tau_{Adsorption}$), the appearance of anions in the effluent indicates resin exhaustion. When the time-constant of flow is approximately equal to or less than the time-constant of adsorption ($\tau_{Flow} \leq \tau_{Adsorption}$), the appearance of anions in the effluent is primarily a result of insufficient residence time for adsorption to occur, which should not be used as an indication of resin exhaustion. This maximum flow rate was determined by finding the capacity of a resin sample at various feed-rates, plotting the capacity as a function of flow rate and locating the inflection point of the curve (refer to figure 9). The flow rate was determined to be 75 ml/min and was used for all resin samples (refer to Appendix E for experimental data).

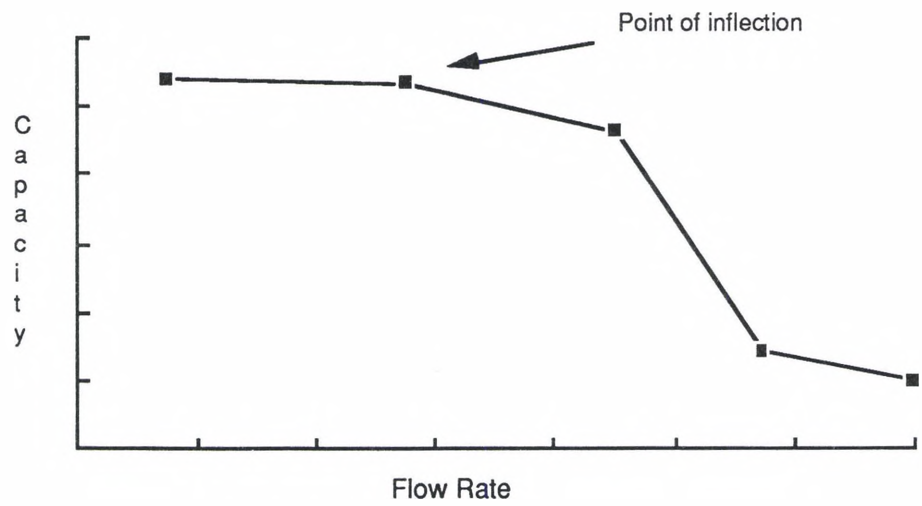

Figure 9. Capacity as a Function of Flow Rate Data for a Resin Sample in a 1" Diameter Test Column.

Capacity testing was then performed for the four virgin and four aged resin samples in triplicate to reduce the effects of feed variation (refer to Appendix D for experimental data). The actual flow rate was recorded for each run, as well as the volume of resin in the column. To reduce the error between runs due to variance in impurity feed rate to the test column, time was expressed as grams of chloride fed to the column. The capacity was then converted to a grams of chloride ion adsorbed per unit resin volume basis. This choice of using the amount of chloride ion adsorbed as a basis for comparison was made due to its relative abundance in the feed and the ease of analysis. Integration of the effluent chloride concentration as a function of time curve from time zero to the time of resin exhaustion using the Newton-Cotes method[5] yields the amount of chloride ion passed through the column during the run. Subtracting this from the calculated grams of chloride fed to the column gives the amount of chloride ion adsorbed (See figure 10). The capacity of each resin was then determined using both conductivity and chloride concentration in the effluent as indicators of exhaustion. pH is also often used as an exhaustion indicator in full-scale operation because of its low cost and ease of measurement. It was not included in this study because of its sensitivity to low levels of impurity in both the feed and effluent streams. This results in significant variation in the data points.

$$\text{Amount Absorbed} = \text{Amount Fed} - \text{Amount Passing Through}$$

$$\text{Mass} = \int_{t_o}^{t_f} Q\, C_o\, dt - \int_{t_o}^{t_f} Q\, C_f\, dt$$

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5 Steven Chapra, Numerical Methods for Engineers, 2nd ed. (New York, McGraw Hill, 1988) 501

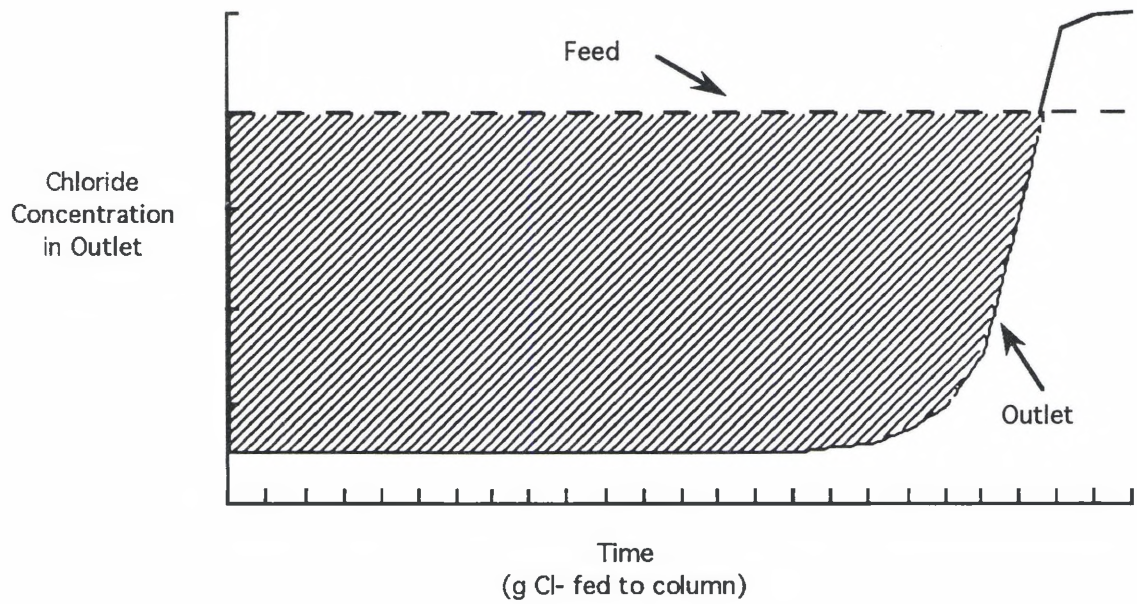

Figure 10. Plot of Chloride Flowrate in Outlet Stream of Test Column as a Function of Time. Shaded area represents amount of chloride ion retained at exhaustion using the effluent chloride concentration as indicator of exhaustion

Determining the resin capacity in this way requires defining the point of resin exhaustion. This was done in two ways: First, the point of exhaustion can be taken as the time when the effluent chloride concentration equals that of the feed. Using this indicator of exhaustion leads to the virgin and aged capacities presented in table 1. These capacities can then be used to determine the decay coefficients a and b that are also presented in this table.

Resin	Virgin Capacity g Cl^-/cm^3	Aged Capacity g Cl^-/cm^3	Delta Capacity Virgin-Aged	a	b $* 10^{-9}$
1	.72	.56	.16	.72	-9.62
2	.76	.65	.11	.76	-5.99
3	.74	.66	.08	.74	-4.38
4	.71	.56	.15	.71	-9.09

Table 1. Capacity data from column contact study of four anion exchange resins using effluent chloride concentration as exhaustion indicator. Capacity is expressed in grams of chloride ion retained per cubic centimeter of test resin.

The second method of defining the point of resin exhaustion is based upon specifying an upper limit of effluent conductivity which is indicative of unwanted anions passing through the resin bed. Using conditions that approximate full-scale process applications leads to setting a conductivity limit of 10 microsiemens/cm. Given the point of exhaustion, the resin capacity can be calculated in the manner described previously. This yields the virgin and aged capacities and decay coefficients presented in table 2.

Resin	Virgin Capacity g Cl^-/cm^3	Aged Capacity g Cl^-/cm^3	Delta Capacity Virgin-Aged	a	b $* 10^{-9}$
1	.01274	.01104	.00170	.01274	-5.47
2	.01503	.01203	.00300	.01503	-8.52
3	.01341	.00854	.00487	.01341	-17.27
4	.01287	.00923	.00364	.01287	-12.73

Table 2. Capacity data from column contact study of four anion exchange resins using conductivity determined exhaustion. Capacity is expressed in grams of chloride ion retained per cubic centimeter of test resin.

The significant difference in the capacity between test runs using the effluent chloride concentration as indicator of exhaustion and the runs using effluent conductivity as indicator of exhaustion is a direct reflection of the degree of exhaustion. In the effluent chloride concentration as exhaustion indicator case, the resin is saturated with the chloride ion to the point where chloride ions pass unadsorbed through the cell. In the effluent conductivity as exhaustion indicator case, exhaustion is reached when the first unadsorbed impurities pass through the cell. Though the resin is not fully exhausted with chloride ion in the second case, it is more indicative of normal process demands which require that the cell be regenerated before any undesired anions emerge. The effluent chloride concentration as exhaustion indicator case therefore is useful to compare total capacities between resins, while the effluent conductivity as exhaustion indicator case is useful to compare anticipated process performance.

Scaling the laboratory column data to approximate a process scale deanionizer (this allows us to compare laboratory data in terms of what may be seen in plant applications) yields the following capacities and decay coefficients decay coefficients for a 275 ft^3 cell (Refer to table 3 and 4, note that only the effluent conductivity as exhaustion indicator data is presented):

Resin	Virgin Capacity gallons	Aged Capacity gallons	Capacity Decrease Virgin-Aged	a $* 10^{5}$	b $* 10^{-9}$
1	532,830	461,838	70,992	5.32	-5.47
2	628,863	503,336	125,527	6.29	-8.52
3	561,249	357,467	203,780	5.61	-17.27
4	538,368	386,040	152,328	5.38	-12.73

Table 3. Resin capacity decay coefficients derived from column contact study of four anion exchange resins using effluent conductivity as exhaustion indicator.

Resin	Virgin Resin Water Cost ($/M gallons)	Aged Resin Water Cost ($/M gallons)	Delta Cost Virgin-Aged ($/M gallons)	a	b $* 10^{-3}$
1	.490	.565	-.075	.490	-5.47
2	.417	.521	-.104	.417	-8.52
3	.467	.730	-.263	.467	-17.27
4	.485	.676	-.191	.485	-12.73

Table 4 Coefficients for water cost increase derived from column contact study of four anion exchange resins using effluent conductivity as exhaustion indicator.

Tabulating the results from the column contact study allows comparison of the loss of capacity for each of the four resins. Applying the cost of new resin, resin capacity and the capacity decay coefficients from above, the following recommended replacement times are derived (refer to table 5, note that both effluent chloride concentration and effluent conductivity as exhaustion indicators have been used).

In summary of the laboratory resin testing, applying the derived model to laboratory test results indicates that differences do exist between resins (refer to table 5). It also indicates that performance increases do not correlate to increasing resin price. Using the effluent chloride concentration as exhaustion indicator capacity runs, it can be inferred that resin 3 has the lowest loss in overall capacity. However, resin 2 has a higher initial capacity as indicated by coefficient a (Refer to table 3 on page 25, and figure 54 in Appendix D). When cost of new resin is placed into the equation, resin 2 and 3 are very close (1506 as opposed to 1508 million gallons between recommended replacement). It should be noted that this is a number generated for comparison only, and under normal operation the process cell would be regenerated long before being fully exhausted by chloride ions.

Resin	Resin Cost for 275 ft^3 cell ($)	Capacity Loss % Cl^- Limited Exhaustion	Capacity Loss % Cond. Limited Exhaustion	T1 MM gals Cl^- Limited Exhaustion	T1 MM gals Cond Limited Exhaustion
1	71875.00	22.2	13.3	1404	60.38
2	56787.50	14.5	10.0	1506	68.94
3	55412.50	10.8	36.3	1508	60.24
4	36460.00	21.1	28.3	1308	57.85

Table 5. Summary of capacity loss data and calculated optimum resin replacement times using both effluent chloride concentration and conductivity as exhaustion indicators.

Predicting performance under typical industrial conditions requires defining exhaustion at a point where the conductivity of the outlet exceeds a predetermined conductivity level. Using effluent conductivity as exhaustion indicator, resin 2 had the lowest relative drop in capacity, with resin 1 being only slightly greater (refer to table 5 on page 27, and figure 55 in Appendix D). Figuring the new resin expense into the equation, resin 2 has the longer service life. This service life reflects the amount of time between resin changes.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Using the developed model for the case of the process water deanionizer columns, the following conclusions can be made. First, the optimum point to replace the resin is after approximately 130 million gallons of throughput. This data can now be used to improve budget estimates for coming years, as well as allowing more accurate capitalization schedules to be generated.

Using the data generated from the laboratory column contact experiments, the following recommendations can be made. First, in view of the results of the overall capacity and the capacity determined by the effluent conductivity as determinant of exhaustion runs, resin 2 is the better overall resin. Second, when resin replacement cost is figured in, resin 2 has the longest service life. This may not reflect the actual service life under process conditions, but should be used as a comparison between test resins. Finally, after the new resin is placed into service, process data should be used to generate the resin decay coefficients under field conditions. This will allow monitoring of resin condition and predict when the next resin change is due.

APPENDIX A: MODEL DERIVATION

The derivation of the model equation involves calculating the area between two exponential curves for time periods T_1 to T_2. This shaded area represents the difference in water cost between continuing to use the existing resin, and the water cost after replacing the resin at T_1.

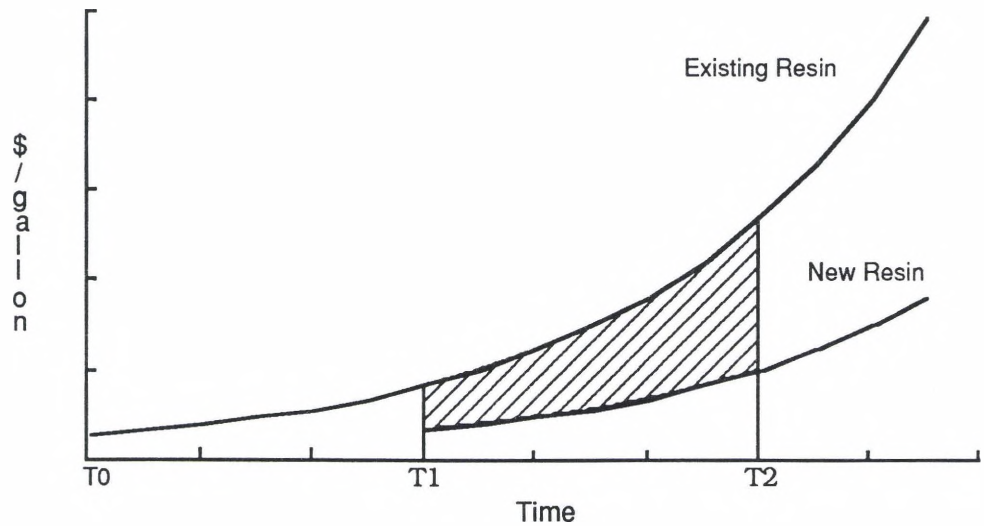

Figure 11. Plot of Deanionized Water Cost vs Time

Since resin #2 is new at point T_1, shift the time variable by subtracting T_1 from t in the capacity decay expression. Integrate both terms through the life of the new resin to arrive at the regenerant cost savings between the old and the new resins.

$$A = \text{area} = \int_{T_1}^{T_2} a_1 e^{b_1 t} dt - \int_{T_1}^{T_2} a_2 e^{b_2 (t - T_1)} dt$$

$$A = \int_{T_1}^{T_2} a_1 e^{b_1 t} dt - \int_{T_1}^{T_2} a_2 e^{b_2 t} e^{-b_2 T_1} dt$$

$$A = \int_{T_1}^{T_2} a_1 e^{b_1 t} dt - a_2 e^{-b_2 T_1} \int_{T_1}^{T_2} e^{b_2 t} dt$$

$$A = \frac{a_1}{b_1}\left[e^{b_1 T_2} - e^{b_1 T_1}\right] - \frac{a_2}{b_2} e^{-b_2 T_1}\left[e^{b_2 T_2} - e^{b_2 T_1}\right]$$

$$A = \frac{a_1}{b_1}\left[e^{b_1 T_2} - e^{b_1 T_1}\right] - \frac{a_2}{b_2}\left[e^{b_2 (T_2 - T_1)} - e^{b_2 (T_1 - T_1)}\right]$$

$$A = \frac{a_1}{b_1}\left[e^{b_1 T_2} - e^{b_1 T_1}\right] - \frac{a_2}{b_2}\left[e^{b_2 (T_2 - T_1)} - 1\right]$$

If we assume that the existing resin is to be replaced with virgin resin having the same decay behavior;

$$a_1 = a_2 = a$$
$$b_1 = b_2 = b$$
$$T_1 = T$$
$$T_2 = 2T_1 = 2T$$

$$A = \frac{a}{b}\left[e^{b(2T)} - e^{bT}\right] - \frac{a}{b}\left[e^{b(2T-T)} - 1\right]$$

$$A = \frac{a}{b}\left[e^{b(2T)} - 2e^{bT} + 1\right]$$

$$A\frac{b}{a} = \left(e^{bT} - 1\right)^2$$

$$\sqrt{A\frac{b}{a}} + 1 = e^{bT}$$

$$T = \frac{\ln\left[\sqrt{A\frac{b}{a}} + 1\right]}{b}$$

Where:	A	Area representing regenerant cost savings due to resin replacement at time T
	T	Time of resin change
	a	Initial capacity constant
	b	Decay constant

APPENDIX B: EXPERIMENTAL PROCEDURE

OBJECTIVE: To determine the service capacity of an anion exchange resin.

EQUIPMENT:

1. Metering pump with rheostat such as Cole-Parmer Masterflex
2. Pump tubing size 13 (.030" ID), such as masterflex series 6404-13
3. Pump tubing size 16 (.123" ID), such as masterflex series 6404-16
4. Chromatography column 1" by 24"
5. Finger clamps
6. Ring stand
7. Neoprene stopper size 5 1/2
8. Powder funnel 2" OD
9. Latex tubing .50" OD
10. Graduated cylinder 100 ml
11. Glass wool
12. SS 100 mesh screen 1" diameter
13. Glass tubing .25" OD

REAGENTS: 4% by weight NaOH in distilled water

Distilled water

Decationized water (~15 liters per run)

PROCEDURE:

Calibrate the pump by plotting rheostat setting as a function of flow rate. Collect data points by recording the time to collect a volume of water (approximately 50 ml) in a graduated cylinder. This should be performed both on the small and large pump tubing.

Assemble the test column in the backwash configuration (Refer to figure 12 and figure 13). Charge the column with approximately 40 to 50 grams of the resin to be tested, flush with distilled water. Backwash resin with distilled water ensuring that all air has been removed from the bead surfaces. Since most anion resins are shipped in their salt form, perform the regeneration cycle twice to ensure complete regeneration. Measure height of the resin bed prior to second backwashing and calculate volume of resin from the column diameter and this height. If bed volume is not between 50 to 55 cm3 (~11 cm bed height), adjust by adding resin.

There are five stages in a column contact resin cycle: Backwash, Regeneration, Slow rinse, Fast rinse, and Operation (Refer to table 6 for flow rates and times). Backwash refers to the upward

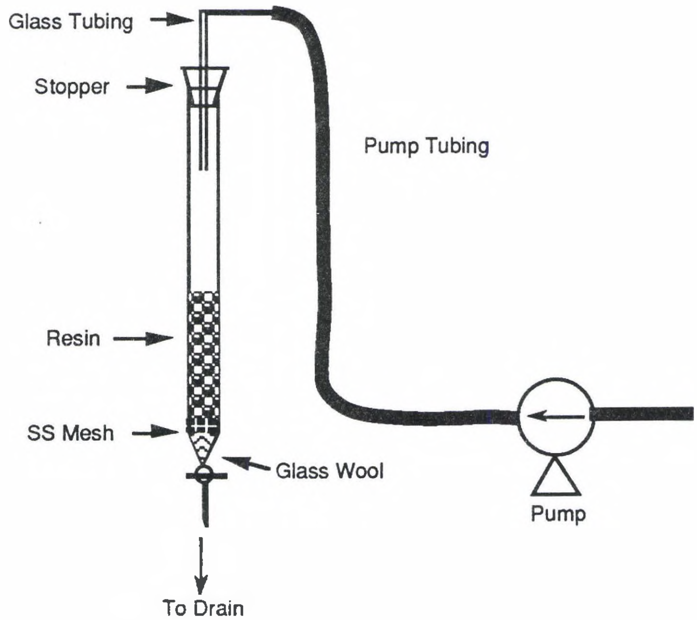

Figure 12. Diagram of column contact experimental apparatus. This is the orientation for regeneration, slow rinse, fast rinse, and operation cycles.

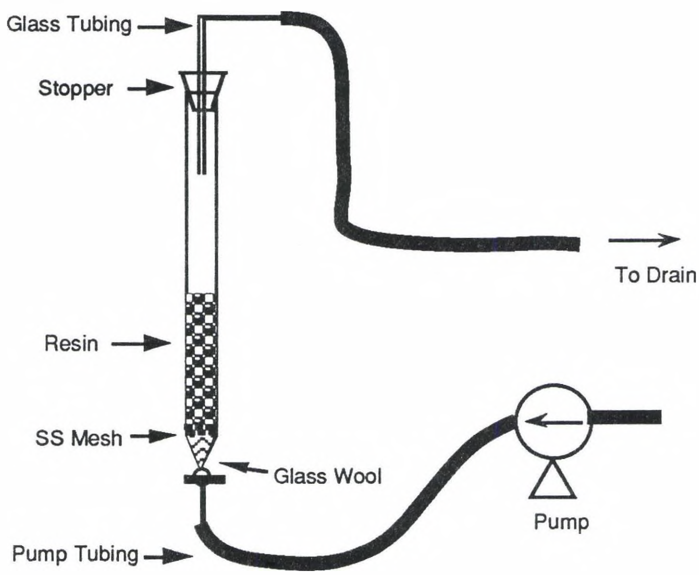

Figure 13. Diagram of Column Contact Experimental apparatus. This is the orientation for the backwash cycle.

flow of distilled water through the column. It performs three important functions; First, it allows removal of particulates that have been retained due to the filtering nature of the resin bed. Second, it will reclassify the bed to prevent channeling and reduce pressure drop across the cell. Finally, it allows the removal of colloidal material adhering to the bead surface by generating a scrubbing effect from bead movement and collision with other beads and the walls of the cell. Bed expansion during backwash should be between 50 to 75 percent. Less than 50 percent reduces the ability of the bead to migrate within the cell, greater than 75 percent expansion makes the bead spacing too great and reduces the scrubbing action.

Regeneration refers to the down-flow of sodium hydroxide through the cell. Because of the large concentration gradient, the -OH groups will displace the other anions within the bead. Residence time is important, as is concentration of the regenerant. The slow rinse step involves down-flow of distilled water at the same rate as the regenerant step. The sodium hydroxide is moved through the cell slowly to allow full regeneration of the lower resin layer. Once a column volume has passed through the cell, the flow rate is increased in the fast rinse portion of the cycle. The fast rinse ensures that all regenerant has been flushed from the cell, and that almost all of the sodium has had a chance to migrate from the resin and be removed. The Operation stage involves operating the column to the resin exhaustion point with a down-flow of decationized water through the cell (refer to table 6 on page 38 for individual stage flow rates).

Samples are taken at regular intervals from the outlet. The time is recorded, and assay for chloride concentration, pH, and conductivity is performed. Flow rate is checked several times during the run, as is the feed chloride concentration, pH and conductivity. Run termination is indicated when the chloride concentration exceeds that of the feed. Data is plotted, and the area under the curve is determined.

Flow rate of the operation step needs to be determined experimentally. If the flow rate is too fast, there is a marked decrease in the capacity due to the anions inability to diffuse completely into the resin bead. Too slow of a flow rate will result in run times of excessive length. The flow rate is determined by performing exhaustion runs at various speeds, and calculating the capacity. This capacity is then plotted against flow rate. At the point in the curve where there is a sharp inflection, the flow rate is too fast. Choose a flow rate less than this value, but that will allow completion of the experimental runs in an efficient manner.

Comparison of individual resin decay coefficients involves finding the loss in capacity between a new or virgin sample, and one that has been aged. Each run should be performed in triplicate to eliminate variation in feed concentration, temperature, and analytical error.

Step	Reagent	Flow rate ml/min	Duration minutes
Backwash	Distilled Water	110	15
Regeneration	4% NaOH	2	45
Slow Rinse	Distilled Water	2	15
Fast Rinse	Distilled Water	15	60
Exhaustion	Decat Water	75	360

Table 6 Flow rates for column contact experiment exhaustion and regeneration cycle.

APPENDIX C: PLANT DATA

This appendix contains the raw data and plots generated from process data on two water deanionization cells (named North and South for the purpose of this study). Data was collected for three years, plotted and numerically integrated. The data is arranged as follows;

Numerical Data

This data reflects the operation of a process water deanionizer containing 275 ft^3 of resin. Data was collected from daily operational log sheets using a totalizer reading to record total volume processed during each cycle. This volume was then divided by the cost of regeneration (a constant) to arrive at a unit water cost per million gallons processed.

		Totalizer Readings (tens of gallons)		Total Flow (million gallons)		Cell Capacity (million gallons)				DI Water Cost ($/million gallons)			
Cycle	Date	N Anion	S Anion	North	South	North	South	N Avg(25)	S Avg(25)	North	South	N Avg(25)	S Avg(25)
1	8-1-86	595474	312930	0.58	0.40	0.58		0.56	0.49	$449.84		$468.70	$529.29
2		653627	353407	1.16	0.96	0.58	0.56	0.56	0.49	$449.85	$468.33	$469.03	$530.42
3		711779	409264	1.75	1.52	0.59	0.56	0.56	0.49	$442.14	$468.34	$469.28	$535.21
4		770945	465120	2.32	2.01	0.56	0.49	0.56	0.49	$464.36	$532.56	$470.63	$538.43
5		827279	514240	2.90	2.49	0.58	0.48	0.56	0.48	$451.23	$543.47	$470.77	$544.09
6		885253	562374	3.47	2.86	0.58		0.55	0.48	$453.62		$471.46	$544.37
7		942921	599281	4.07	3.23			0.56	0.48			$471.14	$544.09
8	9-1-86	2679	636188	4.67	3.74	0.60	0.51	0.56	0.48	$435.45	$516.44	$471.32	$544.63
9		62753	686841	5.24	4.22	0.57	0.48	0.55	0.48	$457.29	$549.31	$472.31	$546.78
10		119958	734463	5.77	4.71	0.52	0.49	0.55	0.48	$502.89	$528.90	$472.67	$546.68
11		171976	783923	6.33	5.12	0.56		0.55	0.48	$464.56		$472.06	$546.90
12		228286	825195	6.74	5.64	0.42	0.51	0.55	0.48		$509.61	$472.85	$546.60
13		269940	876527	7.34	6.10	0.59	0.46	0.56	0.48	$442.77	$564.83	$469.81	$548.06
14	10-1-86	329021	922841	7.87	6.58	0.54	0.48	0.55	0.48	$485.31	$543.77	$471.41	$545.27
15		382924	970949	8.41	7.04	0.53	0.46	0.56	0.48	$490.89	$563.99	$471.32	$544.57
16		436214	17332	8.99	7.55	0.59	0.50	0.55	0.48	$445.88	$521.84	$472.27	$545.52
17		494883	67461	9.58	8.01	0.59	0.47	0.55	0.48	$445.88	$559.73	$473.32	$546.34
18		553552	114197	10.15	8.53	0.57	0.52	0.55	0.48	$459.42	$502.68	$473.97	$547.12
19		610492	166237	10.68	9.02	0.53	0.49	0.55	0.48	$491.83	$537.63	$474.67	$549.85
20		663680	214894	11.24	9.51	0.56	0.49	0.55	0.47	$470.23	$532.58	$474.62	$552.86
21	11-1-86	719311	264012	11.83	10.01	0.59	0.50	0.55	0.47	$442.44	$524.26	$474.58	$554.73
22		778436	313910	12.35	10.51	0.52	0.50	0.55	0.47	$506.36	$520.98	$475.96	$556.91
23		830098	364122	12.86	11.01	0.52	0.50	0.55	0.47	$506.37	$527.94	$475.17	$560.65
24		881759	413672	13.45	11.47	0.59	0.46	0.55	0.46	$443.00	$568.08	$475.60	$563.57
25		940810	459721	14.04	11.96	0.59	0.49	0.55	0.46	$443.01	$530.45	$476.68	$563.38
26		999860	509037	14.55	12.43	0.51	0.47	0.55	0.46	$516.07	$559.26	$477.73	$564.32
27	12-1-86	50550	555812	15.12	12.90	0.57	0.47	0.55	0.46	$457.65	$556.53	$476.82	$564.23
28		107711	602817	15.70	13.36	0.57	0.46	0.55	0.46	$455.65	$572.32	$478.06	$564.41
29		165122	648525	16.25	13.85	0.55	0.49	0.55	0.46	$474.03	$532.43	$478.86	$564.34
30		220307	697657	16.81	14.22	0.56	0.38	0.55	0.46	$467.78	$697.59	$479.07	$566.53
31		276230	735157	17.37	14.70	0.56	0.48	0.54	0.47	$467.78	$549.94	$480.20	$561.54
32		332153	782725	17.95	15.18	0.59	0.49	0.54	0.47	$446.25	$537.77	$481.93	$562.05
33		390774	831369	18.50	15.65	0.55	0.47	0.54	0.46	$475.80	$557.90	$484.39	$563.59
34		445754	878258	19.07	16.11	0.57	0.46	0.54	0.46	$458.58	$569.69	$485.14	$564.02
35	1-1-87	502798	924177	19.63	16.40	0.56		0.54	0.46	$466.35		$486.37	$564.75
36		558892	952820	20.17	16.89	0.54	0.49	0.54	0.46	$485.40	$533.93	$487.32	$566.34
37		612785	1814	20.71	17.37	0.54	0.48	0.53	0.46	$485.39	$539.57	$490.94	$567.00
38		666679	50296	21.22	17.86	0.51	0.48	0.53	0.46	$513.27	$543.35	$495.60	$568.26
39		717645	98441	21.76	18.38	0.54	0.52	0.52	0.46	$482.85	$499.04	$498.85	$567.37
40		771822	150861	22.31	18.88	0.54	0.50	0.52	0.46	$482.86	$526.85	$499.64	$571.07
41		825998	200514	22.81	19.32	0.50	0.44	0.52	0.46	$519.37	$590.67	$505.33	$573.83
42	2-1-87	876366	244802	23.36	19.80	0.55	0.48	0.51	0.45	$471.55	$541.13	$508.13	$575.80
43		931842	293144	23.93	20.25	0.57	0.45	0.51	0.45	$461.42	$581.02	$516.70	$576.32

Cycle	Date	Totalizer Readings (tens of gallons) N Anion	S Anion	Total Flow (million gallons) North	South	Cell Capacity (million gallons) North	South	N Avg(25)	S Avg(25)	DI Water Cost ($/million gallons) North	South	N Avg(25)	S Avg(25)
44		988536	338167	24.48	20.71	0.55	0.46	0.50	0.46	$476.94	$567.49	$525.15	$574.29
45		43385	384264	25.01	21.14	0.53	0.42	0.49	0.46	$490.64	$619.97	$533.17	$574.45
46		96702	426459	25.57	21.59	0.56	0.45	0.49	0.46	$469.01	$579.66	$535.50	$572.43
47		152478	471588	26.18	22.04		0.45	0.48	0.46		$577.73	$542.27	$572.30
48		213737	516868	26.72	22.46	0.54	0.42	0.48	0.46	$485.06	$617.33	$547.37	$574.93
49	3-1-87	267667	559243	27.23	22.90	0.50	0.44	0.47	0.46	$518.62	$601.20	$553.67	$573.06
50		318108	602755	27.79	23.14	0.56		0.47	0.46	$467.84		$558.77	$573.41
51		374023	627391	28.35	23.62	0.56	0.47	0.46	0.46	$466.80	$551.09	$566.91	$574.85
52		430063	674860	28.88	24.09	0.53	0.47	0.46	0.45	$490.85	$557.24	$573.05	$576.22
53		483357	721805	29.41	24.56	0.54	0.47	0.45	0.45	$488.03	$560.74	$580.07	$577.74
54		536959	768457	29.97	25.01	0.55	0.46	0.44	0.45	$474.54	$570.66	$588.46	$578.48
55		592085	814298	30.12	25.46		0.45	0.44	0.45		$583.55	$595.67	$584.03
56		607655	859126	30.65	25.94	0.53	0.47	0.44	0.45	$495.08	$552.39	$596.68	$583.11
57	4-1-87	660494	906483	31.16	26.27	0.51		0.43	0.45	$510.72		$603.82	$583.55
58		711715	940314	31.68	26.73	0.52	0.46	0.43	0.45	$502.87	$572.17	$608.96	$584.09
59		763735	986034	32.21	27.19	0.53	0.46	0.42	0.44	$493.95	$567.66	$618.65	$588.14
60		816695	32117	32.24	27.64		0.45	0.42	0.45		$587.40	$625.70	$587.13
61		819764	76651	32.40	28.07		0.43	0.42	0.45		$605.36	$625.19	$587.00
62		835041	119864	32.85	28.55	0.45	0.48	0.42	0.45	$578.97	$548.54	$625.75	$586.05
63		880224	167553	33.28	28.75	0.43		0.42	0.45	$610.29		$627.33	$587.61
64		923088	187593	33.71	29.24	0.43	0.50	0.42	0.45	$602.64	$525.27	$625.36	$586.29
65	5-1-87	966496	237395	33.97	29.70		0.46	0.42	0.44		$574.33	$626.39	$589.03
66		992127	282943	34.38	30.15	0.42	0.45	0.42	0.44	$626.06	$586.76	$625.68	$589.66
67		33911	327526	34.83	30.55	0.44	0.41	0.42	0.44	$589.48	$642.66	$625.66	$588.11
68		78288	368231	35.20	31.03	0.38	0.47	0.42	0.45	$696.55	$551.89	$624.88	$585.95
69		115844	415631	35.60	31.51	0.40	0.49	0.42	0.45	$661.03	$536.91	$622.38	$585.24
70		155418	464353	35.99	31.97	0.39	0.46	0.42	0.45	$668.89	$571.22	$621.75	$586.61
71		194527	510149	36.13	32.43		0.46	0.42	0.45		$569.95	$621.03	$586.60
72		208893	556047	36.57	32.88	0.44	0.45	0.42	0.44	$600.46	$576.73	$622.15	$587.87
73	6-1-87	252459	601405	36.96	33.29	0.39	0.40	0.42	0.45	$674.11	$646.34	$621.17	$586.90
74		291265	641878	37.38	33.75	0.43	0.46	0.42	0.45	$615.27	$571.28	$620.22	$584.46
75		333782	687669	37.80	34.18	0.41	0.43	0.42	0.45	$632.27	$610.06	$621.07	$585.10
76		375156	730549	38.21	34.60	0.42	0.43	0.42	0.45	$625.78	$610.06	$625.04	$583.91
77		416959	773429	38.67	35.05	0.46	0.45	0.42	0.45	$572.99	$583.12	$629.98	$585.35
78		462613	818290	39.09	35.49	0.42	0.44	0.41	0.44	$627.28	$593.44	$637.40	$588.34
79		504316	862371	39.49	35.95	0.40	0.45	0.41	0.44	$652.47	$577.94	$642.38	$588.40
80		544409	907634	39.93	36.30	0.44	0.36	0.41	0.44	$596.92	$736.51	$643.09	$588.96

		Totalizer Readings (tens of gallons)		Total Flow (million gallons)		Cell Capacity (million gallons)				DI Water Cost ($/million gallons)			
Cycle	Date	N Anion	S Anion	North	South	North	South	N Avg(25)	S Avg(25)	North	South	N Avg(25)	S Avg(25)
81	7-1-87	588233	943152	40.35	36.77	0.42	0.47	0.40	0.45	$618.69	$562.12	$648.08	$583.45
82		630515	989689	40.76	37.23	0.41	0.47	0.40	0.45	$631.23	$562.12	$649.01	$584.68
83		671957	36226	41.20	37.67	0.43	0.44	0.40	0.45	$606.08	$597.19	$649.38	$587.56
84		715119	80030	41.57	38.05	0.37	0.38	0.40	0.45	$702.81	$688.37	$650.92	$587.01
85		752340	118032	41.99	38.53	0.42	0.48	0.40	0.45	$615.75	$545.13	$647.30	$581.65
86		794824	166020	42.42	38.98	0.43	0.45	0.41	0.44	$614.30	$584.06	$645.55	$591.20
87		837408	210809	42.83	39.43	0.41	0.45	0.40	0.44	$638.75	$581.05	$646.98	$597.83
88		878362	255830	43.26	39.88	0.43	0.45	0.41	0.44	$613.24	$584.93	$641.96	$597.46
89	8-1-87	921020	300552	43.72	40.35	0.46	0.47	0.40	0.44	$568.62	$555.21	$646.36	$598.70
90		967025	347668	43.94	40.59			0.40	0.43			$655.27	$602.21
91		989278	372105	44.37	40.84	0.43		0.40	0.44	$609.78		$657.53	$601.05
92		32178	397399	44.63	41.32		0.47	0.40	0.43		$552.03	$660.80	$607.39
93		58671	444787	45.09	41.60	0.46		0.39	0.43	$573.95		$664.71	$611.00
94		104249	473196	45.50	42.09	0.41	0.49	0.39	0.43	$631.40	$537.74	$671.05	$611.00
95		145680	521843	45.91	42.55	0.41	0.46	0.39	0.42	$645.21	$564.77	$675.22	$621.88
96		186224	568162	46.31	43.01	0.40	0.46	0.39	0.42	$650.22	$571.08	$679.46	$628.28
97	9-1-87	226456	613969	46.71	43.45	0.40	0.44	0.38	0.41	$649.05	$598.78	$686.21	$639.60
98		266760	657657	47.16	43.92	0.45	0.47	0.38	0.40	$579.27	$556.02	$688.33	$647.06
99		311919	704705	47.57	44.11	0.40		0.38	0.40	$648.22		$693.77	$654.64
100		352275	723928	47.98	44.32	0.41		0.38	0.40	$636.07		$696.55	$654.64
101		393402	745050	48.33	44.55	0.35		0.37	0.40	$748.44		$702.13	$656.03
102		428354	767655	48.67	44.95	0.34	0.41	0.37	0.40	$770.78	$643.26	$702.15	$659.90
103		462293	808322	49.01	45.36	0.34	0.40	0.37	0.39	$768.15	$648.83	$702.71	$667.77
104		496348	848640	49.35	45.80	0.34	0.44	0.38	0.39	$768.15	$594.59	$696.25	$671.43
105		530403	892636	49.74	46.02	0.39		0.38	0.39	$670.41		$693.42	$676.13
106		569423	914921	50.10	46.45	0.36	0.43	0.38	0.38	$720.69	$601.57	$694.51	$681.95
107	10-1-87	605721	958406	50.51	46.50	0.41		0.38	0.38	$639.69		$693.31	$692.08
108		646615	963110	50.92	46.93	0.41	0.43	0.37	0.38	$639.71	$614.20	$703.76	$692.68
109		687508	5701	51.33	47.22	0.41		0.37	0.37	$639.88		$712.17	$699.23
110		728390	35393	51.76	47.52	0.43		0.36	0.38	$613.88		$718.05	$697.35
111		771003	65084	52.21	47.89	0.45	0.36	0.36	0.38	$579.83	$719.42	$722.27	$695.43
112		816119	101446	52.49	48.25		0.37	0.36	0.38		$708.22	$733.73	$693.69
113		844345	138383	52.97	48.71	0.48	0.45	0.35	0.38	$542.43	$575.45	$738.58	$691.74
114		892571	183842	53.33	49.14	0.36	0.43	0.35	0.38	$721.08	$604.54	$754.59	$696.60
115		928849	227114	53.67	49.57	0.33	0.43	0.34	0.37	$784.32	$607.70	$762.64	$701.46
116		962202	270161	54.03	50.02	0.37	0.45	0.34	0.37	$714.37	$583.20	$759.95	$708.04

		Totalizer Readings (tens of gallons)		Total Flow (million gallons)		Cell Capacity (million gallons)				DI Water Cost ($/million gallons)			
Cycle	Date	N Anion	S Anion	North	South	North	South	N Avg(25)	S Avg(25)	North	South	N Avg(25)	S Avg(25)
117	11-1-87	998821	315016	54.42	50.37	0.38	0.35	0.34	0.37	$685.11	$740.05	$768.02	$714.04
118		37004	350364	54.75	50.61	0.34		0.34	0.37	$774.84		$773.50	$709.71
119		70765	374269	55.12	50.85	0.36		0.34	0.37	$720.94		$773.90	$707.02
120		107050	398175	55.47	51.21	0.35	0.36	0.33	0.37	$738.84	$728.55	$782.44	$704.58
121		142456	434081	55.81	51.60	0.34	0.39	0.34	0.37	$758.29	$670.14	$780.51	$703.42
122		176954	473117	56.12	51.93	0.31	0.33	0.34	0.37	$850.35	$786.16	$780.58	$702.89
123		207717	506392	56.50	52.29	0.37	0.36	0.34	0.37	$699.88	$733.29	$773.65	$700.72
124		245094	542066	56.66	52.68		0.39	0.34	0.38		$669.09	$775.00	$696.74
125		261863	581163	57.03	52.77	0.37		0.34	0.38	$711.88		$773.65	$695.94
126		298610	590168	57.37	53.16	0.34	0.38	0.34	0.38	$770.14	$680.62	$779.05	$693.55
127		332577	628603	57.72	53.51	0.35	0.35	0.34	0.38	$749.15	$738.32	$779.46	$694.10
128	12-1-87	367496	664034	58.05	53.83	0.33	0.32	0.33	0.38	$787.34	$822.94	$780.97	$692.29
129		400721	695822	58.48	54.19	0.42	0.36	0.34	0.38	$617.64	$721.46	$780.65	$687.33
130		443075	732081	58.67	54.58		0.39	0.33	0.38		$673.26	$791.65	$685.79
131		462929	770936	58.86	54.90		0.32	0.33	0.38		$815.42	$795.24	$689.26
132		481330	803017	59.03	55.22		0.32	0.33	0.38		$811.05	$797.20	$686.85
133		498842	835271	59.32	55.59	0.29	0.37	0.33	0.38	$898.15	$704.90	$798.47	$685.17
134		527968	872382	59.64	55.95	0.32	0.35	0.33	0.38	$825.82	$743.95	$796.24	$689.91
135		559645	907545	59.99	56.34	0.35	0.40	0.33	0.38	$756.78	$659.96	$796.82	$687.41
136		594212	947183	60.37	56.74	0.38	0.40	0.33	0.38	$685.95	$655.77	$798.94	$688.92
137		632348	987074	60.70	57.13	0.33	0.39	0.32	0.38	$786.89	$678.85	$805.25	$690.86
138		665592	25609	61.01	57.52	0.30	0.39	0.32	0.38	$857.88	$664.30	$806.20	$692.90
139	1-1-88	696085	64988	61.32	57.91	0.32	0.39	0.33	0.38	$825.32	$664.13	$803.44	$697.55
140		727781	104377	61.61	58.18	0.28		0.33	0.37	$926.65		$799.39	$701.07
141		756011	130593	61.97	58.53	0.36	0.35	0.33	0.37	$726.15	$738.55	$790.55	$701.64
142		792036	166013	62.25	58.91	0.29	0.38	0.33	0.37	$912.82	$687.94	$793.68	$703.26
143		820694	204039	62.58	59.31	0.33	0.40	0.33	0.37	$795.58	$649.68	$787.77	$701.45
144		853575	244304	62.91	59.71	0.33	0.40	0.33	0.37	$783.92	$652.68	$783.88	$701.86
145		886945	284384	63.20	60.12	0.28	0.40	0.33	0.37	$928.73	$652.70	$791.83	$703.96
146		915112	324463	63.57	60.49	0.37	0.37	0.33	0.37	$702.59	$699.99	$791.78	$710.37
147		952345	361834	63.91	60.89	0.34	0.40	0.33	0.36	$759.83	$658.75	$796.95	$719.34
148		986773	401545	64.29	61.25	0.37	0.36	0.33	0.36	$700.07	$725.80	$799.01	$726.32
149		24140	437587	64.65	61.65	0.36	0.41	0.32	0.36	$724.96	$641.24	$808.51	$734.39
150	2-1-88	60224	478382	65.00	62.06	0.35	0.40	0.32	0.35	$745.11	$651.79	$813.83	$740.37
151		95332	518517	65.31	62.46	0.31	0.41	0.32	0.35	$834.38	$640.77	$819.76	$751.93
152		126684	559342	65.46	62.75			0.32	0.34			$815.05	$759.37

		Totalizer Readings (tens of gallons)		Total Flow (million gallons)		Cell Capacity (million gallons)				DI Water Cost ($/million gallons)			
Cycle	Date	N Anion	S Anion	North	South	North	South	N Avg(25)	S Avg(25)	North	South	N Avg(25)	S Avg(25)
153		141792	588153	65.60	62.92			0.32	0.34			$813.69	$759.23
154		155805	605283	65.80	63.05			0.32	0.35			$816.59	$753.54
155		175965	617489	66.06	63.31			0.32	0.34			$815.66	$758.54
156		201730	644252	66.36	63.66	0.30	0.35	0.32	0.35	$870.36	$751.28	$816.84	$754.11
157		231786	679072	66.68	64.01	0.31	0.35	0.32	0.35	$838.52	$749.98	$813.01	$751.13
158		262983	713952	66.99	64.35	0.32	0.34	0.32	0.35	$825.95	$764.52	$812.88	$750.18
159		294655	748169	67.30	64.67	0.31	0.32	0.32	0.35	$839.92	$827.73	$813.91	$749.49
160		325800	779773	67.61	64.89	0.31		0.32	0.35	$839.95		$813.35	$748.37
161	3-1-88	356944	802372	67.94	65.06	0.33		0.32	0.35	$801.09		$810.30	$746.03
162		389599	818815	68.54	65.22			0.32	0.35			$811.19	$747.67
163		449286	835257	68.62	65.59		0.37	0.32	0.35		$716.17	$816.04	$752.08
164		457251	871784	68.94	65.94	0.33	0.35	0.32	0.35	$799.47	$750.74	$816.90	$754.18
165		489972	906629	69.29	66.30	0.35	0.36	0.32	0.35	$747.56	$726.57	$818.72	$756.16
166		524965	942633	69.65	66.66	0.36	0.37	0.32	0.35	$735.93	$712.17	$823.33	$757.12
167		560511	979365	69.98	67.00	0.33	0.34	0.32	0.34	$782.77	$774.06	$827.43	$761.47
168		593930	13160	70.32	67.40	0.34	0.40	0.31	0.34	$778.51	$656.45	$836.34	$763.25
169		627532	53010	70.68	67.80	0.36	0.40	0.31	0.34	$723.14	$656.45	$841.18	$768.46
170		663707	92860	70.95	68.18	0.27	0.38	0.31	0.34	$980.97	$689.08	$849.02	$775.19
171		690374	130823	71.23	68.52	0.28	0.34	0.31	0.34	$927.25	$776.01	$844.08	$772.14
172	4-1-88	718586	164533	71.56	68.80	0.33	0.29	0.31	0.34	$794.03	$913.29	$835.43	$771.97
173		751531	193176	71.75	69.13		0.33	0.31	0.34		$790.91	$836.87	$764.65
174		770652	226251	72.05	69.42	0.30	0.29	0.31	0.34	$870.39	$917.17	$836.25	$761.56
175		800707	254773	72.37	69.59	0.32		0.31	0.35	$815.80		$834.48	$752.46
176		832773	272255	72.68	69.90	0.31	0.30	0.31	0.35	$852.41	$861.90	$837.25	$752.26
177		863462	302606	73.03	70.24	0.35	0.35	0.31	0.35	$750.50	$754.07	$838.49	$746.86
178		898318	337297	73.36	70.59	0.33	0.35	0.31	0.35	$788.74	$756.71	$843.72	$746.23
179		931484	371867	73.66	70.99	0.30	0.40	0.31	0.35	$879.31	$659.59	$847.46	$746.17
180		961234	411527	73.99	71.29	0.33	0.30	0.31	0.35	$796.50	$874.52	$845.13	$749.45
181		994077	441440	74.30	71.67	0.31	0.39	0.31	0.35	$843.61	$671.74	$845.47	$744.34
182		25086	480383	74.63	72.05	0.34	0.38	0.31	0.35	$780.34	$691.30	$844.49	$744.54
183		58609	518224	74.94	72.41	0.31	0.36	0.31	0.35	$835.39	$729.59	$848.26	$745.50
184	5-1-88	89923	554079	75.25	72.76	0.31	0.35	0.31	0.35	$851.10	$749.02	$854.07	$744.84
185		120659	589004	75.57	73.09	0.32	0.33	0.31	0.35	$826.44	$798.69	$853.41	$747.50
186		152312	621757	75.91	73.46	0.34	0.37	0.31	0.35	$771.03	$698.14	$855.34	$745.43
187		186240	659227	76.23	73.80	0.32	0.33	0.30	0.35	$821.44	$787.48	$861.32	$746.37
188		218086	692446	76.50	74.09	0.28	0.30	0.30	0.35	$946.16	$875.87	$865.15	$746.24

		Totalizer Readings (tens of gallons)		Total Flow (million gallons)		Cell Capacity (million gallons)				DI Water Cost ($/million gallons)			
Cycle	Date	N Anion	S Anion	North	South	North	South	N Avg(25)	S Avg(25)	North	South	N Avg(25)	S Avg(25)
189		245734	722313	76.81	74.43	0.31	0.34	0.30	0.35	$838.15	$767.09	$864.63	$742.07
190		276945	756415	77.12	74.76	0.31	0.33	0.30	0.35	$845.49	$803.18	$859.56	$741.00
191		307885	788985	77.43	75.11	0.31	0.35	0.30	0.35	$857.15	$749.32	$862.48	$738.02
192		338404	823896	77.66	75.43		0.32	0.30	0.35		$822.70	$865.00	$739.72
193		361281	855693	77.91	75.75	0.25	0.32	0.30	0.35	$1,032.54	$822.73	$864.02	$737.01
194	6-1-88	386616	887489	78.20	75.95	0.29		0.30	0.36	$893.33		$862.11	$735.71
195		415899	907515	78.50	76.27	0.29	0.33	0.30	0.35	$893.33	$798.66	$863.71	$738.27
196		445182	940269	78.68	76.69		0.41	0.31	0.36		$635.49	$854.69	$735.07
197		463753	981433	79.04	77.18	0.36		0.31	0.35	$735.00		$850.81	$741.01
198		499344	30752	79.36	77.54	0.32	0.36	0.31	0.35	$825.09	$724.52	$855.74	$742.38
199		531049	66858	79.67	77.90	0.32	0.36	0.30	0.35	$822.29	$721.32	$858.26	$738.90
200		562862	103124	79.99	78.28	0.32	0.38	0.31	0.35	$826.63	$687.05	$856.67	$743.19
201		594508	141199	80.29	78.63	0.30	0.35	0.31	0.35	$884.30	$747.67	$857.04	$744.93
202		624090	176187	80.58	79.00	0.30	0.36	0.30	0.35	$884.30	$719.02	$858.97	$744.66
203		653672	212569	80.88	79.35	0.30	0.35	0.31	0.35	$865.78	$738.86	$854.73	$746.68
204		683887	247974	81.18	79.70	0.30	0.35	0.31	0.35	$875.54	$755.16	$851.77	$747.00
205		713765	282615	81.50	80.06	0.32	0.36	0.31	0.35	$822.78	$727.12	$849.27	$753.01
206		745559	318592	81.83	80.41	0.33	0.36	0.31	0.35	$803.77	$733.56	$853.17	$753.29
207	7-1-88	778105	354253	82.14	80.80	0.32	0.39	0.31	0.35	$820.87	$675.64	$857.49	$754.48
208		809973	392971	82.45	81.17	0.30	0.37	0.30	0.35	$865.61	$711.65	$859.02	$756.35
209		840194	429730	82.71	81.53	0.26	0.37	0.31	0.35	$995.45	$714.84	$856.79	$752.07
210		866473	466325	83.02	81.85	0.31	0.32	0.31	0.35	$835.77	$819.43	$851.84	$751.61
211		897773	498249	83.32	82.10	0.30		0.31	0.35	$872.04		$852.56	$749.03
212		927771	523200	83.61	82.47	0.29	0.36	0.31	0.35	$907.31	$717.76	$848.26	$749.03
213		956603	559646	83.90	82.80	0.29	0.33	0.31	0.35	$914.16	$784.18	$842.64	$743.44
214		985219	593005	84.18	83.14	0.28	0.34	0.31	0.35	$931.41	$760.49	$832.79	$740.69
215		13305	627403	84.53	83.50	0.35	0.35	0.31	0.35	$737.09	$741.59	$837.37	$740.31
216	8-1-88	48795	662678	84.82	83.86	0.28	0.36	0.31	0.35	$918.91	$729.77	$850.82	$738.74
217		77263	698524	85.10	84.19	0.28	0.33	0.31	0.35	$921.01	$791.73	$848.53	$740.21
218		105666	731565	85.41	84.53	0.31	0.35	0.31	0.36	$841.19	$751.90	$845.50	$736.68
219		136764	766356	85.68	84.87	0.27	0.33	0.31	0.36	$968.40	$787.25	$842.42	$735.52
220		163777	799585	85.96	85.19	0.28	0.33	0.31	0.35	$938.49	$802.46	$836.98	$739.26
221		191651	832184	86.33	85.56	0.37	0.36	0.31	0.36	$701.70	$717.56	$832.65	$736.15
222		228931	868640	86.68	85.90	0.34	0.34	0.31	0.36	$764.27	$762.24	$841.99	$736.43
223		263159	902959	86.99	86.24	0.31	0.34	0.31	0.36	$844.23	$776.73	$844.82	$735.70
224		294145	936638	87.28	86.64	0.29	0.40	0.31	0.36	$890.66	$649.80	$847.11	$732.07

		Totalizer Readings (tens of gallons)		Total Flow (million gallons)		Cell Capacity (million gallons)				DI Water Cost ($/million gallons)			
Cycle	Date	N Anion	S Anion	North	South	North	South	N Avg(25)	S Avg(25)	North	South	N Avg(25)	S Avg(25)
225		323516	976896	87.61	86.95	0.33	0.31	0.31	0.36	$785.76	$839.63	$849.76	$736.12
226		356808	8052	87.93	87.31	0.31	0.36	0.31	0.36	$835.85	$726.43	$853.63	$727.33
227	9-1-88	388105	44063	88.20	87.66	0.28	0.35	0.31	0.36	$940.85	$740.83	$848.74	$729.98
228		415909	79374	88.54	88.00	0.34	0.34	0.31	0.36	$780.67	$769.40	$842.04	$729.50
229		449418	113374	88.87	88.35	0.33	0.35	0.31	0.36	$793.22	$746.60	$842.70	$726.60
230		482397	148412	89.19	88.63	0.32	0.28	0.31	0.36	$811.65	$946.23	$846.24	$723.93
231		514627	176058	89.47	88.99	0.28	0.36	0.31	0.37	$929.92	$733.72	$847.96	$714.64
232		542758	211711	89.76	89.33	0.29	0.34	0.31	0.37	$916.97	$762.64	$844.24	$716.23
233		571286	246012	89.99	89.70		0.37	0.31	0.37		$715.21	$838.40	$715.80
234		594198	282588	90.31	90.11	0.32	0.42	0.31	0.36	$812.20	$627.69	$835.00	$718.13
235		626406	324264	90.72	90.48		0.37	0.31	0.36		$704.63	$832.90	$723.47
236	10-1-88	667056	361389	91.40	90.60			0.31	0.36			$834.27	$723.80
237		735082	372587	91.73	90.71	0.34		0.31	0.36	$779.25		$832.83	$723.45
238		768652	383785	92.07	91.14	0.34	0.43	0.31	0.36	$779.25	$611.96	$837.50	$723.29
239		802222	426532	92.44	91.50	0.37	0.36	0.31	0.36	$705.89	$716.80	$843.50	$726.90
240		839281	463027	92.68	91.85	0.24	0.35	0.31	0.36	$1,084.11	$751.04	$853.78	$728.74
241		863411	497858	92.92	92.22	0.24	0.37	0.31	0.36	$1,084.11	$705.56	$846.11	$725.70
242		887541	534934	93.22	92.56	0.30	0.34	0.31	0.36	$860.96	$765.81	$835.17	$727.26
243		917925	569093	93.27	92.93		0.37	0.31	0.36		$705.07	$837.32	$727.30
244		922340	606195	93.60	93.29	0.34	0.36	0.31	0.36	$778.88	$723.80	$837.36	$734.32
245		955926	642337	93.92	93.58	0.31	0.29	0.31	0.36	$831.67	$905.08	$843.07	$736.24
246		987380	671240	94.23	93.94	0.31	0.36	0.31	0.36	$831.67	$722.88	$849.08	$731.55
247	11-1-88	18834	707428	94.53	94.31	0.30	0.36	0.31	0.36	$883.53	$724.00	$851.35	$735.78
248		48442	743560	94.85	94.66	0.32	0.35	0.31	0.35	$819.07	$743.82	$851.26	$739.73
249		80380	778729	95.14	95.04	0.29	0.38	0.31	0.35	$897.41	$690.08	$850.53	$739.74
250		109530	816637	95.41	95.26	0.27		0.31	0.35	$960.16		$848.60	$742.88
251		136775	839147	95.72	95.67	0.30	0.41	0.31	0.35	$865.55	$637.51	$851.15	$743.61
252		166998	880181	96.07	96.00	0.35	0.33	0.31	0.35	$743.59	$792.45	$855.02	$748.27
253		202178	913192	96.40	96.24	0.33		0.30	0.35	$787.82		$867.64	$746.54
254	12-1-88	235383	936821	96.73	96.61	0.33	0.37	0.30	0.35	$793.38	$704.20	$874.98	$746.54
255		268355	973969	97.03	96.99	0.30	0.38	0.30	0.35	$868.42	$689.28	$884.04	$747.00
256		298478	11921	97.25	97.37		0.38	0.29	0.35		$688.73	$887.67	$754.56
257		320560	49903	97.69	97.71		0.34	0.29	0.35		$772.46	$887.67	$757.71
258		364967	83768	98.02	98.06	0.33	0.35	0.29	0.34	$796.48	$752.03	$890.94	$760.47
259		397811	118553	98.36	98.40	0.34	0.34	0.29	0.34	$772.37	$770.03	$901.74	$761.71
260		431680	152525	98.70	98.75	0.34	0.36	0.29	0.34	$772.33	$731.57	$910.02	$767.04

		Totalizer Readings (tens of gallons)		Total Flow (million gallons)		Cell Capacity (million gallons)				DI Water Cost ($/million gallons)			
Cycle	Date	N Anion	S Anion	North	South	North	South	N Avg(25)	S Avg(25)	North	South	N Avg(25)	S Avg(25)
261		465551	188283	99.00	99.12	0.30	0.37	0.28	0.34	$864.23	$711.59	$919.07	$774.45
262		495820	225045	99.33	99.49	0.33	0.37	0.28	0.34	$802.39	$715.87	$923.50	$780.65
263	1-1-89	528422	261587	99.62	99.85	0.30	0.36	0.28	0.33	$885.56	$719.62	$927.37	$789.68
264		557962	297939	99.91	100.23	0.28	0.38	0.28	0.33	$918.97	$680.53	$929.34	$798.09
265		586428	336379	100.19	100.58	0.28	0.34	0.28	0.32	$919.00	$762.53	$933.56	$807.27
266		614893	370685	100.50	100.96	0.31	0.38	0.28	0.32	$857.21	$680.35	$936.79	$811.50
267		645410	409135	100.83	101.31	0.33	0.35	0.28	0.32	$782.09	$742.81	$939.58	$819.05
268		678858	444352	101.12	101.66	0.29	0.34	0.28	0.32	$916.72	$767.05	$943.63	$827.22
269		707394	478456	101.43	101.94	0.31	0.29	0.28	0.32	$838.28	$906.61	$945.51	$829.15
270		738600	507310	101.72	102.28	0.29	0.34	0.28	0.32	$917.71	$771.44	$951.24	$826.73
271		767105	541220	101.98	102.63	0.26	0.34	0.27	0.31	$998.99	$760.96	$962.15	$834.77
272		793291	575597	102.27	102.94	0.29	0.31	0.27	0.31	$887.39	$837.21	$966.50	$841.71
273		822770	606843	102.57	103.25	0.30	0.32	0.27	0.31	$881.06	$828.20	$966.64	$841.54
274	2-1-89	852461	638429	102.90	103.61	0.33	0.35	0.27	0.31	$803.18	$744.27	$972.12	$842.74
275		885031	673577	103.12	103.95		0.34	0.27	0.31		$762.09	$981.54	$848.84
276		907827	707903	103.37	104.29	0.25	0.34	0.27	0.30	$1,041.21	$761.65	$983.67	$858.33
277		932951	742249	103.64	104.65	0.27	0.36	0.27	0.30	$968.12	$735.68	$977.59	$861.98
278		959972	777807	103.89	104.75	0.25		0.27	0.30	$1,048.56		$980.28	$865.58
279		984920	788358	104.17	104.97	0.27		0.27	0.30	$955.35		$974.66	$860.79
280		12302	809757	104.43	105.33	0.26	0.37	0.27	0.30	$1,009.12	$714.21	$972.06	$865.48
281		38225	846384	104.70	105.63	0.27	0.30	0.27	0.30	$956.79	$885.98	$969.23	$876.37
282		65566	875910	104.74	105.63			0.27	0.30			$973.03	$870.65
283		69353	876032	105.01	105.94	0.27	0.31	0.27	0.30	$973.41	$844.29	$972.59	$869.05
284		96227	907016	105.25	106.28	0.24	0.33	0.27	0.30	$1,071.93	$780.93	$975.17	$869.17
285		120631	940514	105.53	106.56	0.28	0.28	0.27	0.30	$949.91	$918.33	$972.62	$866.44
286		148170	969000	105.80	106.84	0.27	0.28	0.27	0.30	$966.22	$926.00	$976.21	$860.16
287	3-1-89	175244	997250	106.07	107.15	0.27	0.31	0.27	0.31	$969.19	$855.16	$979.17	$852.96
288		202235	27840	106.37	107.43	0.30	0.28	0.27	0.31	$878.87	$943.26	$978.87	$850.65
289		232000	55573	106.65	107.71	0.28	0.28	0.27	0.31	$930.71	$923.55	$986.35	$847.83
290		260107	83898	106.90	108.01	0.25	0.30	0.26	0.31	$1,029.33	$875.92	$988.72	$846.38
291		285521	113763	107.16	108.31	0.26	0.30	0.26	0.31	$1,000.48	$859.86	$989.92	$845.58
292		311668	144186	107.45	108.63	0.29	0.32	0.26	0.31	$917.07	$827.60	$989.17	$843.30
293		340193	175795	107.75	108.91	0.31	0.28	0.26	0.31	$855.44	$935.50	$993.10	$845.30
294		370773	203758	108.03	109.23	0.27	0.32	0.26	0.31	$961.39	$806.94	$1,000.23	$843.81
295		397983	236176	108.30	109.54	0.27	0.31	0.26	0.31	$961.43	$844.45	$1,004.29	$845.17
296		425192	267154	108.51	109.81	0.21	0.27	0.26	0.31	$1,244.33	$972.62	$1,006.16	$845.20

		Totalizer Readings (tens of gallons)		Total Flow (million gallons)		Cell Capacity (million gallons)				DI Water Cost ($/million gallons)			
Cycle	Date	N Anion	S Anion	North	South	North	South	N Avg(25)	S Avg(25)	North	South	N Avg(25)	S Avg(25)
297		446215	294050	108.74	110.10	0.23	0.28	0.26	0.31	$1,125.38	$919.94	$987.88	$838.68
298		469460	322486	109.03	110.41	0.29	0.31	0.27	0.31	$890.23	$833.32	$973.17	$838.18
299		498845	353878	109.29	110.72	0.26	0.31	0.27	0.31	$1,004.90	$855.95	$983.10	$838.17
300	4-1-89	524877	384440	109.56	111.02	0.26	0.30	0.27	0.31	$991.87	$871.49	$975.07	$837.27
301		551251	414457	109.81	111.28	0.25	0.26	0.27	0.31	$1,037.87	$987.56	$971.25	$833.26
302		576456	440946	110.10	111.59	0.29	0.31	0.27	0.32	$893.97	$833.58	$966.97	$827.87
303		605718	472328	110.35	111.92	0.25	0.33	0.27	0.31	$1,038.69	$801.09	$967.40	$833.06
304		630903	504983	110.64	112.26	0.29	0.34	0.27	0.31	$908.60	$763.65	$959.78	$840.34
305		659694	539239	110.93	112.53	0.29	0.26	0.27	0.31	$896.61	$995.72	$959.33	$844.02
306		688870	565511	111.21	112.80	0.28	0.27	0.27	0.31	$937.88	$960.23	$960.66	$834.59
307		716762	592754	111.46	113.14	0.25	0.34	0.27	0.31	$1,058.96	$759.90	$965.98	$832.01
308		741465	627179	111.73	113.46	0.27	0.31	0.27	0.31	$961.67	$830.96	$959.35	$837.95
309		768667	658660	111.98	113.77	0.25	0.31	0.27	0.31	$1,045.25	$847.02	$958.33	$841.70
310		793694	689544	112.24	114.13	0.26	0.36	0.27	0.31	$997.35	$727.54	$951.39	$845.97
311		819923	725500	112.49	114.47	0.25	0.34	0.27	0.31	$1,047.72	$764.47	$953.19	$854.04
312	5-1-89	844891	759719	112.74	114.82	0.25	0.35	0.28	0.30	$1,047.76	$749.00	$948.68	$858.61
313		869858	794645	113.02	115.14	0.27	0.33	0.28	0.30	$961.57	$798.74	$948.35	$866.14
314		897063	827396	113.26	115.45	0.24	0.30	0.28	0.30	$1,067.95	$860.65	$944.98	$861.36
315		921558	857791	113.60	115.75		0.30	0.28	0.30		$880.82	$948.90	$863.24
316		954983	887490	113.84	116.05	0.25	0.31	0.28	0.30	$1,062.96	$854.05	$947.16	$866.80
317		979593	918120	114.11	116.38	0.27	0.33	0.28	0.30	$981.70	$802.66	$940.08	$868.63
318		6240	950711	114.37	116.67	0.26	0.30	0.28	0.30	$1,009.59	$880.73	$942.06	$865.75
319		32151	980413	114.63	116.97	0.26	0.29	0.28	0.30	$1,010.72	$890.26	$942.72	$866.23
320		58033	9797	114.87	117.28	0.25	0.31	0.28	0.30	$1,064.86	$840.49	$943.35	$861.51
321		82599	40921	115.20	117.61			0.28	0.30			$940.79	$861.53
322	6-1-89	115172	73831	115.52	117.94	0.33	0.33	0.28	0.30	$803.10	$794.88	$945.44	$861.53
323		147745	106741	115.85	118.23	0.33	0.29	0.27	0.30	$796.31	$905.05	$953.35	$861.49
324		180596	135645	116.08	118.54	0.23	0.31	0.27	0.30	$1,143.83	$833.21	$960.36	$858.32
325		203466	167041	116.39	118.86	0.31	0.31	0.27	0.31	$836.09	$833.13	$954.55	$852.82
326		234754	198440	116.68	119.19	0.29	0.34	0.27	0.31	$904.95	$774.32	$963.29	$850.55
327		263661	232224	116.96	119.61	0.28		0.27	0.31	$932.07		$963.73	$854.95
328		291727	274064	117.25	119.88	0.29	0.27	0.27	0.30	$902.80	$981.48	$964.06	$859.08
329		320703	300717	117.56	120.14	0.30	0.26	0.27	0.31	$862.44	$1,001.09	$965.64	$854.45
330		351035	326848	117.85	120.38	0.29		0.27	0.31	$899.04		$969.62	$847.03
331		380132	350568	118.13	120.72	0.28	0.34	0.27	0.31	$925.18	$762.04	$975.05	$847.99
332		408407	384896	118.37	121.01	0.24	0.29	0.27	0.31	$1,076.83	$887.54	$979.38	$856.31

		Totalizer Readings (tens of gallons)		Total Flow (million gallons)		Cell Capacity (million gallons)				DI Water Cost ($/million gallons)			
Cycle	Date	N Anion	S Anion	North	South	North	South	N Avg(25)	S Avg(25)	North	South	N Avg(25)	S Avg(25)
333		432700	414370	118.66	121.31	0.29	0.29	0.27	0.31	$896.12	$892.63	$976.75	$854.07
334		461892	443676	118.94	121.59	0.28	0.28	0.27	0.31	$937.68	$925.11	$979.16	$851.64
335	7-1-89	489790	471953	119.24	121.86	0.30	0.27	0.27	0.31	$877.57	$959.10	$979.75	$843.85
336		519599	499228	119.49	122.16	0.25	0.29	0.27	0.31	$1,047.09	$894.74	$982.31	$840.44
337		544582	528465	119.77	122.26	0.28		0.27	0.31	$931.07		$979.25	$841.89
338		572678	538806	120.02	122.55	0.25	0.29	0.27	0.31	$1,038.03	$899.01	$981.26	$839.47
339		597879	567904	120.32	122.91	0.30	0.36	0.27	0.31	$884.93	$717.90	$979.83	$838.34
340		627440	604343	120.54	123.20	0.22	0.29	0.27	0.31	$1,202.46	$903.76	$984.05	$846.45
341		649195	633288	120.83	123.47	0.29	0.27	0.27	0.31	$907.40	$970.23	$976.66	$847.30
342		678024	660250	121.12	123.77	0.30	0.29	0.27	0.31	$877.51	$894.98	$979.24	$843.39
343		707835	689479	121.38	124.11	0.25	0.35	0.27	0.31	$1,038.53	$751.77	$984.20	$845.10
344		733024	724276	121.63	124.41	0.25	0.29	0.26	0.31	$1,029.05	$891.81	$988.02	$852.41
345		758445	753609	121.88	124.74	0.25	0.33	0.26	0.31	$1,029.09	$792.16	$989.44	$846.99
346		783865	786632	122.15	125.05	0.26	0.31	0.26	0.31	$988.98	$840.98	$997.40	$848.34
347	8-1-90	810316	817738	122.39	125.45	0.24		0.26	0.31	$1,078.52		$994.96	$847.59
348		834571	858246	122.66	125.78	0.27	0.33	0.27	0.31	$983.40	$794.06	$986.02	$847.59
349		861172	891190	122.93	126.10	0.28	0.31	0.26	0.31	$946.33	$833.85	$988.99	$850.38
350		888815	922562	123.21	126.45	0.27	0.36	0.26	0.30	$962.35	$732.47	$988.44	$858.71
351		915998	958276	123.45	126.79	0.25	0.33	0.26	0.30	$1,053.75	$787.82	$998.03	$869.13
352		940823	991481	123.74	127.09	0.29	0.30	0.26	0.30	$915.24	$863.38	$1,003.85	$874.39
353		969405	21780	124.02	127.36	0.28	0.27	0.26	0.30	$940.21	$961.18	$1,003.44	$874.45
354		997228	48996	124.30	127.67	0.28	0.30	0.26	0.30	$940.21	$859.21	$1,001.14	$867.28
355		25051	79442	124.57	127.99	0.27	0.32	0.26	0.30	$953.44	$809.77	$1,004.10	$863.90
356		52488	111747	124.82	128.29	0.25	0.30	0.26	0.30	$1,038.36	$870.82	$1,000.99	$866.78
357		77681	141787	125.07	128.56	0.25	0.27	0.26	0.30	$1,038.36	$964.16	$999.27	$866.97
358		102874	168919	125.34	128.87	0.26	0.31	0.26	0.30	$1,000.02	$833.00	$997.41	$859.53
359		129033	200323	125.61	129.19	0.27	0.31	0.26	0.30	$951.95	$833.00	$993.80	$859.46
360		156513	231727	125.89	129.54	0.27	0.35	0.26	0.30	$951.98	$745.73	$997.18	$859.26
361	9-1-89	183992	266806	126.17	129.84	0.28	0.30	0.26	0.30	$934.23	$863.55	$1,002.70	$864.75
362		211993	297099	126.44	130.12	0.27	0.28	0.26	0.30	$963.62	$936.07	$1,006.39	$868.01
363		239140	325045	126.70	130.45	0.27	0.33	0.26	0.30	$980.86	$785.10	$1,014.72	$866.61
364		265810	358365	126.97	130.76	0.26	0.30	0.26	0.30	$997.84	$867.79	$1,017.92	$874.82
365		292026	388510	124.05	131.05		0.29	0.26	0.30		$903.27	$1,020.11	$871.53
366			417471	128.60	131.33		0.28	0.26	0.30		$928.40	$1,021.12	$864.96
367		455161	445648	128.87	131.63	0.27	0.31	0.25	0.30	$964.08	$856.68	$1,030.23	$867.03
368		482295	476184	128.89	131.91		0.28	0.25	0.30		$945.82	$1,026.02	$873.47

		Totalizer Readings (tens of gallons)		Total Flow (million gallons)		Cell Capacity (million gallons)				DI Water Cost ($/million gallons)			
Cycle	Date	N Anion	S Anion	North	South	North	South	N Avg(25)	S Avg(25)	North	South	N Avg(25)	S Avg(25)
369		484071	503842	129.11	132.19	0.23	0.28	0.25	0.30	$1,145.89	$928.73	$1,026.16	$869.40
370	10-1-89	506900	532009	129.36	132.53	0.25	0.34	0.26	0.30	$1,065.65	$764.03	$1,021.31	$870.18
371		531448	566248	129.57	132.85	0.21	0.32	0.26	0.30	$1,272.04	$822.88	$1,011.68	$878.36
372		552013	598038	129.84	133.17	0.28	0.32	0.26	0.30	$936.71	$822.88	$996.27	$884.15
373		579940	629828	130.14	134.70	0.30		0.26	0.29	$879.63		$993.81	$887.80
374		609679	783054	130.39	135.01	0.25	0.30	0.26	0.29	$1,056.22	$860.14	$997.28	$890.73
375		634446	813467	130.67	135.24	0.28	0.24	0.26	0.29	$934.77	$1,093.81	$996.92	$892.05
376		662431	837383	130.88	135.51	0.21	0.27	0.26	0.30	$1,226.36	$984.29	$1,006.12	$886.26
377		683762	863960	131.10	135.80	0.21	0.29	0.26	0.30	$1,226.36	$912.02	$1,003.70	$882.84
378		705093	892643	131.38	136.10	0.29	0.30	0.26	0.30	$907.37	$864.89	$989.99	$881.61
379		733923	922889	131.68	136.43	0.29	0.33	0.26	0.30	$895.96	$783.29	$989.38	$879.26
380		763120	956286	132.20	136.77		0.33	0.26	0.30		$783.31	$1,000.86	$882.73
381		815705	989682	132.49	137.07	0.29	0.30	0.26	0.29	$895.26	$878.07	$1,000.86	$892.14
382		844925	19474	132.67	137.36		0.30	0.26	0.29		$875.72	$1,006.51	$896.91
383		862218	49346	132.93	137.70	0.26	0.34	0.26	0.29	$997.69	$777.01	$1,006.51	$895.95
384	11-1-89	888438	83013	133.21	138.02	0.28	0.31	0.26	0.29	$928.89	$831.44	$1,006.96	$903.32
385		916600	114476	133.47	138.33	0.26	0.32	0.26	0.29	$1,021.65	$828.38	$1,011.43	$901.98
386		942205	146055	133.71	138.95	0.24		0.26	0.29	$1,070.18		$1,010.87	$909.85
387		966649	207682	133.91	139.22		0.28	0.26	0.29		$948.98	$1,007.59	$909.85
388		986618	235248	134.14	139.51	0.23	0.29	0.26	0.29	$1,143.28	$898.49	$1,007.59	$908.15
389		9499	264363	134.39	139.78	0.25	0.27	0.26	0.29	$1,044.42	$986.48	$1,000.17	$908.61
390		34546	290881	134.64	140.11	0.25	0.33	0.26	0.29	$1,041.71	$796.19	$997.35	$905.04
391		59658	323737	134.89	140.45	0.25	0.34	0.26	0.29	$1,041.75	$759.79	$994.32	$911.60
392		84769	358167	135.10	140.72	0.21	0.26	0.26	0.28	$1,267.66	$989.02	$990.85	$921.83
393		105405	384617	135.39	140.97	0.29	0.25	0.27	0.28	$889.02	$1,038.49	$973.15	$918.16
394		134830	409807	135.65	141.28	0.25	0.31	0.27	0.29	$1,029.13	$843.12	$981.59	$911.56
395		160249	440834	135.77	141.55		0.28	0.27	0.29		$950.53	$977.08	$916.52
396		172902	468355	136.07	141.83	0.30	0.28	0.27	0.29	$874.58	$950.56	$977.08	$914.18
397	12-1-89	202813	495875	136.37	142.10	0.29	0.27	0.26	0.29	$890.96	$965.01	$989.97	$911.50
398		232174	522983	136.66	142.39	0.29	0.29	0.26	0.29	$890.96	$906.14	$1,003.91	$907.31
399		261535	551852	136.94	142.66	0.28	0.27	0.26	0.29	$943.67	$967.29	$1,022.43	$907.42
400		289256	578896	137.19	142.66	0.25		0.25	0.29	$1,047.38		$1,036.85	$901.83
401		314232	578892	137.41	142.94	0.23	0.29	0.25	0.29	$1,151.94	$917.36	$1,034.77	$901.83
402		336941	607408	137.64	143.24	0.23	0.29	0.26	0.29	$1,151.94	$892.14	$1,009.11	$900.14
403		359650	636730	137.93	143.40	0.29		0.27	0.29	$893.64		$969.06	$901.15
404		388923	652659	138.23	143.72	0.29	0.32	0.26	0.29	$896.39	$815.70	$1,011.76	$901.15

		Totalizer Readings (tens of gallons)		Total Flow (million gallons)		Cell Capacity (million gallons)				DI Water Cost ($/million gallons)			
Cycle	Date	N Anion	S Anion	North	South	North	South	N Avg(25)	S Avg(25)	North	South	N Avg(25)	S Avg(25)
405		418106	684729	138.45	144.03	0.23	0.31	0.23	0.29	$1,161.20	$851.79	$1,161.20	$914.84
406		440634	715440		144.29		0.26		0.28		$998.30		$926.27
407			741644		144.55		0.26		0.29		$998.34		$913.09
408			767847		144.86		0.31		0.29		$855.19		$894.00
409			798436		145.14		0.28		0.29		$928.00		$907.74
410			826625		145.46		0.32		0.29		$805.97		$897.93
411			859082		145.72		0.26		0.26		$1,013.58		$1,013.58
412			884891		146.07								
413			919899										

Plots of Capacity as a Function of Time

The following plots reflect the numerical data of the previous section. Data points that were not obtained under normal operation were omitted. As an example, when an operational cycle was cut short due to maintenance requirements. Time smoothing of the data was performed to reduce variations in flow rate, temperature and feed concentration. The 25 point time smoothing curves prove adequate for regression analysis, thus further data manipulation was not required. As expected, the exponential decay behavior is apparent once the random variation is reduced. Figures 14, 15, and 16 are from the data collected on the North anion cell. Figures 17, 18, and 19 are from the data collected on the South anion cell.

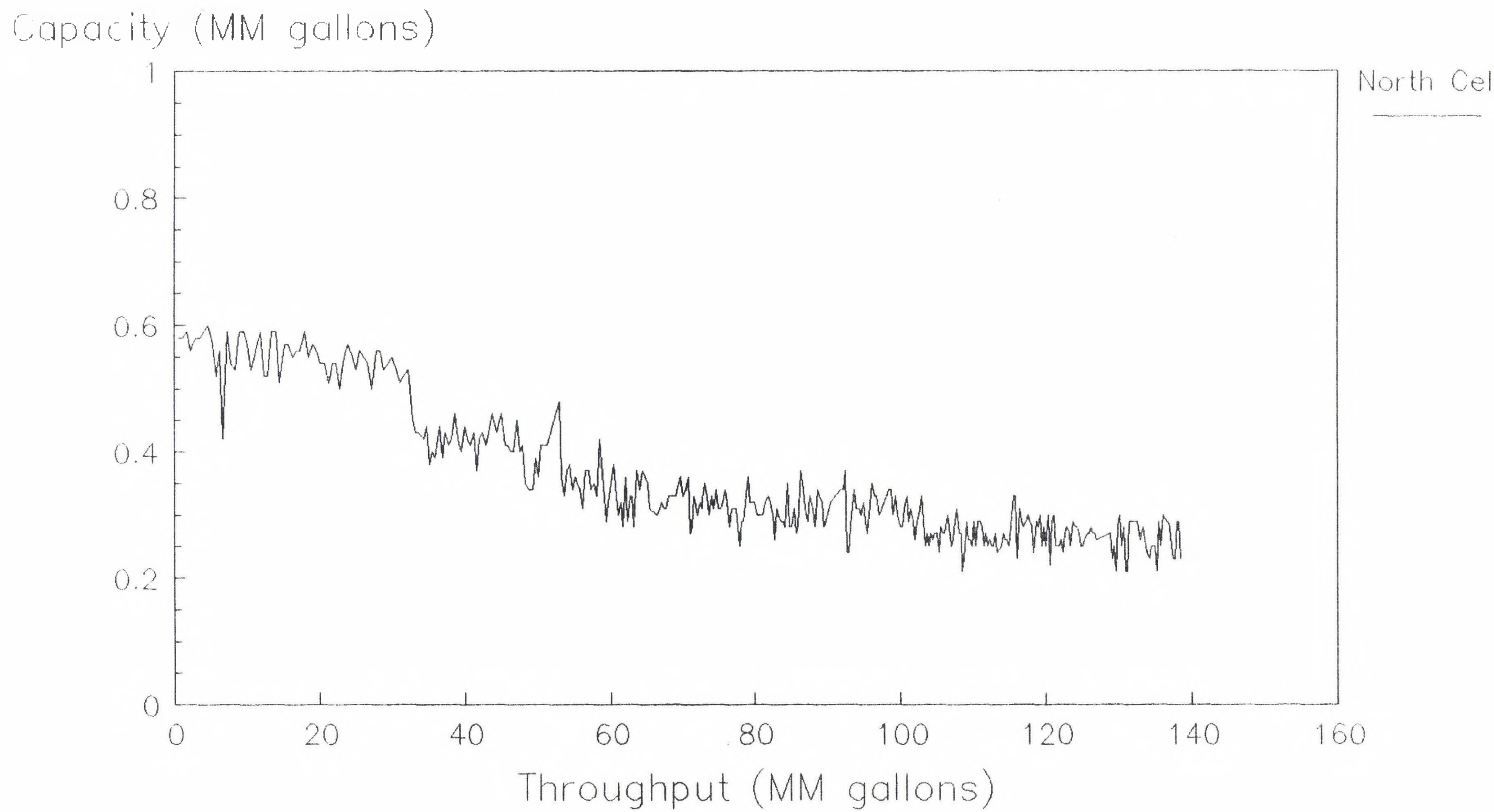

Figure 14. North Cell Capacity as a Function of Throughput

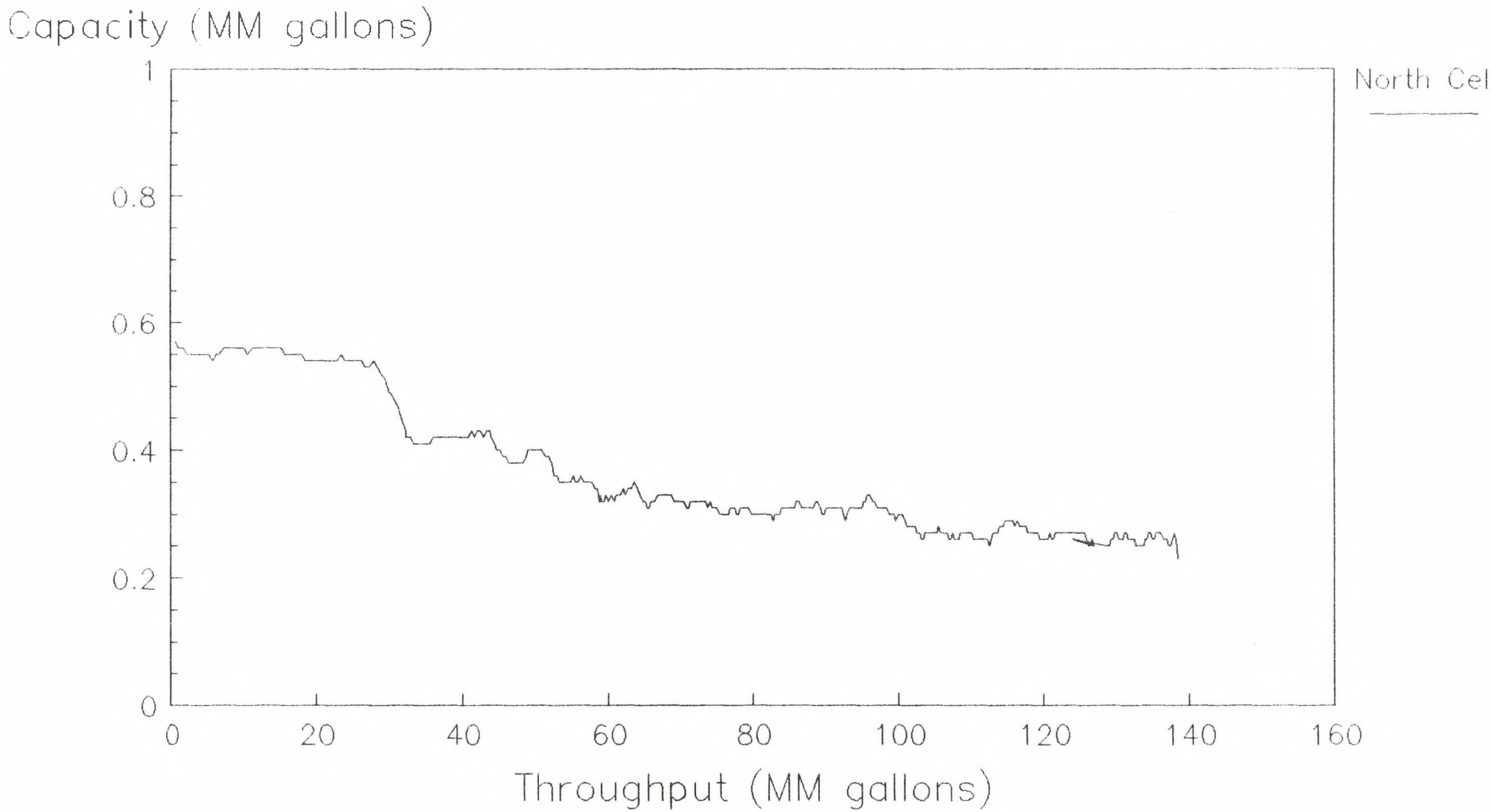

Figure 15. North Cell Capacity as a Function of Throughput Using 10 Point Time-Smoothing Average

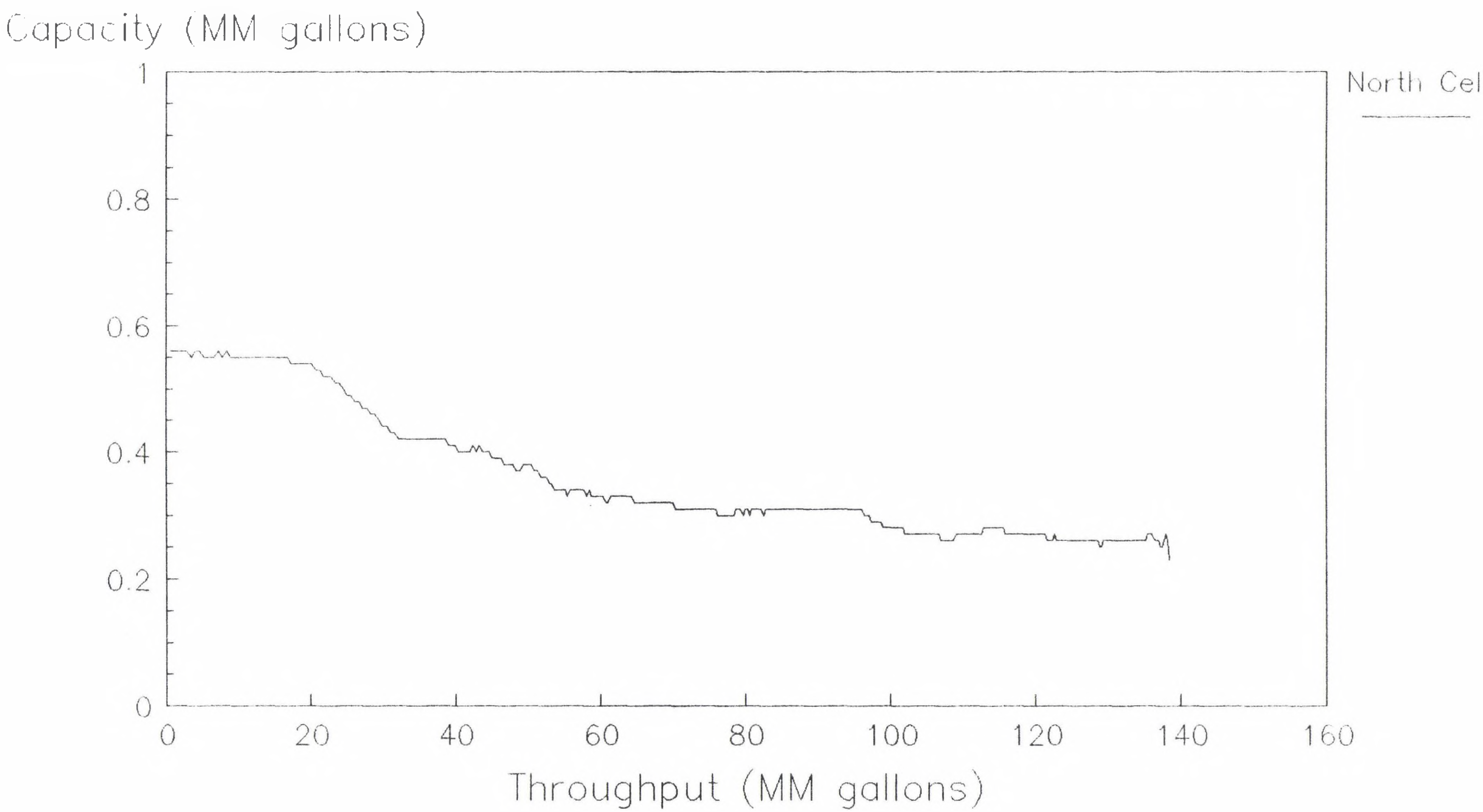

Figure 16. North Cell Capacity as a Function of Throughput Using 25 Point Time-Smoothing Average

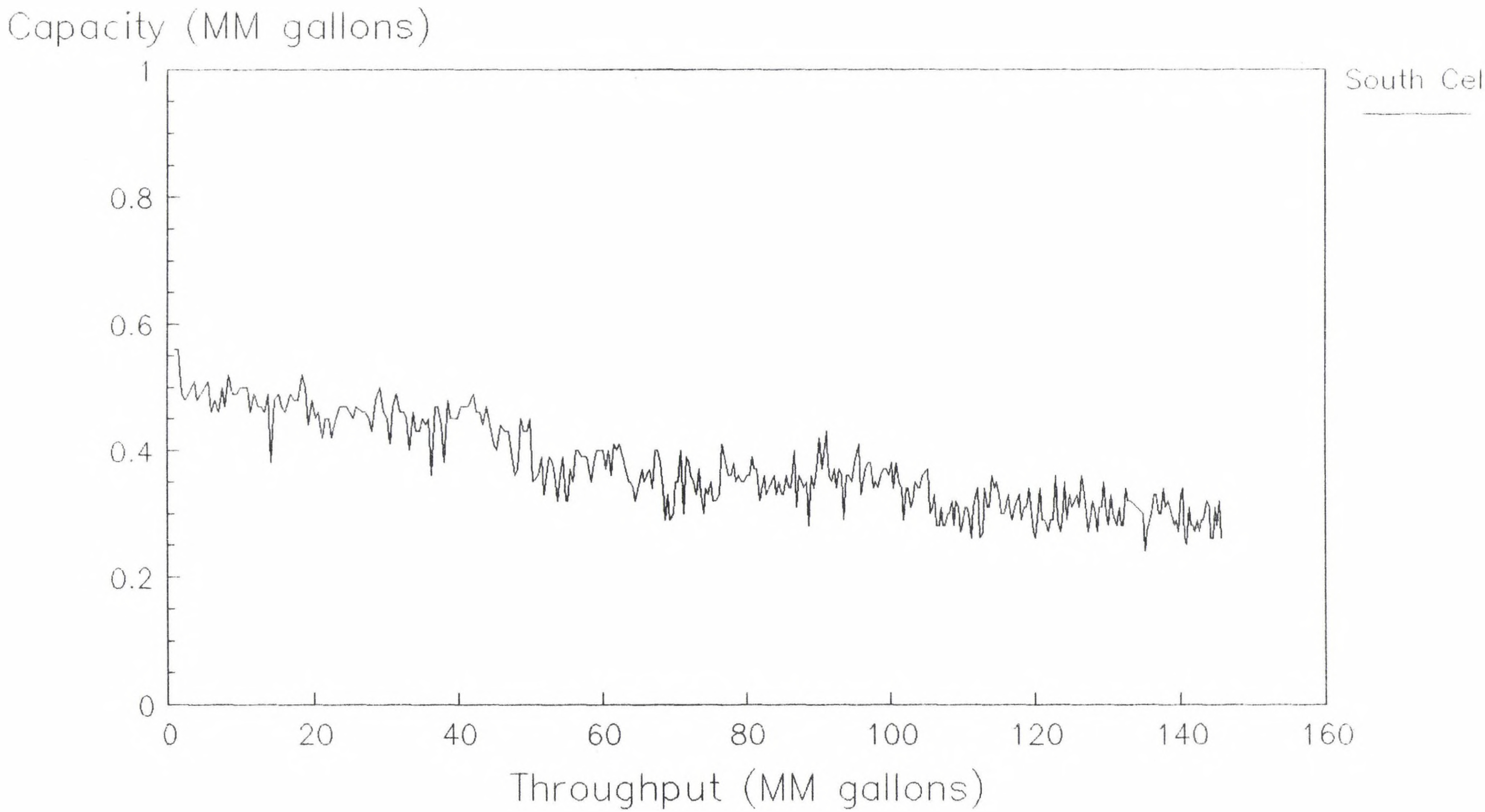

Figure 17. South Cell Capacity as a Function of Throughput

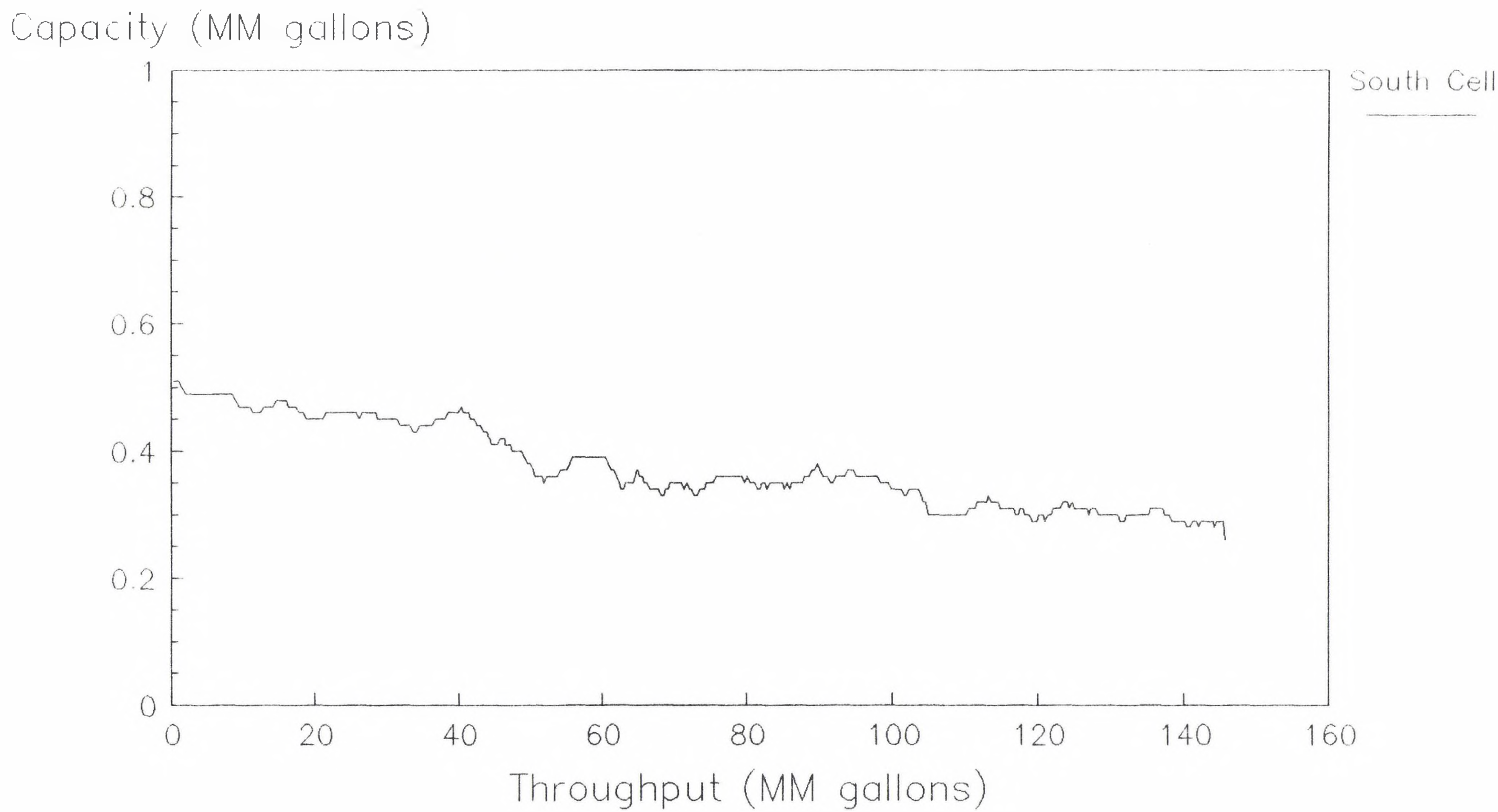

Figure 18. South Cell Capacity as a Function of Throughput Using 10 Point Time-Smoothing Average

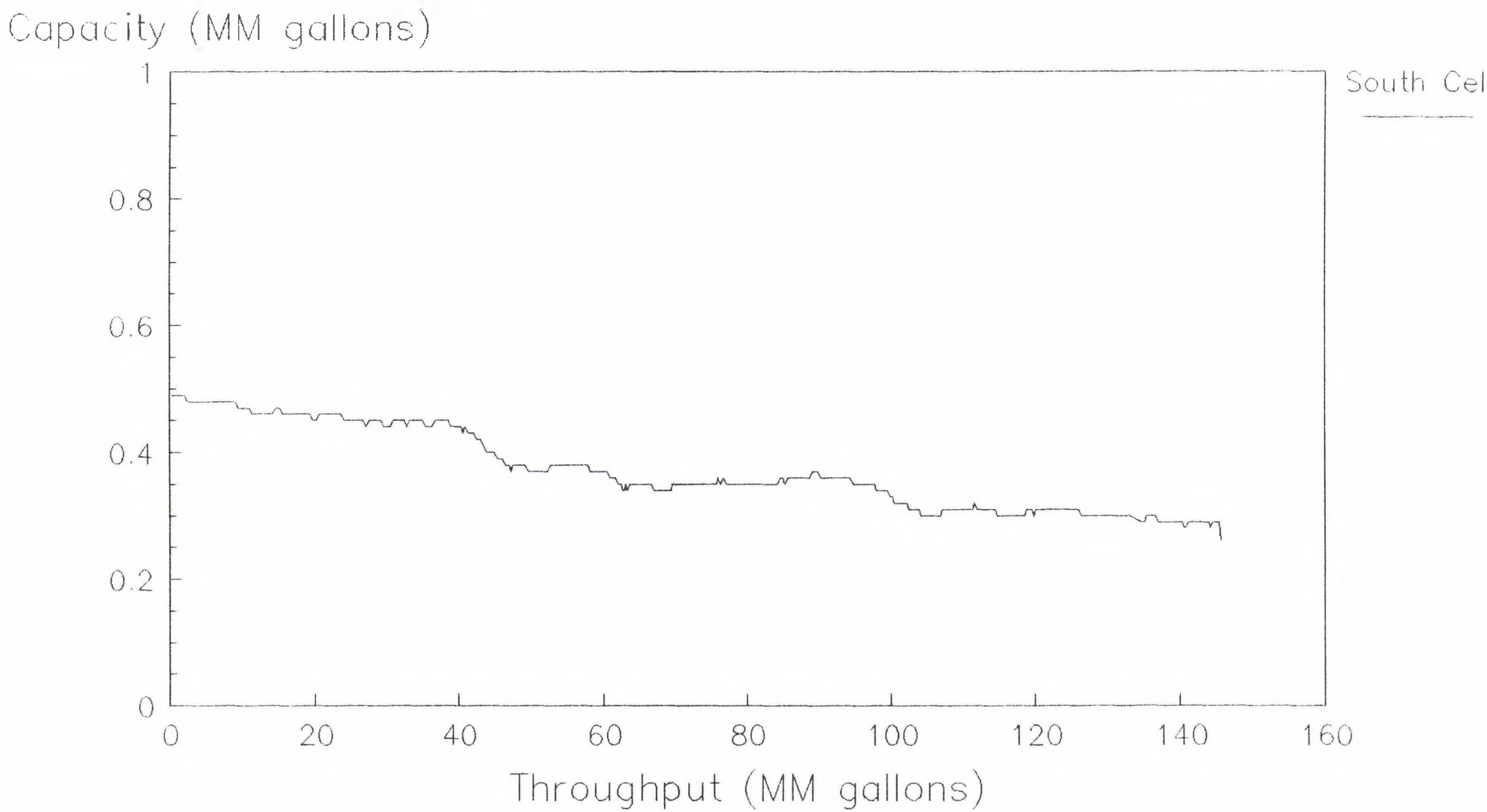

Figure 19. South Cell Capacity as a Function of Throughput Using 25 Point Time-Smoothing Average

Plots of Water Cost as a Function of Time

The following plots reflect the numerical data of the previous section. Water cost was obtained by dividing the cost of regeneration by the capacity of the resin at that point in time. Again, time smoothing of the data was required to reduce the random variation in process operating conditions. The 25 point time smoothing curves prove adequate for regression analysis, thus further data manipulation was not required. Water cost is expressed as dollars per million gallons of water processed using a raw material cost based on the year 1990. Figures 20, 21 and 22 are from the data collected for the North anion cell. Figures 23, 24 and 25 are from the data collected for the South anion cell.

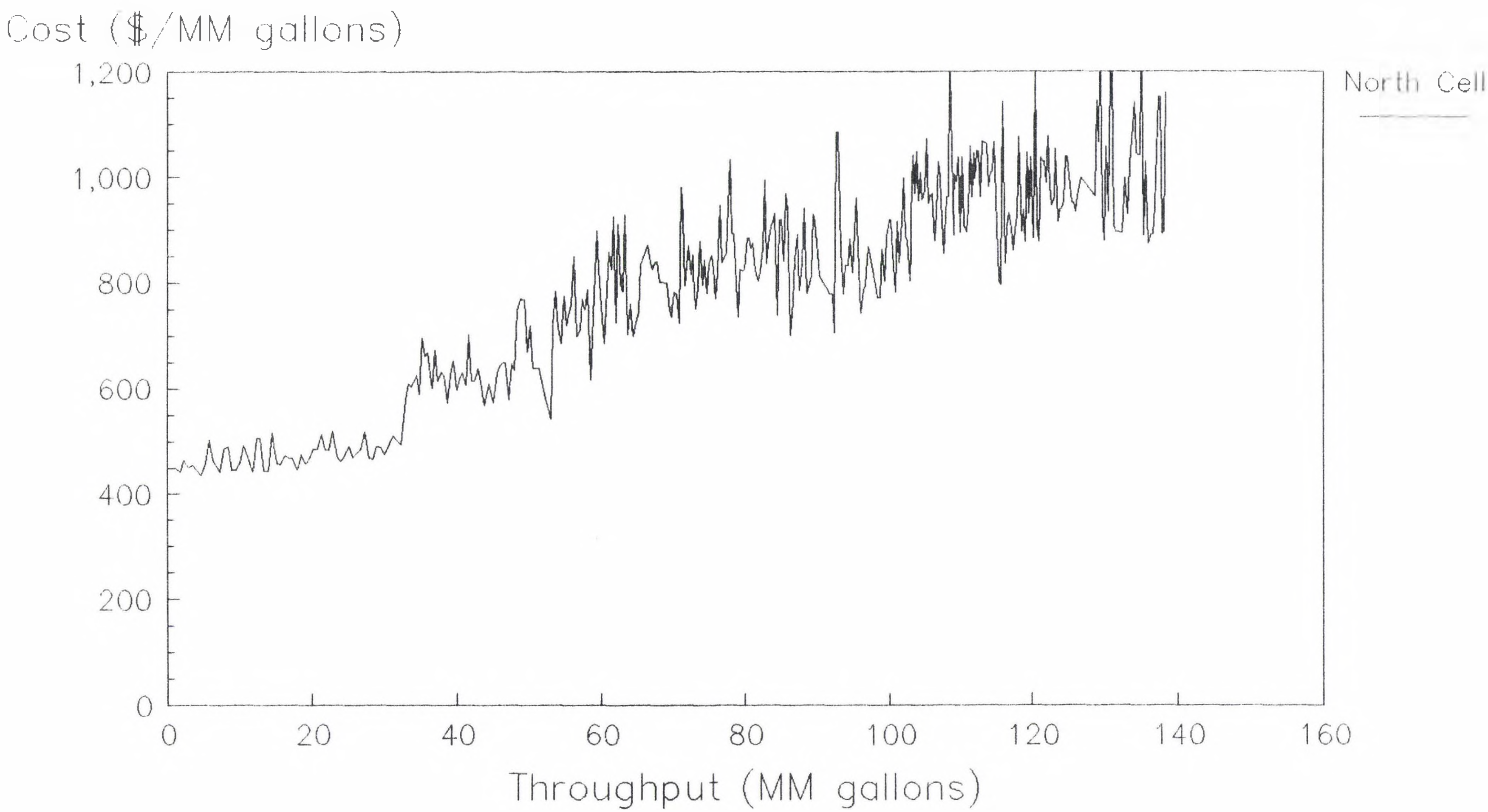

Figure 20. North Cell Water Cost as a Function of Throughput

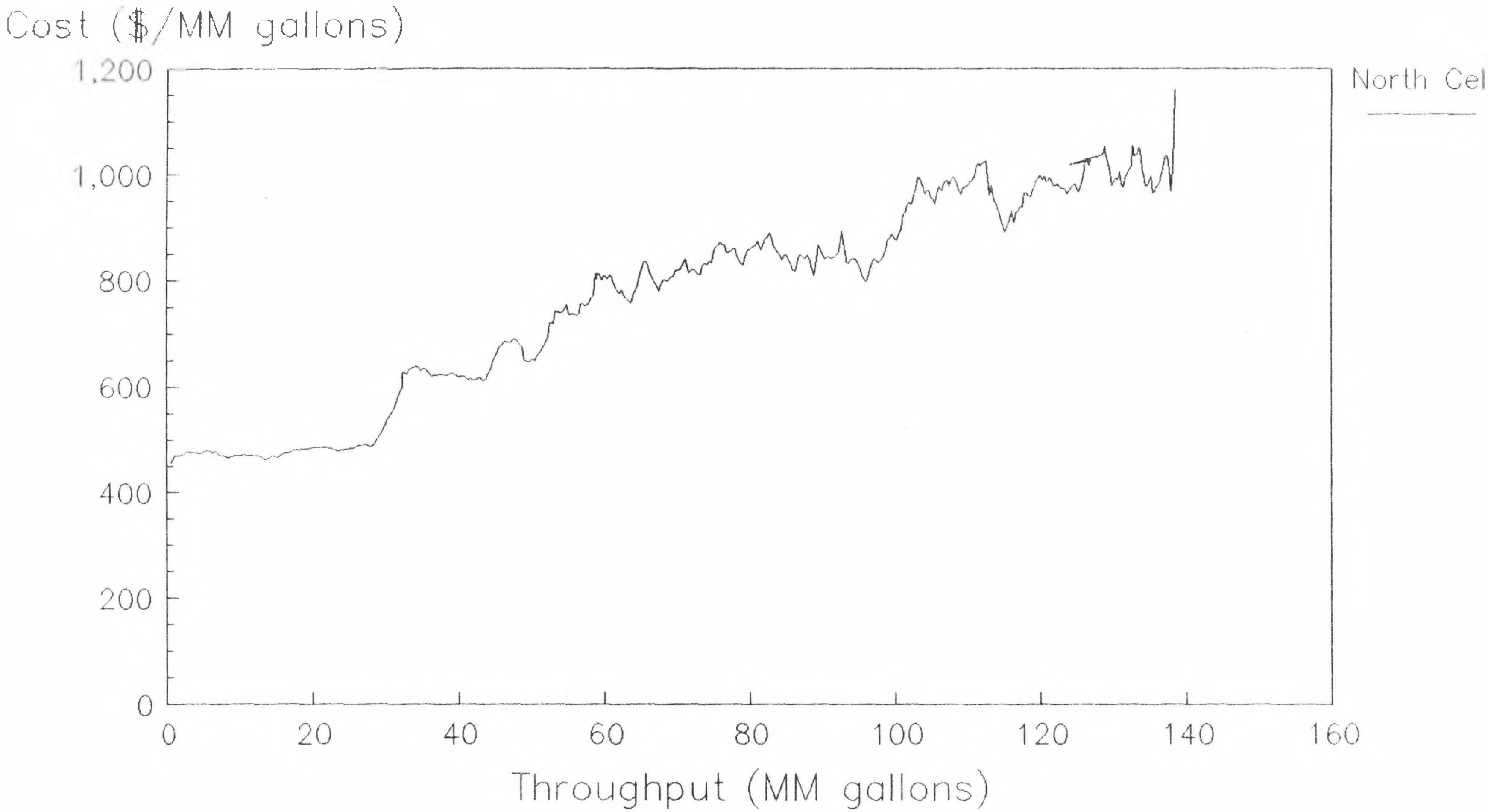

Figure 21. North Cell Water Cost as a Function of Throughput Using 10 Point Time-Smoothing Average

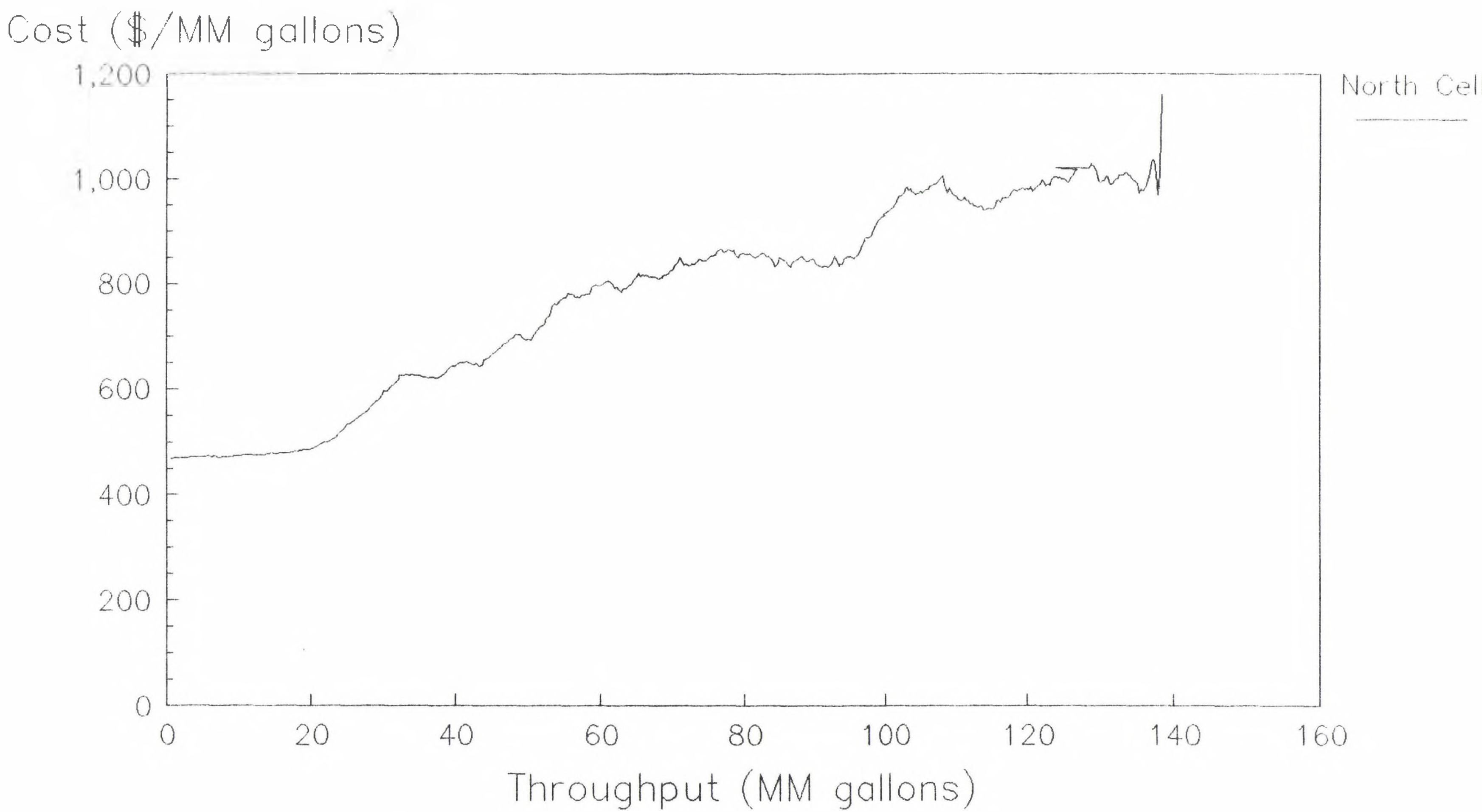

Figure 22. North Cell Water Cost as a Function of Throughput Using 25 Point Time-Smoothing Average

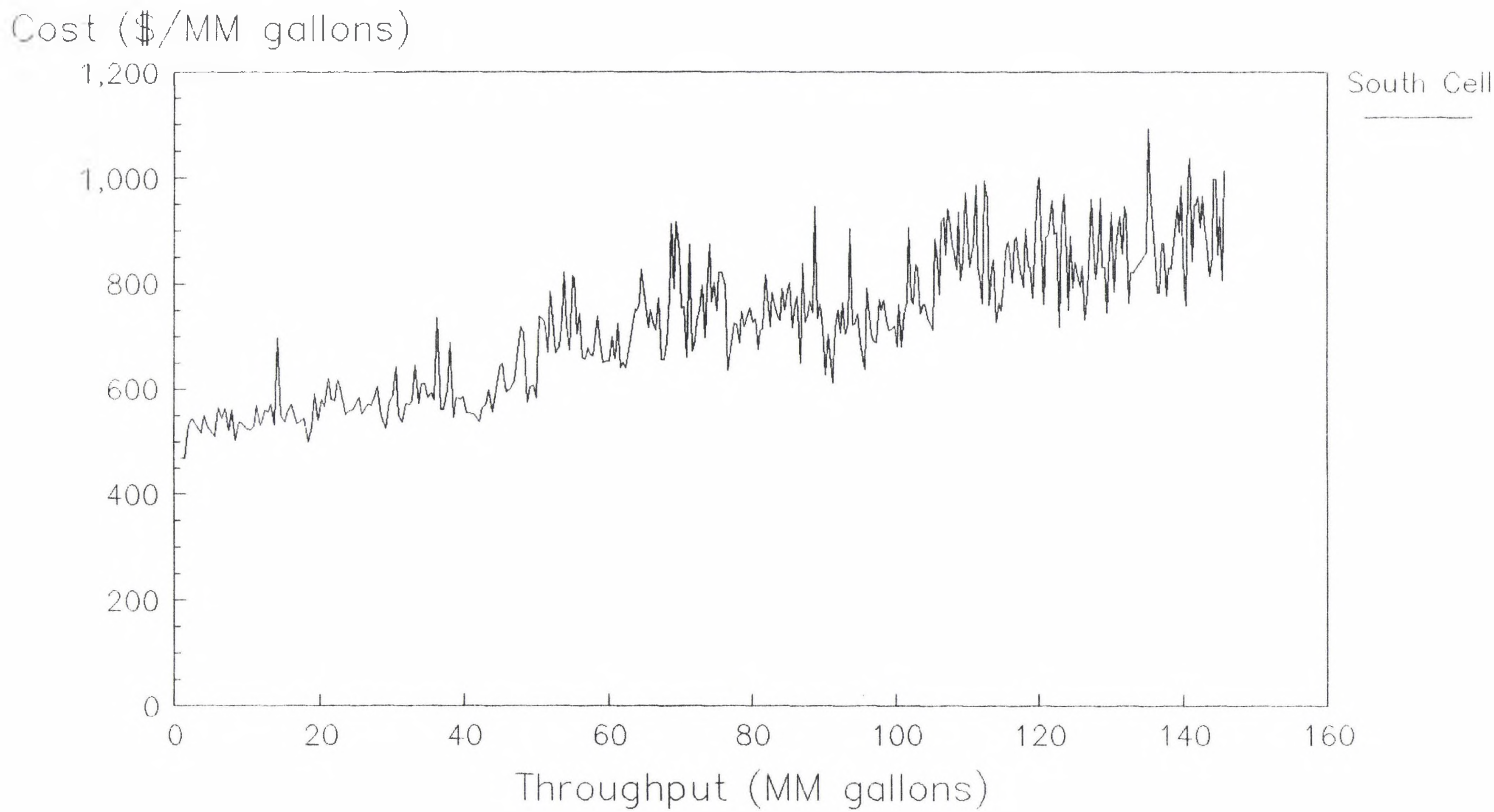

Figure 23. South Cell Water Cost as a Function of Throughput

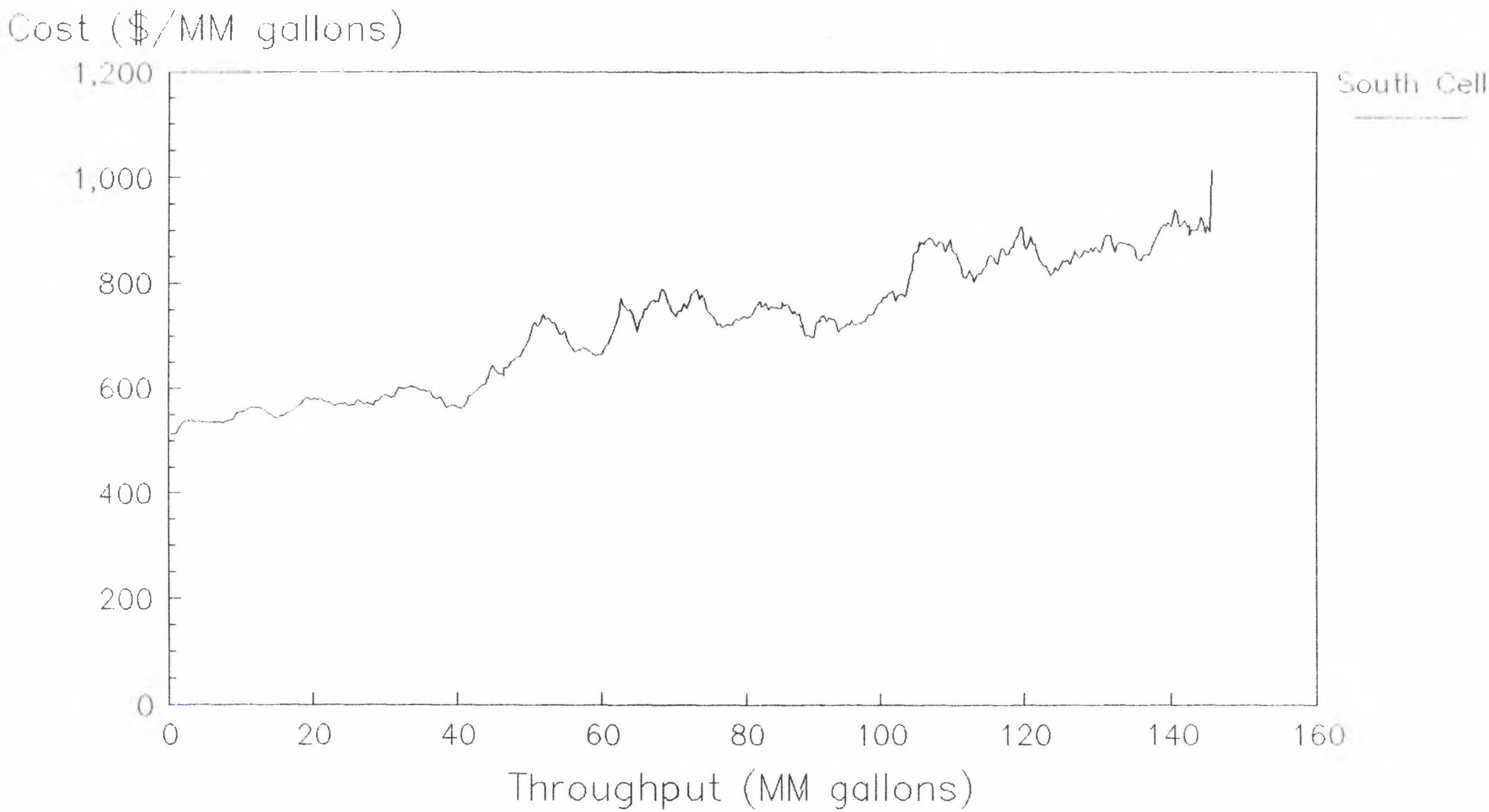

Figure 24. South Cell Water Cost as a Function of Throughput Using 10 Point Time-Smoothing Average

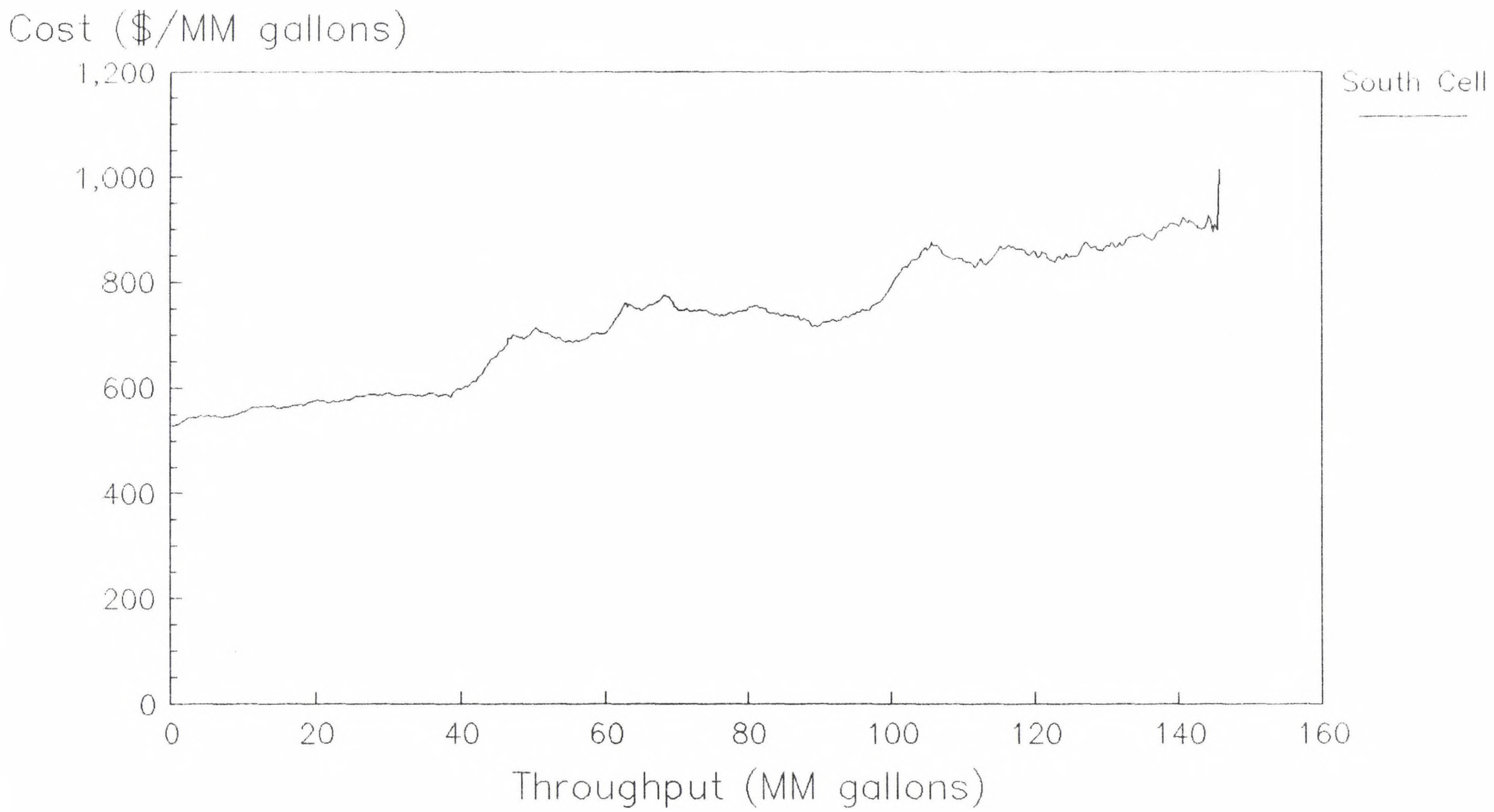

Figure 25. South Cell Water Cost as a Function of Throughput Using 25 Point Time-Smoothing Average

Plots of Logarithm of Capacity as a Function of Time

The following plots are of the logarithm of capacity as a function of throughput with time smoothing to reduce operational variations. Applying linear regression, the initial capacity constant (a) and the capacity decay constant (b) can be found. Correlation coefficients of .904 and .934 indicate model agreement. Figure 26 is from the data collected on the North anion cell. Figure 27 is from the data collected on the South cell.

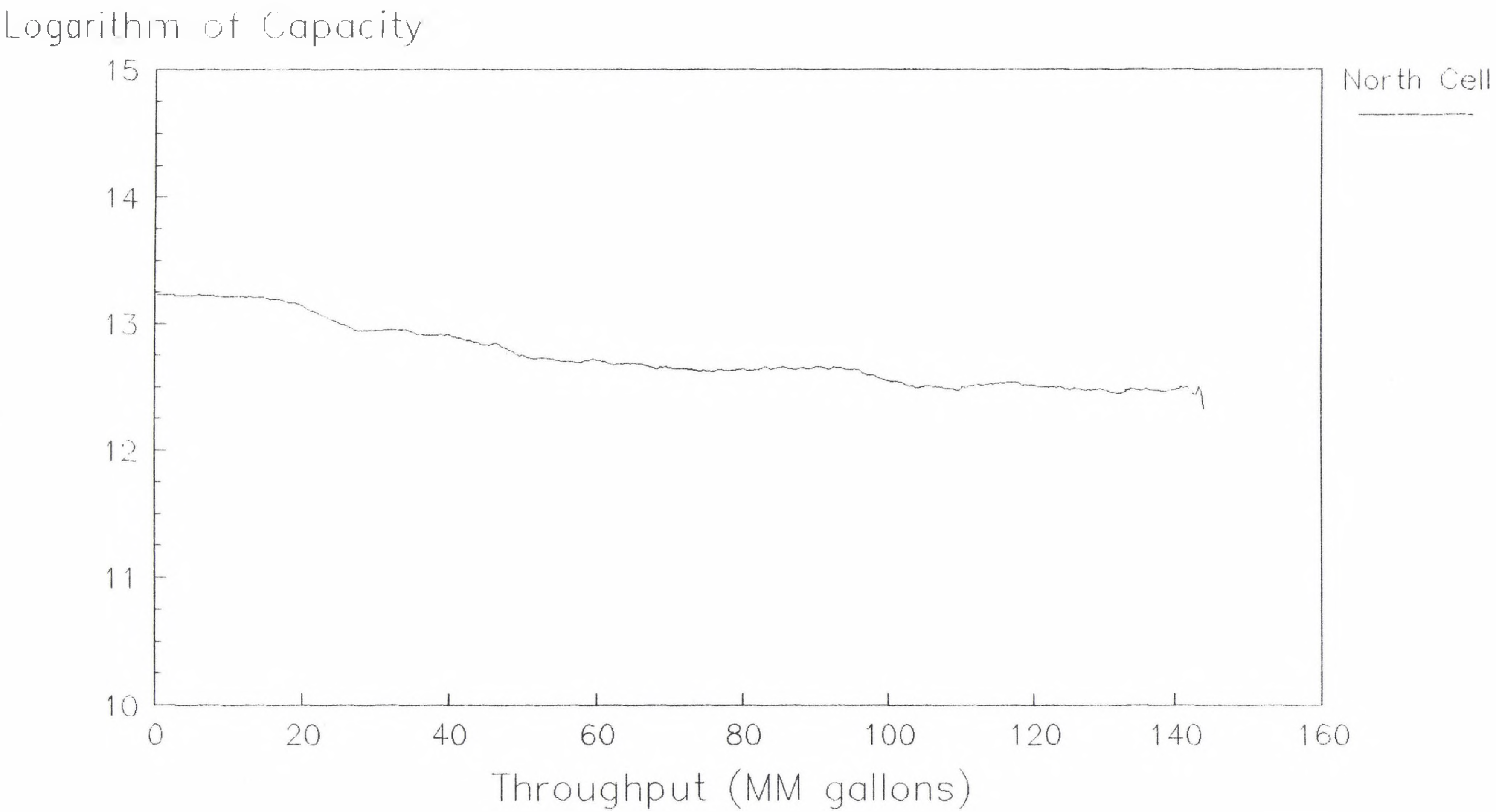

Figure 26. North Cell Logarithm of Capacity as a Function of Throughput Using 25 Point Time-Smoothing Average

R Sq	0.9042828
b	-0.0046353
a	13.0402230

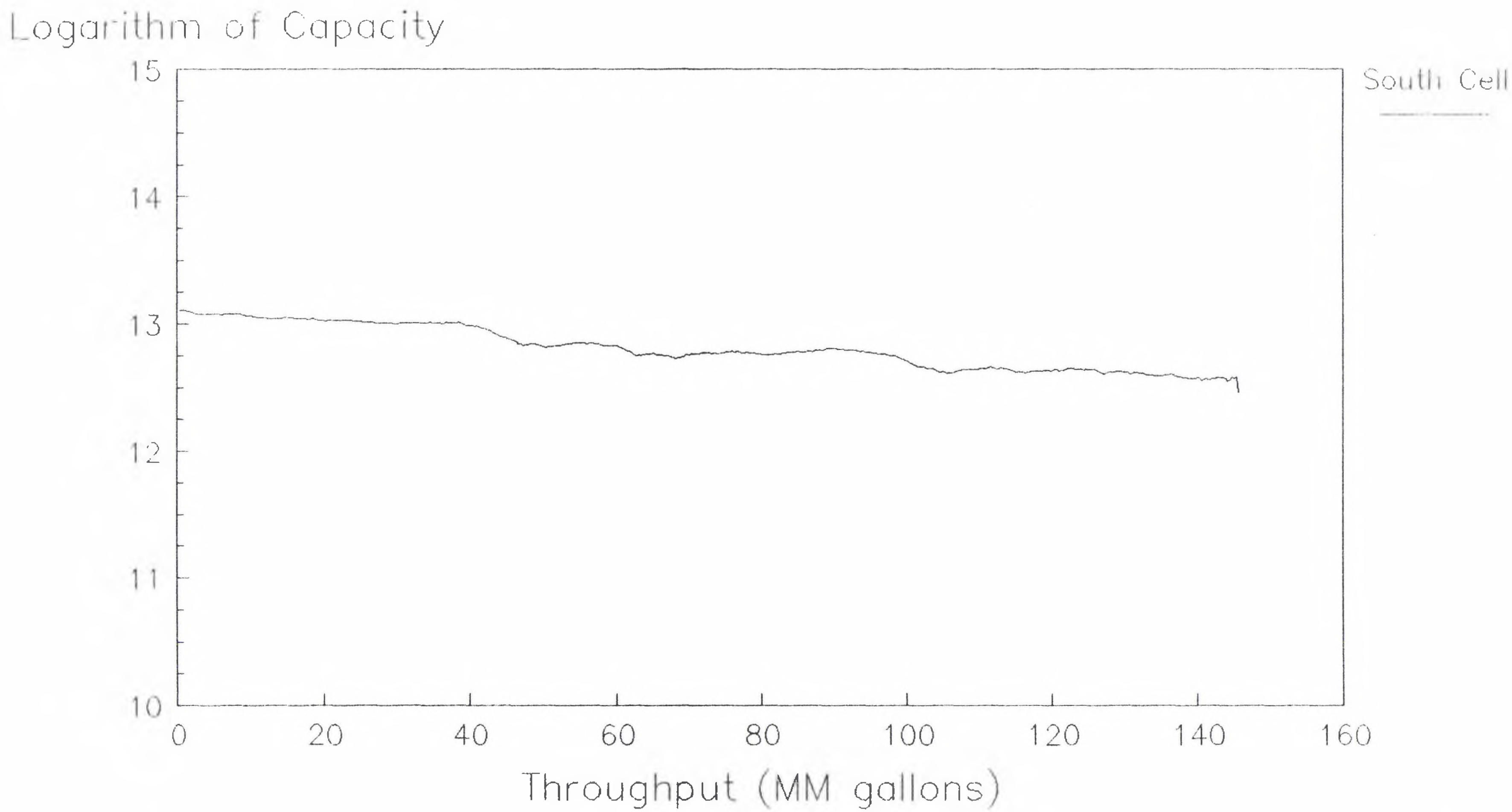

Figure 27. South Cell Logarithm of Capacity as a Function of Throughput Using 25 Point Time-Smoothing Average

R Sq 0.9338584
b -0.0037621
a 13.0814638

Plots of Logarithm of Water Cost as a Function of Time

The following plots are of the logarithm of water cost as a function of throughput with time smoothing to reduce operational variations. Applying linear regression, the initial water cost constant (a) and the capacity decay constant (b) can be found. Correlation coefficients of .904 and .934 indicate model agreement. Figure 28 is from the data collected on the North anion cell. Figure 29 is from the data collected on the South cell.

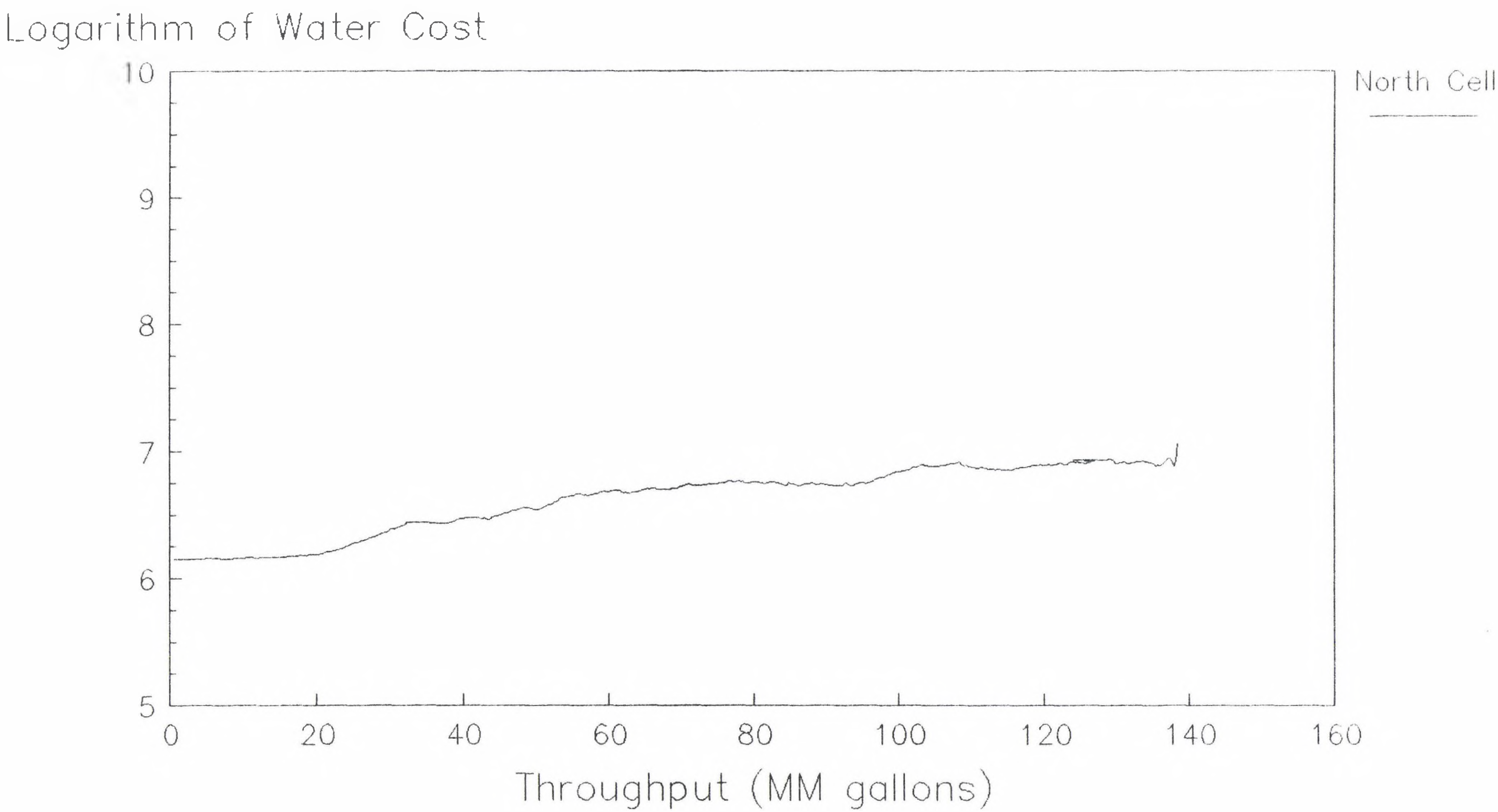

Figure 28. North Cell Logarithm of Water Cost as a Function of Throughput Using 25 Point Time–Smoothing Average

R Sq	0.90428278
b	0.00463599
a	6.34208362

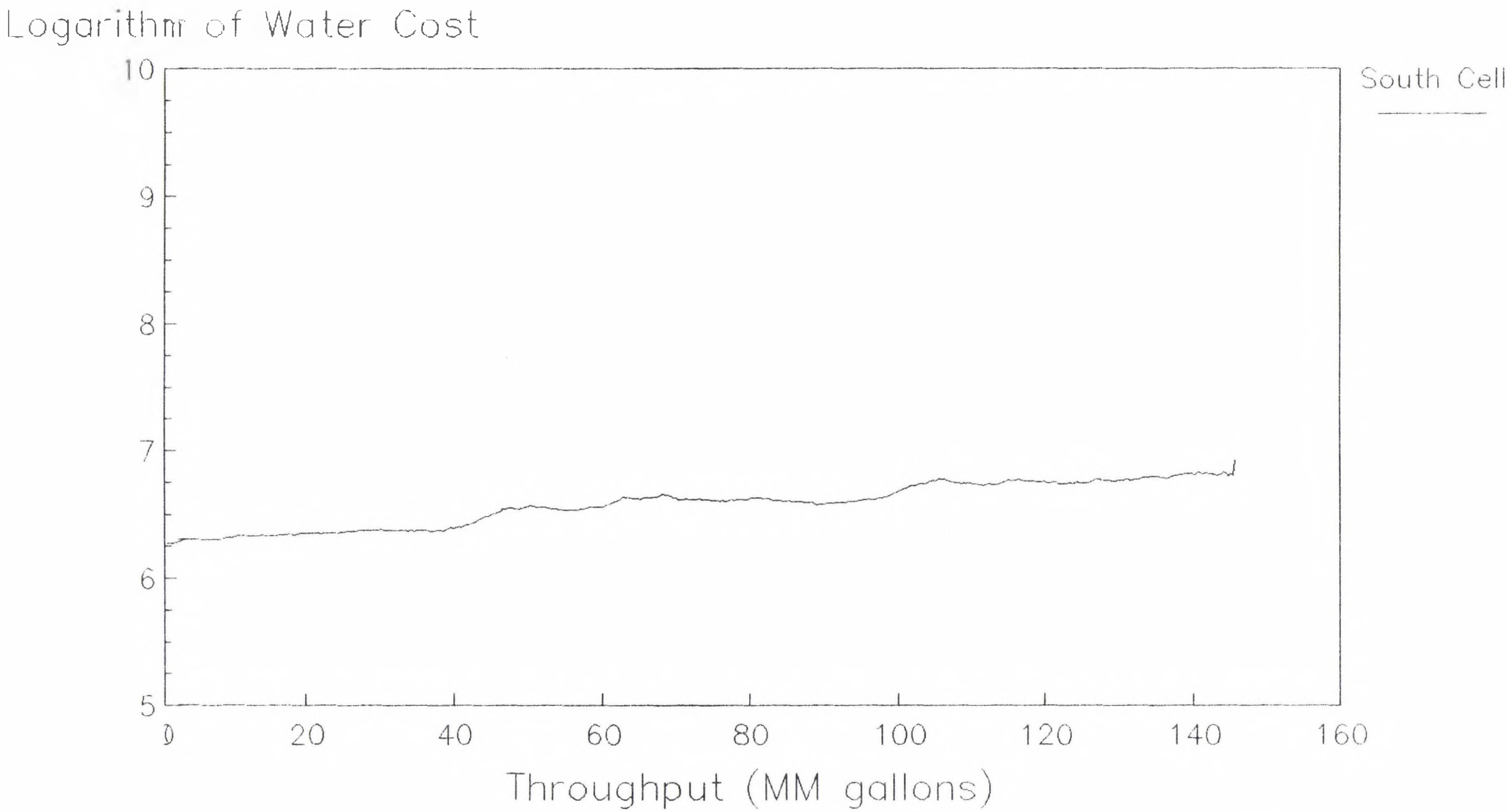

Figure 29. South Cell Logarithm of Water Cost as a Function of Throughput Using 25 Point Time-Smoothing Average

R Sq	0.93385838
b	0.00376209
a	6.30084285

Regression Analysis of Data

Table 8 is a detail of the regression calculation results for the plots of logarithm of capacity and logarithm of water cost as a function of throughput. Also tabulated are the regression calculation results for a linear fit of the capacity and water cost data assuming a linear as opposed to exponential model. The correlation coefficients of .869 and .916 are lower than those obtained through the exponential model. The differences between the two models diverge significantly as the resin ages, with the exponential fit best approximating the data collected.

Regression Analysis Data

North Cell LN (Capacity) vs Total Flow		South Cell LN (Capacity) vs Total Fl	
Regression Output:		Regression Output:	
Constant	13.04022	Constant	13.08146
Std Err of Y Est	0.047103	Std Err of Y Est	0.041018
R Squared	0.904283	R Squared	0.933858
No. of Observations	354	No. of Observations	410
Degrees of Freedom	352	Degrees of Freedom	408
X Coefficient(s)	-0.00464	X Coefficient(s)	-0.00376
Std Err of Coef.	0.00008	Std Err of Coef.	0.00005

North Cell LN (Cost) vs Total Flow		South Cell LN (Cost) vs Total Flow	
Regression Output:		Regression Output:	
Constant	6.342084	Constant	6.300843
Std Err of Y Est	0.047103	Std Err of Y Est	0.041018
R Squared	0.904283	R Squared	0.933858
No. of Observations	354	No. of Observations	410
Degrees of Freedom	352	Degrees of Freedom	408
X Coefficient(s)	0.004636	X Coefficient(s)	0.003762
Std Err of Coef.	0.00008	Std Err of Coef.	0.00005

North Cell Capacity vs Total Flow		South Cell Capacity vs Total Flow	
Regression Output:		Regression Output:	
Constant	0.442277	Constant	0.471426
Std Err of Y Est	0.018236	Std Err of Y Est	0.017301
R Squared	0.869022	R Squared	0.91611
No. of Observations	354	No. of Observations	410
Degrees of Freedom	352	Degrees of Freedom	408
X Coefficient(s)	-0.0015	X Coefficient(s)	-0.0014
Std Err of Coef.	0.000031	Std Err of Coef.	0.000021

North Cell Cost vs Total Flow		South Cell Cost vs Total Flow	
Regression Output:		Regression Output:	
Constant	528.9424	Constant	529.743
Std Err of Y Est	32.96297	Std Err of Y Est	27.12753
R Squared	0.928399	R Squared	0.943097
No. of Observations	354	No. of Observations	410
Degrees of Freedom	352	Degrees of Freedom	408
X Coefficient(s)	3.800809	X Coefficient(s)	2.695681
Std Err of Coef.	0.056259	Std Err of Coef.	0.032781

Constants Used in Calculations

Table 9 is a summation of constants used in the determination of water cost for the plant data. Included are the volume of regenerant used, regenerant cost, rinse water cost and the water disposal cost.

Parameters used for calculation of deanionized water cost		
Volume of NaOH per regeneration (gallons):	173.00	gallons
Cost of NaOH, $/lb:	0.20	$/lb
Density of NaOH solution (lbs/gallon):	12.72	lb/gal
Concentration of NaOH solution (wt %):	0.50	%
Cost of NaOH used per regeneration ($):	217.36	$
Volume of decationized water used per regeneration (M gals):	23.10	(1000) gallons
Cost of producing decationized water ($/1000 gal):	1.02	$/1000 gallons
Decationized water cost per regeneration ($):	23.56	$
Sewer billing schedule for flow ($ per 1000 cubic feet):	14.33	$/1000 ft3
Sewer flow charge per regeneration ($):	44.25	$
Cost per ton for lime ($):	72.57	$
Neutralization credit for NaOH sewered ($ per regeneration):	24.07	$
Total cost per regeneration ($):	261.59	$
Volume of Anion Cell (cubic feet):	275	ft3
Cost of Anion Resin ($/cubic foot):	270	$/ft3
Estimated yearly process volume (MM gallons/cell):	42	MM gallons

Table 9. Constants used in the calculation of water cost for process demineralizers.

APPENDIX D: EXPERIMENTAL DATA

This appendix contains the experimental data for the column contact experiments. Resin samples are labeled one through four. Three runs were made on each of the virgin and aged samples. Data collected on chloride concentration, pH and conductivity was then plotted for each case. Overall averages are tabulated with the numerical integration giving amount of chloride ion retained in the cell. The following items are in this appendix;

Experimental Data for Resin One

Data was collected for aged and virgin resin 1 samples according to procedures developed in Appendix B. Tabulated data for virgin runs one to three are found in tables 10, 11 and 12. The plots of the effluent chloride concentration (figure 30), effluent pH (figure 31) and the effluent conductivity (figure 32) for all three runs follow. Tabulated data for aged runs one to three are found in table 13, 14 and 15. The plots of the effluent chloride concentration (figure 33), effluent pH (figure 34) and the effluent conductivity (figure 35) for all three runs follow.

Resin 1 Virgin Run 1

Bed Ht 10.5 cm Volume 51.54 cm3

Time	Flow	Total Cl-	Reading	ppm Cl-	pH	Cond.
Feed	68.0		73	48.9	2.56	1250.0
15		0.050	10	4.5	7.63	24.0
30		0.100	8	3.0	10.27	46.0
45		0.150	7	2.3	8.11	21.5
60	68.0	0.200	12	5.9	10.15	39.0
75		0.249	10	4.5	9.27	22.0
90		0.299	10	4.5	9.86	18.0
105		0.349	8	3.0	9.11	20.0
120		0.399	10	4.5	9.76	26.0
135		0.449	18	10.1	8.07	18.0
150	68.0	0.499	12	5.9	9.18	20.0
165		0.549	15	8.0	7.40	18.0
180		0.599	16	8.7	7.56	18.0
195		0.649	16	8.7	7.30	18.0
210	68.0	0.698	17	9.4	6.21	18.0
225		0.748	17	9.4	4.50	32.0
240		0.798	23	13.6	3.85	80.0
255		0.848	34	21.4	3.51	150.0
270		0.898	50	32.7	3.23	280.0
285	68.0	0.948	75	50.3	2.98	480.0
300		0.998	107	72.9	2.73	850.0
315		1.048	147	101.1	2.59	1100.0
330		1.098	149	102.5	2.56	1200.0
345		1.147	151	103.9	2.56	1200.0

Table 10. **Experimental Column Contact Data Collected for Virgin Resin 1, Run 1.**

Resin 1 Virgin Run 2

Bed Ht 10.5 cm Volume 51.54 cm3

Time	Flow	Total Cl-	Reading	ppm Cl-	pH	Cond.
Feed	68.5		67	44.7	2.58	1150.0
10	68.5	0.031	5	0.9	6.26	1.0
20		0.061	5	0.9	6.05	1.6
35		0.107	6	1.6	6.03	0.8
50		0.153	5	0.9	6.08	0.8
65		0.199	0	0.0	6.06	0.8
80		0.245	5	0.9	6.04	0.8
95		0.291	0	0.0	6.01	0.9
110	68.5	0.337	3	0.0	6.04	0.9
125		0.383	2	0.0	5.90	1.0
140		0.428	4	0.2	5.83	1.2
155		0.474	8	3.0	5.60	1.9
170		0.520	4	0.2	5.30	2.7
185		0.566	8	3.0	5.01	5.0
200		0.612	7	2.3	4.76	9.0
215	68.5	0.658	5	0.9	4.48	15.0
230		0.704	14	7.3	4.27	24.5
265		0.811	16	8.7	3.53	90.0
275		0.842	24	14.3	3.51	130.0
285		0.872	33	20.7	3.36	185.0
295		0.903	43	27.7	3.21	270.0
305		0.933	51	33.4	3.06	375.0
315		0.964	65	43.3	2.94	500.0
325		0.995	83	56.0	2.81	700.0
335		1.025	116	79.2	2.69	900.0

Table 11. Experimental Column Contact Data Collected for Virgin Resin 1, Run 2.

Resin 1 Virgin Run 3

Bed Ht 10.5 cm Volume 51.54 cm3

Time	Flow	Total Cl-	Reading	ppm Cl-	pH	Cond.
Feed	67.6		69	46.1	2.58	1150.0
15	67.5	0.047	10	4.5	5.95	7.0
30		0.093	11	5.2	5.95	0.8
45		0.140	11	5.2	6.12	0.7
60		0.187	1	0.0	6.31	0.7
75		0.234	3	0.0	6.18	0.7
90		0.280	3	0.0	6.13	0.7
105		0.327	5	0.9	6.20	0.7
120	68.0	0.374	6	1.6	6.09	0.7
135		0.421	5	0.9	6.14	0.7
150		0.467	5	0.9	5.87	0.9
165		0.514	5	0.9	5.95	0.9
180	67.5	0.561	12	5.9	5.78	1.2
195		0.608	12	5.9	5.38	2.4
210		0.654	11	5.2	4.98	5.5
225		0.701	11	5.2	4.60	11.5
240		0.748	12	5.9	4.23	26.0
255	67.5	0.795	10	4.5	3.88	60.0
270		0.841	24	14.3	3.54	125.0
285		0.888	40	25.6	3.26	245.0
300		0.935	54	35.5	3.02	410.0
315		0.982	83	56.0	2.81	700.0
330		1.028	133	91.2	2.62	1100.0

Table 12. Experimental Column Contact Data Collected for Virgin Resin 1, Run 3.

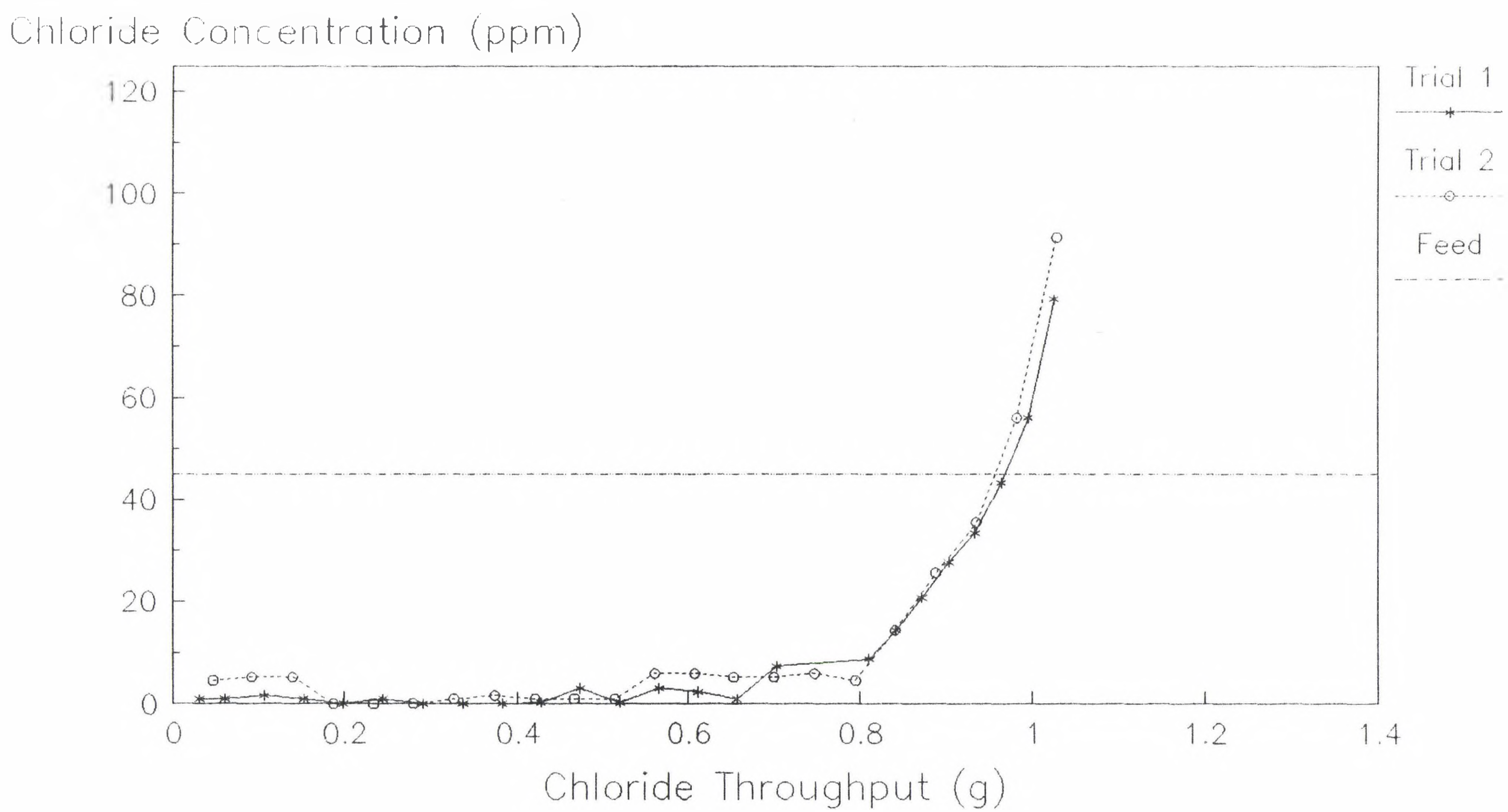

Figure 30. Virgin Resin 1 Effluent Chloride Concentration as a Function of Chloride Throughput

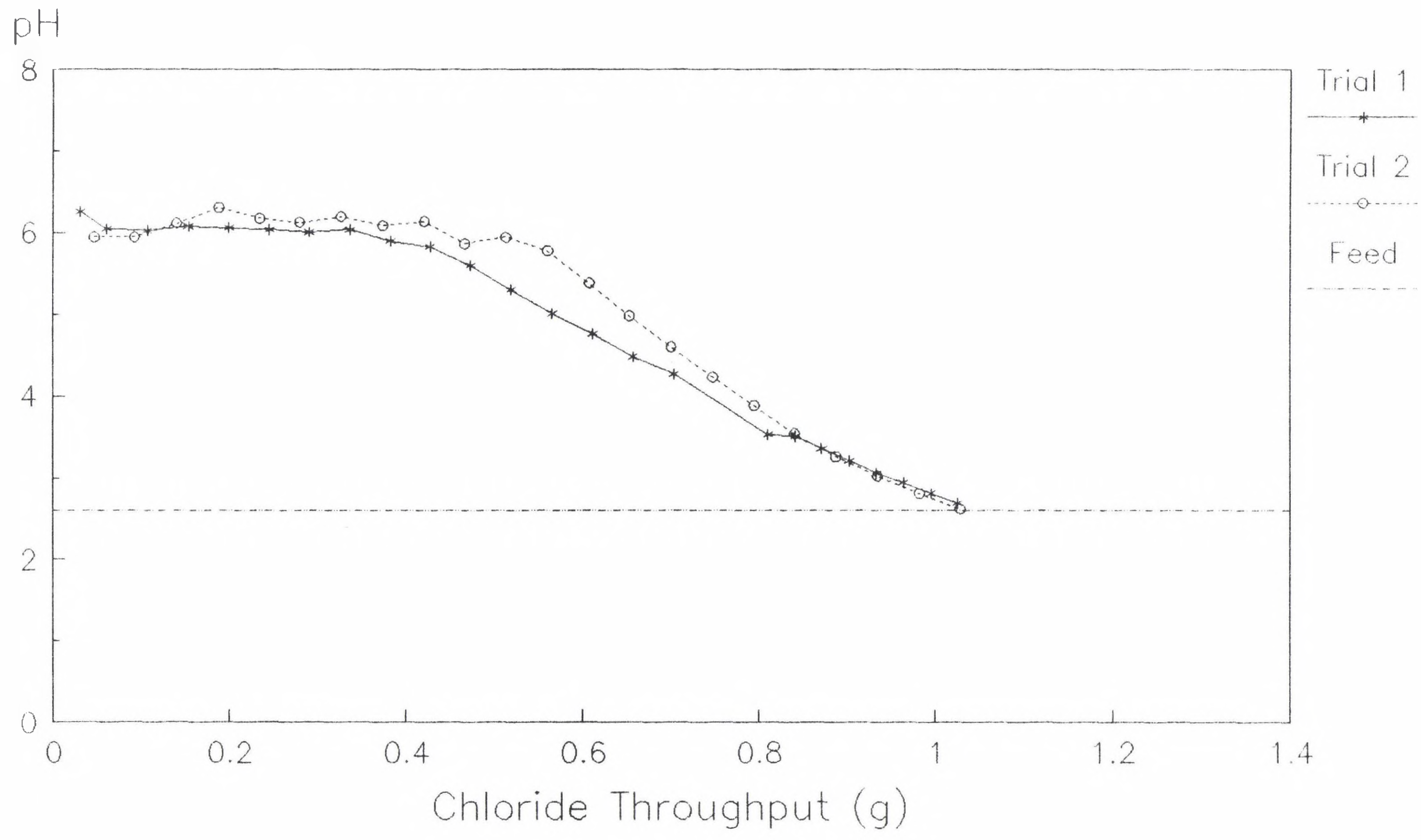

Figure 31. Virgin Resin 1 Effluent pH as a Function of Chloride Throughput

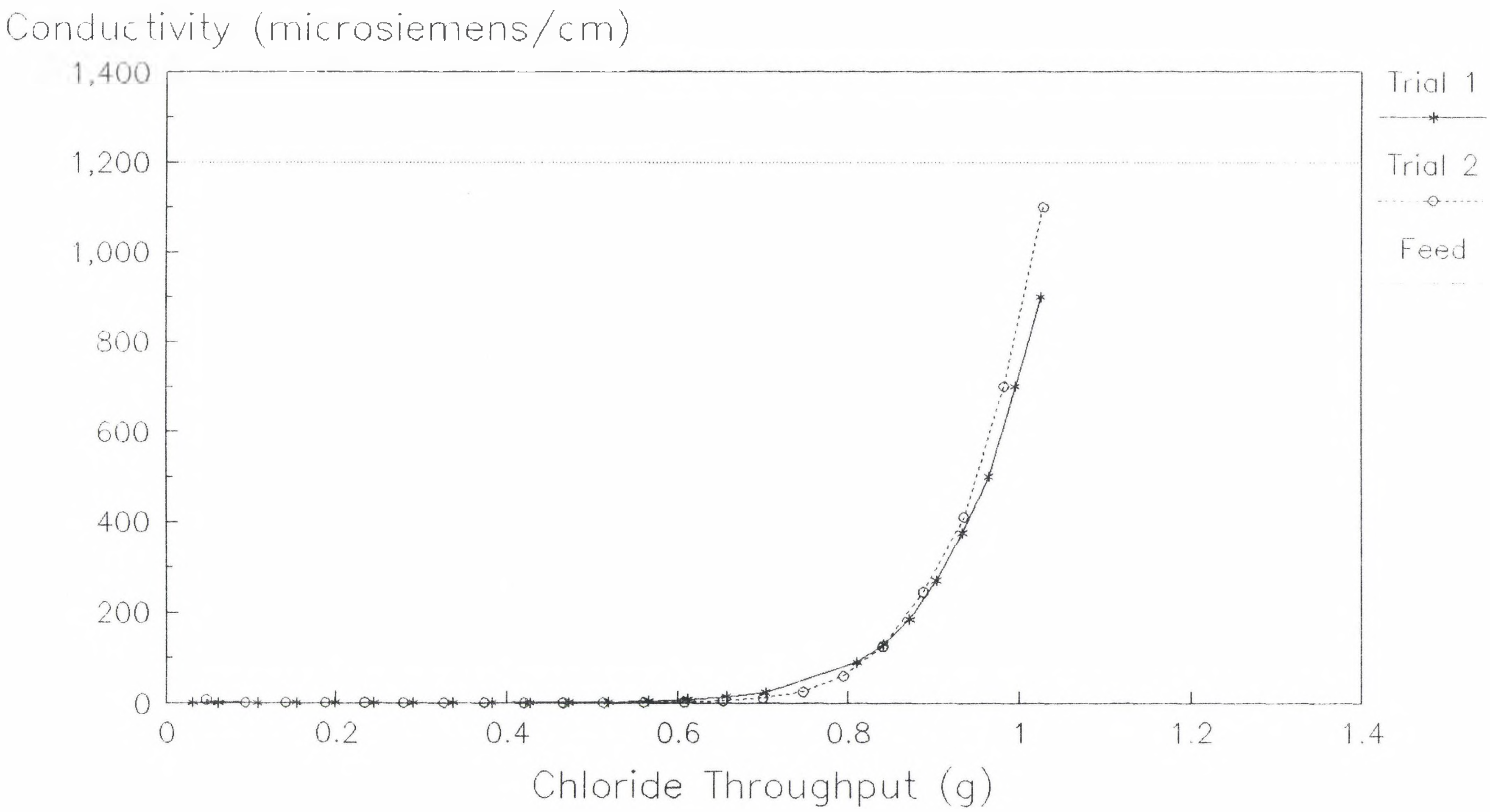

Figure 32. Virgin Resin 1 Effluent Conductivity as a Function of Chloride Throughput

Resin 1 Aged Run 1

Bed Ht 11.0 cm Volume 54.00 cm3

Time	Flow	Total Cl-	Reading	ppm Cl-	pH	Cond.
Feed	74.9		73	48.9	2.58	1150.0
15		0.055	13	6.6	7.47	10.0
30	74.5	0.110	11	5.2	7.32	3.5
45		0.165	12	5.9	7.36	3.3
60	75.0	0.220	5	0.9	7.40	3.2
75	74.5	0.275	5	0.9	7.29	3.3
90		0.330	11	5.2	7.44	3.5
105	75.0	0.385	10	4.5	7.50	3.5
120		0.440	13	6.6	7.45	3.4
135		0.495	18	10.1	7.33	3.5
150	74.5	0.550	16	8.7	6.89	3.6
165		0.605	13	6.6	6.03	4.3
180		0.660	14	7.3	4.73	12.5
195		0.715	21	12.2	4.06	41.5
210		0.770	26	15.7	3.62	105.0
225		0.825	40	25.6	3.32	210.0
240	76.0	0.880	52	34.1	3.05	390.0
255		0.934	94	63.7	2.82	700.0
270	75.0	0.989	125	85.6	2.65	1000.0
285		1.044	151	103.9	2.60	1100.0

Table 13. Experimental Column Contact Data Collected for Aged Resin 1, Run 1.

Resin 1 Aged Run 2

Bed Ht 11.0 cm Volume 54.00 cm3

Time	Flow	Total Cl-	Reading	ppm Cl-	pH	Cond.
Feed	75.5		72	48.2	2.59	1150.0
15		0.055	13	6.6	6.58	7.5
30		0.109	17	9.4	6.81	3.4
45		0.164	13	6.6	6.35	3.4
60	76.0	0.218	12	5.9	6.84	3.4
75		0.273	12	5.9	6.82	3.4
90		0.328	14	7.3	6.80	3.4
105		0.382	13	6.6	6.82	3.5
120	75.0	0.437	12	5.9	6.69	3.5
135		0.491	12	5.9	6.57	3.7
150		0.546	13	6.6	6.26	4.2
165		0.600	12	5.9	4.66	14.5
180		0.655	16	8.7	4.02	46.0
195	75.5	0.710	27	16.5	3.65	100.0
210		0.764	33	20.7	3.39	180.0
225		0.819	48	31.3	3.20	285.0
240		0.873	56	36.9	3.01	430.0
255		0.928	87	58.8	2.82	700.0
270		0.983	122	83.5	2.65	1000.0
285		1.037	136	93.4	2.59	1150.0

Table 14. Experimental Column Contact Data Collected for Aged Resin 1, Run 2.

Resin 1 Aged Run 3

Bed Ht 11.0 cm Volume 54.00 cm3

Time	Flow	Total Cl-	Reading	ppm Cl-	pH	Cond.
Feed	74.0		75	50.3	2.59	1150.0
15		0.056	14	7.3	6.15	11.5
30		0.112	12	5.9	6.73	3.6
45		0.168	11	5.2	6.80	3.4
60	74.0	0.223	12	5.9	6.83	3.4
75		0.279	12	5.9	6.84	3.4
90		0.335	13	6.6	6.88	3.5
105	74.0	0.391	12	5.9	6.82	3.6
120		0.447	11	5.2	6.73	3.7
135		0.503	7	2.3	6.56	4.0
150		0.559	16	8.7	5.31	7.0
165		0.614	14	7.3	4.38	24.0
180		0.670	17	9.4	3.90	65.0
195		0.726	27	16.5	3.55	130.0
210		0.782	37	23.5	3.30	230.0
225		0.838	59	39.0	3.06	390.0
240	74.0	0.894	85	57.4	2.85	650.0
255		0.950	114	77.8	2.70	900.0
270		1.005	135	92.7	2.62	1100.0
285		1.061	143	98.3	2.59	1150.0
300		1.117	142	97.6	2.59	1150.0
315		1.173	135	92.7	2.59	1150.0
330		1.229	136	93.4	2.59	1150.0
345		1.285	130	89.1	2.59	1150.0

Table 15. Experimental Column Contact Data Collected for Aged Resin 1, Run 3.

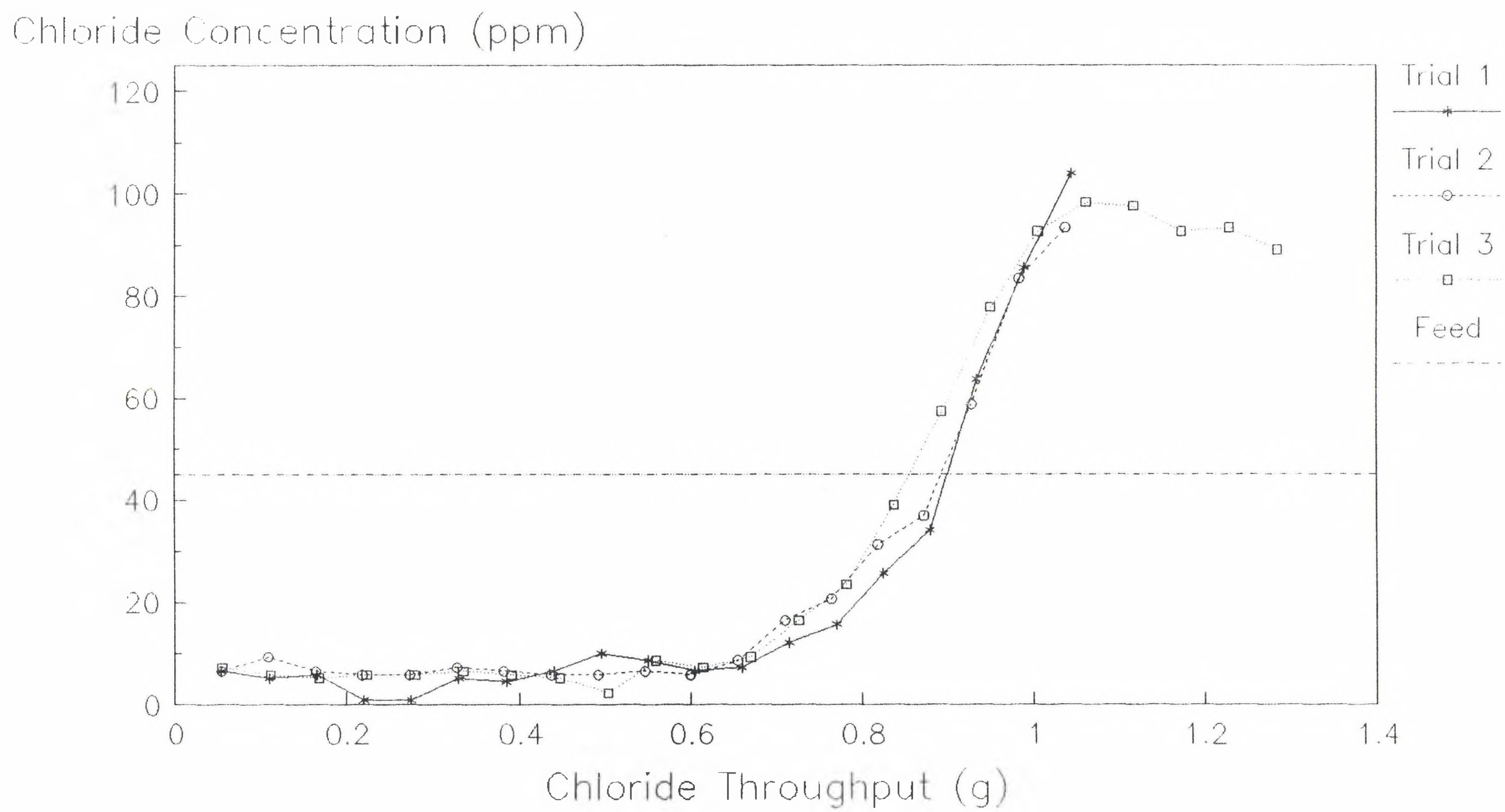

Figure 33. Aged Resin 1 Effluent Chloride Concentration as a Function of Chloride Throughput

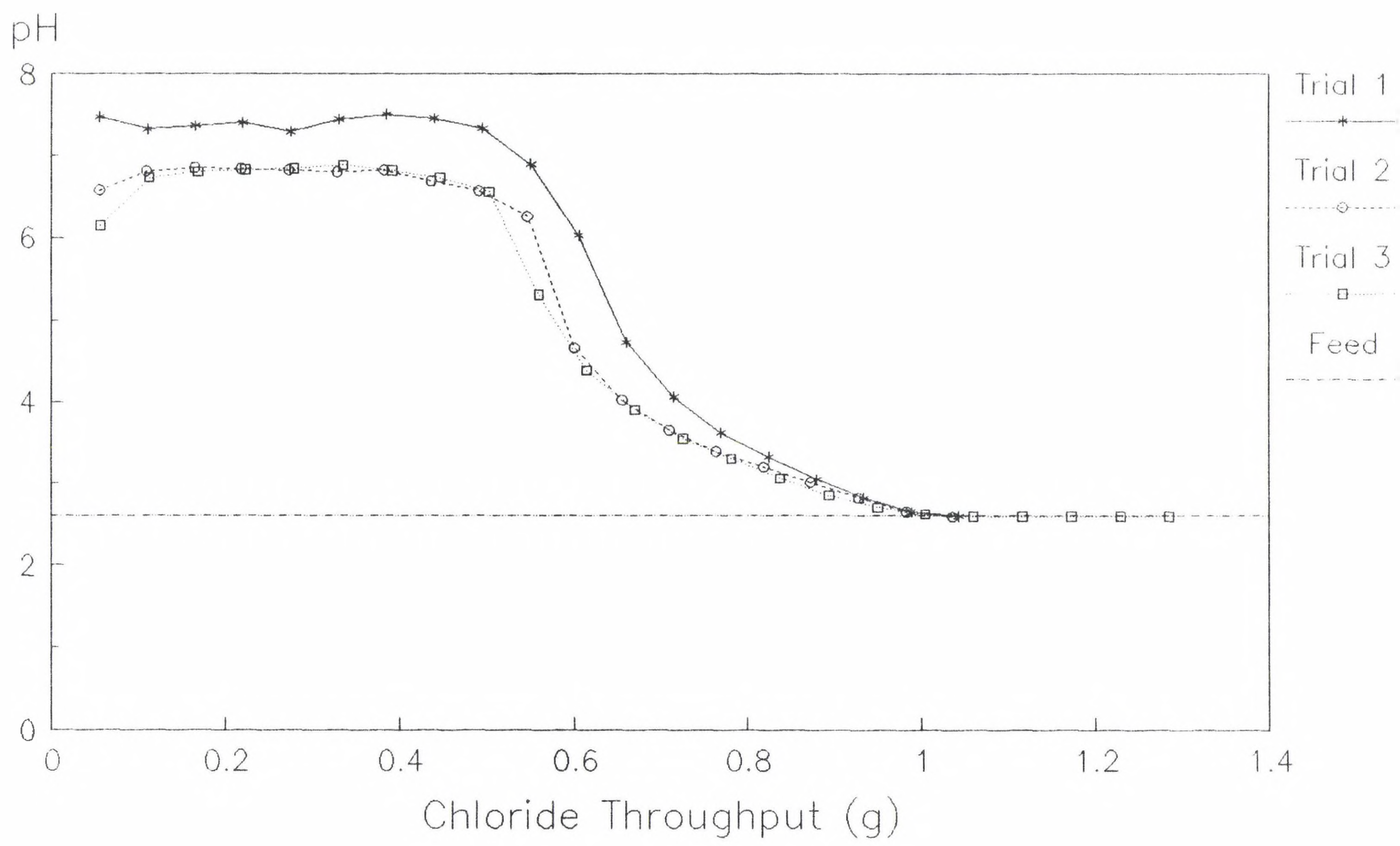

Figure 34. Aged Resin 1 Effluent pH as a Function of Chloride Throughput

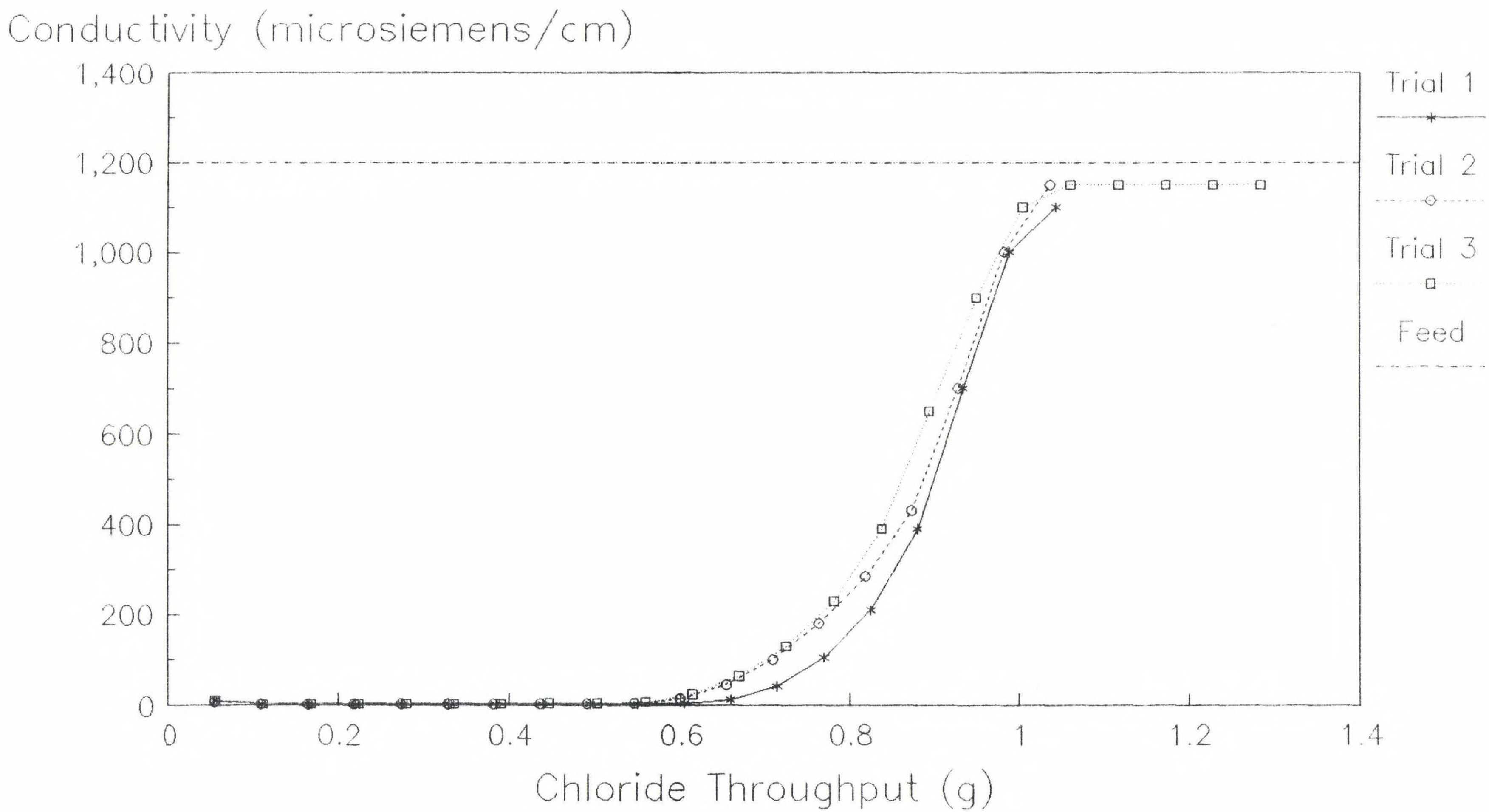

Figure 35. Aged Resin 1 Effluent Conductivity as a Function of Chloride Throughput

Experimental Data for Resin Two

Data was collected for aged and virgin resin 2 samples according to procedures developed in Appendix B. Tabulated data for virgin runs one to three are found in tables 16, 17 and 18. The plots of the effluent chloride concentration (figure 36), effluent pH (figure 37) and the effluent conductivity (figure 38) for all three runs follow. Tabulated data for aged runs one to three are found in table 19, 20 and 21. The plots of the effluent chloride concentration (figure 39), effluent pH (figure 40) and the effluent conductivity (figure 41) for all three runs follow.

Resin 2 Virgin Run 1

Bed Ht 10.8 cm Volume 53.01 cm3

Time	Flow	Total Cl-	Reading	ppm Cl-	pH	Cond.
Feed	73.8		67	44.7	2.59	1150.0
15		0.049	8	3.0	5.97	10.5
30		0.099	3	0.0	5.93	1.3
45		0.148	6	1.6	5.93	1.0
60		0.198	8	3.0	5.98	0.9
75	74.0	0.247	10	4.5	5.96	0.9
90		0.297	7	2.3	5.93	0.9
105		0.346	14	7.3	5.92	0.9
120		0.396	9	3.8	5.90	1.0
135		0.445	12	5.9	5.88	1.0
150	74.0	0.495	11	5.2	5.87	1.0
165		0.544	11	5.2	5.85	1.0
180		0.594	13	6.6	5.80	1.2
195		0.643	16	8.7	5.63	1.5
210		0.693	9	3.8	5.46	2.1
225		0.742	11	5.2	4.93	3.3
240	73.5	0.792	12	5.9	4.88	7.0
255		0.841	11	5.2	4.57	13.0
270		0.891	15	8.0	4.19	29.0
285		0.940	21	12.2	3.82	70.0
300		0.990	24	14.3	3.44	160.0
315		1.039	46	29.9	3.10	355.0
330		1.089	91	61.6	2.81	700.0
345		1.138	129	88.4	2.64	1000.0

Table 16. Experimental Column Contact Data Collected for Virgin Resin 2, Run 1.

Resin 2 Virgin Run 2

Bed Ht 10.8 cm Volume 53.01 cm3

Time	Flow	Total Cl-	Reading	ppm Cl-	pH	Cond.
Feed	73.0		70	46.8	2.58	1150.0
15		0.051	3	0.0	5.91	1.3
30		0.102	8	3.0	6.03	0.9
45		0.154	11	5.2	5.96	0.9
60	72.0	0.205	12	5.9	5.99	0.9
75		0.256	9	3.8	5.96	0.9
90	73.5	0.307	3	0.0	5.88	0.9
105		0.359	7	2.3	5.96	0.9
120		0.410	9	3.8	5.90	0.9
135		0.461	5	0.9	5.89	1.0
150		0.512	6	1.6	5.84	1.0
165		0.564	3	0.0	5.74	1.1
180		0.615	6	1.6	5.63	1.4
195		0.666	10	4.5	5.39	2.4
210	73.5	0.717	7	2.3	5.15	3.8
225		0.769	10	4.5	4.75	9.0
240		0.820	11	5.2	4.38	19.0
255		0.871	10	4.5	4.01	43.0
270		0.922	21	12.2	3.70	90.0
285		0.974	26	15.7	3.42	175.0
300		1.025	48	31.3	3.15	310.0
315		1.076	84	56.7	2.88	600.0
330		1.127	122	83.5	2.68	950.0
345		1.178	149	102.5	2.58	1150.0
360		1.230	159	109.6	2.58	1150.0

Table 17. Experimental Column Contact Data Collected for Virgin Resin 2, Run 2.

Resin 2 Virgin Run 3

Bed Ht 10.8 cm Volume 53.01 cm3

Time	Flow	Total Cl-	Reading	ppm Cl-	pH	Cond.
Feed	73.8		71	47.5	2.58	1150.0
15		0.053	5	0.9	6.00	1.5
30		0.105	9	3.8	6.18	0.8
45		0.158	11	5.2	6.14	0.8
60		0.210	11	5.2	6.12	0.8
75	73.5	0.263	10	4.5	6.12	0.8
90		0.315	15	8.0	6.06	0.8
105		0.368	13	6.6	6.07	0.8
120		0.420	11	5.2	6.02	0.8
135		0.473	11	5.2	6.02	0.9
150		0.525	12	5.9	5.99	0.9
165		0.578	13	6.6	5.92	1.0
180		0.631	13	6.6	5.79	1.2
195		0.683	16	8.7	5.47	2.0
210		0.736	9	3.8	5.20	3.5
225		0.788	19	10.8	4.82	8.0
240		0.841	9	3.8	4.42	17.0
255	74.0	0.893	21	12.2	4.07	38.0
270		0.946	24	14.3	3.71	85.0
285		0.998	34	21.4	3.40	175.0
300		1.051	50	32.7	3.12	340.0
315		1.103	94	63.7	2.83	700.0
330		1.156	136	93.4	2.64	1050.0
345		1.209	154	106.1	2.58	1150.0

Table 18. Experimental Column Contact Data Collected for Virgin Resin 2, Run 3.

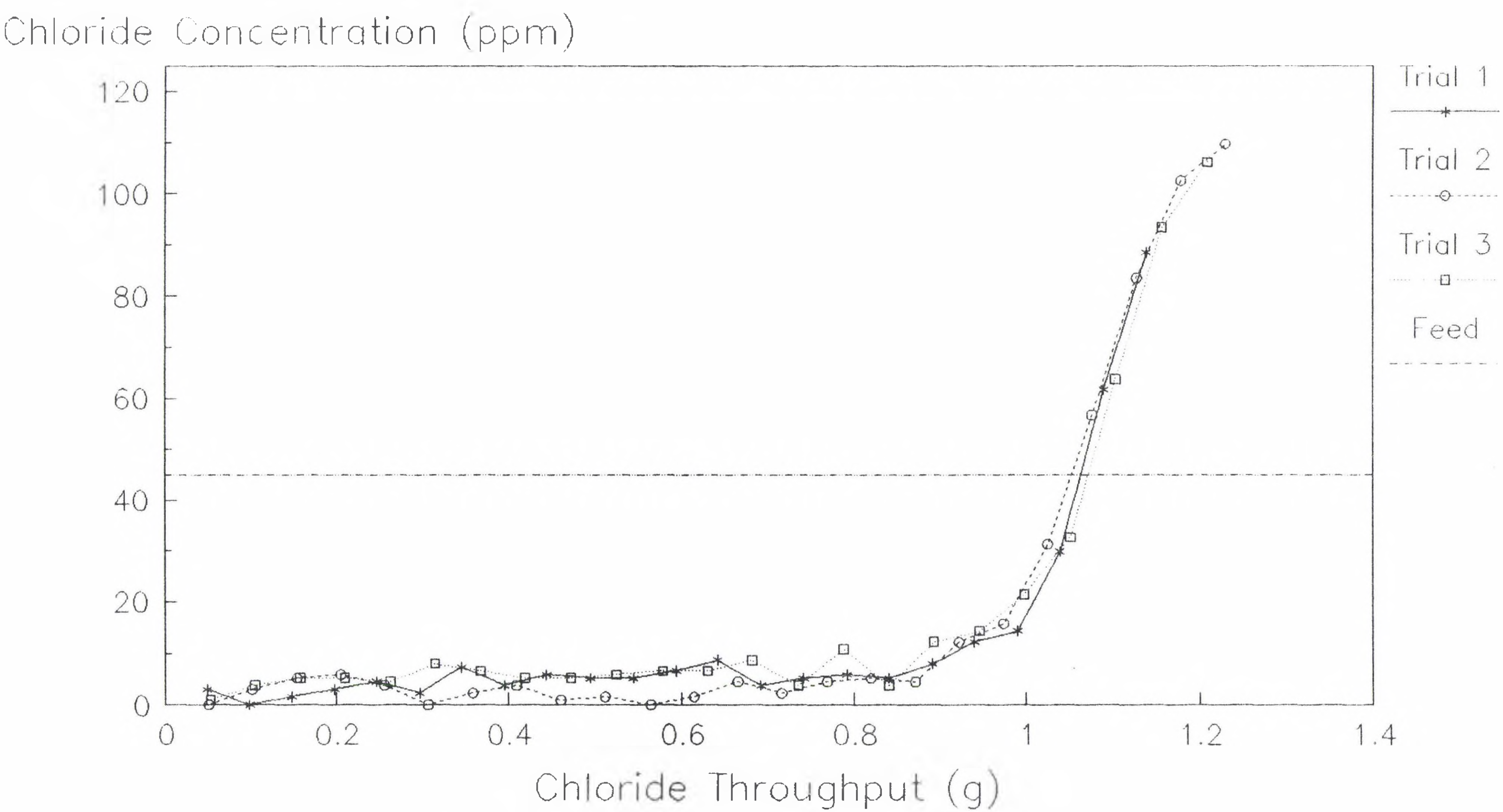

Figure 36. Virgin Resin 2 Effluent Chloride Concentration as a Function of Chloride Throughput

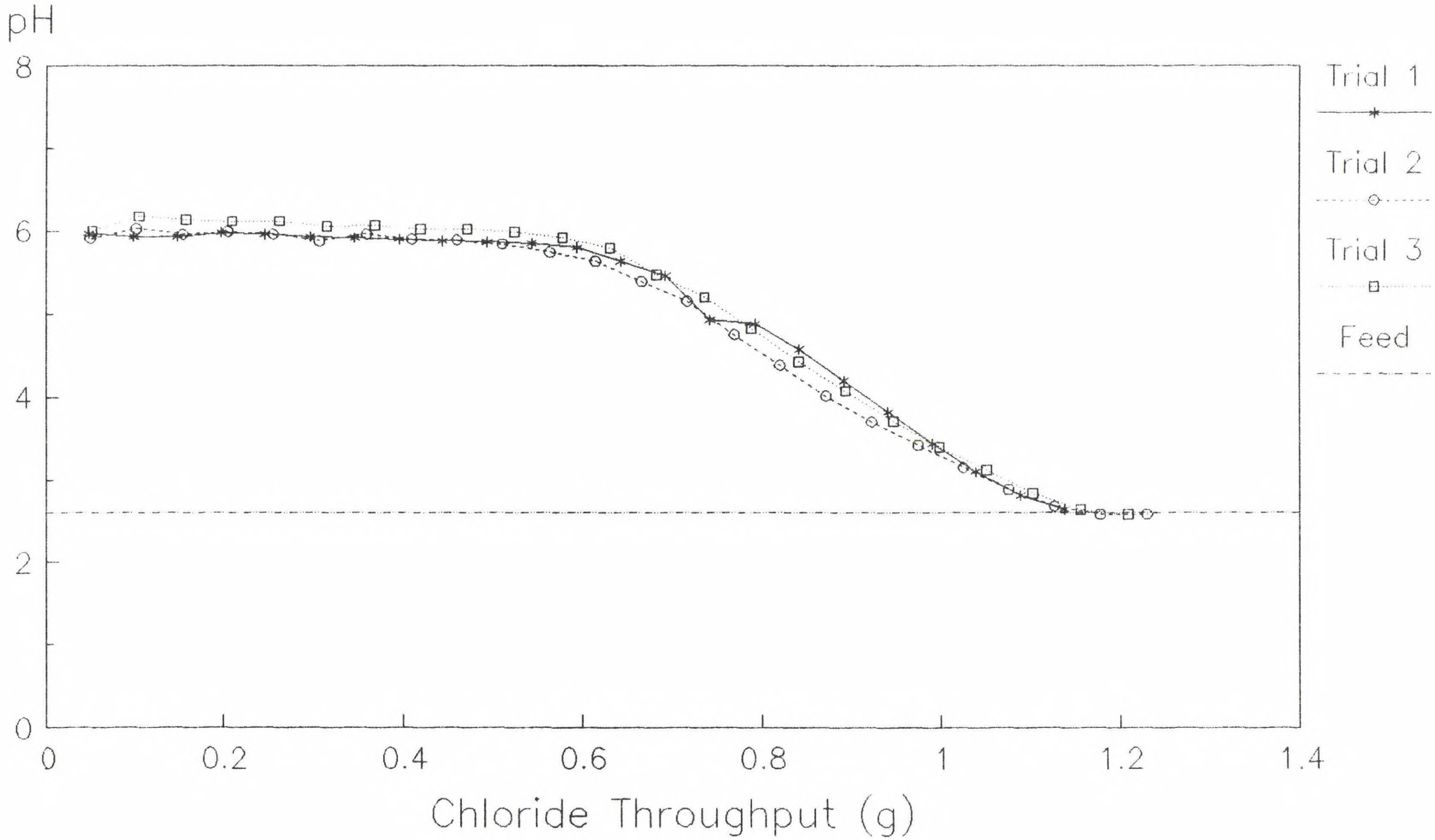

Figure 37. Virgin Resin 2 Effluent pH as a Function of Chloride Throughput

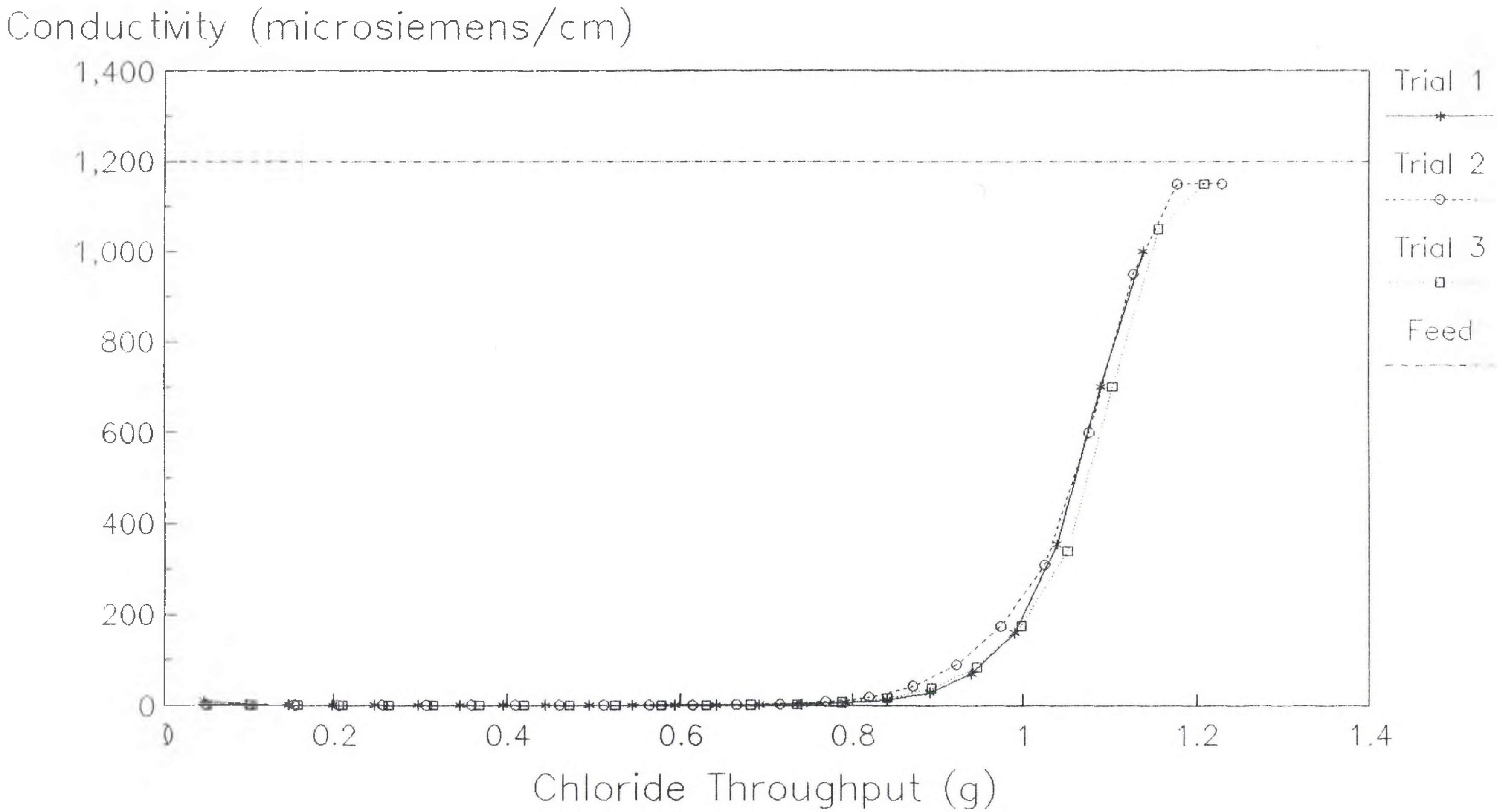

Figure 38. Virgin Resin 2 Effluent Conductivity as a Function of Chloride Throughput

Resin 2 Aged Run 1

Bed Ht 10.9 cm Volume 53.51 cm3

Time	Flow	Total Cl-	Reading	ppm Cl-	pH	Cond.
Feed	72.0		65	43.3	2.58	1150.0
15		0.047	10	4.5	5.97	1.2
30	72.0	0.093	5	0.9	6.25	1.0
45		0.140	9	3.8	6.38	1.0
60		0.187	15	8.0	6.36	1.0
75		0.234	11	5.2	6.29	1.0
90		0.280	9	3.8	6.23	1.0
105		0.327	15	8.0	6.23	1.0
120		0.374	4	0.2	6.29	1.1
135		0.421	7	2.3	6.30	1.2
150		0.467	8	3.0	6.18	1.3
165		0.514	7	2.3	5.88	2.1
180		0.561	9	3.8	5.43	4.3
195	72.0	0.607	6	1.6	5.05	9.0
210		0.654	5	0.9	4.66	21.0
225		0.701	14	7.3	4.17	42.0
240		0.748	21	12.2	3.69	90.0
255		0.794	25	15.0	3.43	165.0
270		0.841	37	23.5	3.22	265.0
285		0.888	56	36.9	2.99	450.0
300		0.935	75	50.3	2.85	650.0
315		0.981	100	68.0	2.74	800.0
330		1.028	116	79.2	2.65	1000.0
345		1.075	132	90.5	2.61	1100.0

Table 20. Experimental Column Contact Data Collected for Aged Resin 2, Run 1

Resin 2 Aged Run 2

Bed Ht 10.9 cm Volume 53.51 cm3

Time	Flow	Total Cl-	Reading	ppm Cl-	pH	Cond.
Feed	77.0		65	43.5	2.58	1150.0
15		0.050	9	3.8	6.65	11.0
30		0.100	5	0.9	6.69	3.3
45		0.150	8	3.0	6.90	3.2
60		0.200	7	2.3	6.87	3.2
75		0.250	7	2.3	6.84	3.2
90		0.300	8	3.0	6.98	3.1
105		0.350	5	0.9	6.90	3.2
120		0.400	7	2.3	6.81	3.2
135		0.450	9	3.8	6.80	3.3
150	77.0	0.500	7	2.3	6.74	3.3
165		0.550	8	3.0	6.70	3.5
180		0.600	5	0.9	6.23	3.9
195		0.650	12	5.9	4.86	10.0
210		0.700	17	9.4	4.23	30.0
225		0.750	19	10.8	3.84	70.0
240		0.800	29	17.9	3.55	125.0
255		0.849	34	21.4	3.30	220.0
270		0.899	53	34.8	3.09	360.0
285	77.0	0.949	80	53.8	2.87	600.0
300		0.999	124	84.9	2.68	900.0
315		1.049	145	99.7	2.60	1100.0
330		1.099	143	98.3	2.60	1100.0
345		1.149	145	99.7	2.60	1100.0

Table 20. Experimental Column Contact Data Collected for Aged Resin 2, Run 2.

Resin 2 Aged Run 3 2/26/91

Bed Ht 10.9 cm Volume 53.51 cm3

Time	Flow	Total Cl-	Reading	ppm Cl-	pH	Cond.
Feed	74.6		70	46.8	2.59	1125.0
15	74.5	0.052	2	0.0	6.68	6.00
30		0.105	9	3.8	6.83	3.4
45		0.157	14	7.3	6.84	3.3
60		0.209	7	2.3	6.84	3.3
75	74.5	0.262	10	4.5	6.82	3.3
90		0.314	12	5.9	6.85	3.3
105	74.5	0.367	10	4.5	6.79	3.3
120		0.419	8	3.0	6.79	3.3
135		0.471	5	0.9	6.75	3.4
150		0.524	14	7.3	6.71	3.35
165		0.576	7	2.3	6.55	3.55
180	75	0.628	7	2.3	6.24	4
195		0.681	10	4.5	4.83	11.5
210		0.733	11	5.2	4.19	35
225		0.785	21	12.2	3.73	88
240		0.838	29	17.9	3.45	155
255		0.890	46	29.9	3.23	265
270		0.942	61	40.4	3.02	420
285		0.995	77	51.7	2.84	650
300		1.047	114	77.8	2.69	900
315		1.100	136	93.4	2.63	1050
330	74.5	1.152	140	96.2	2.61	1100
345		1.204	142	97.6	2.61	1100

Table 21. Experimental Column Contact Data Collected for Aged Resin 2, Run 3.

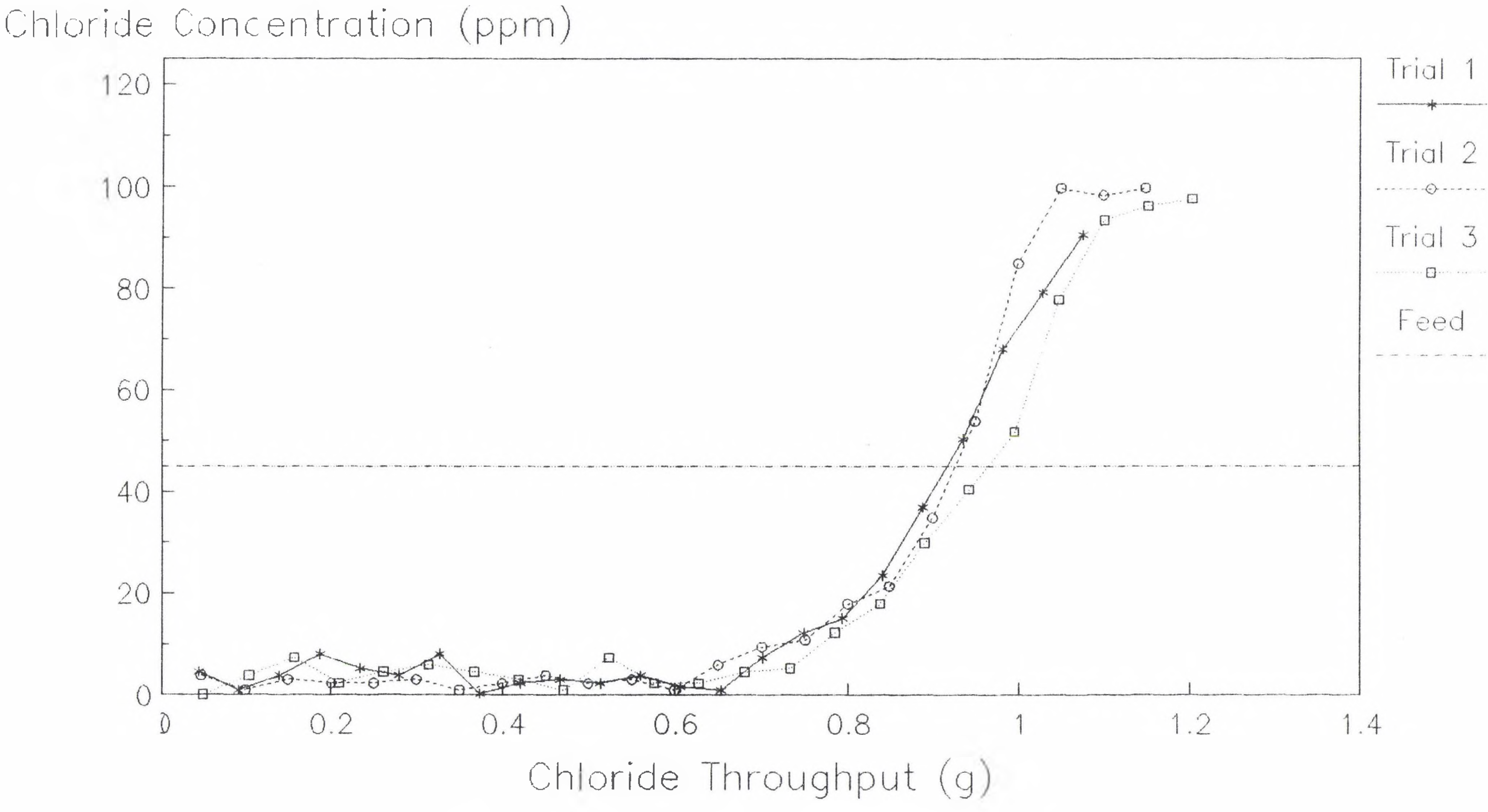

Figure 39. Aged Resin 2 Effluent Chloride Concentration as a Function of Chloride Throughput

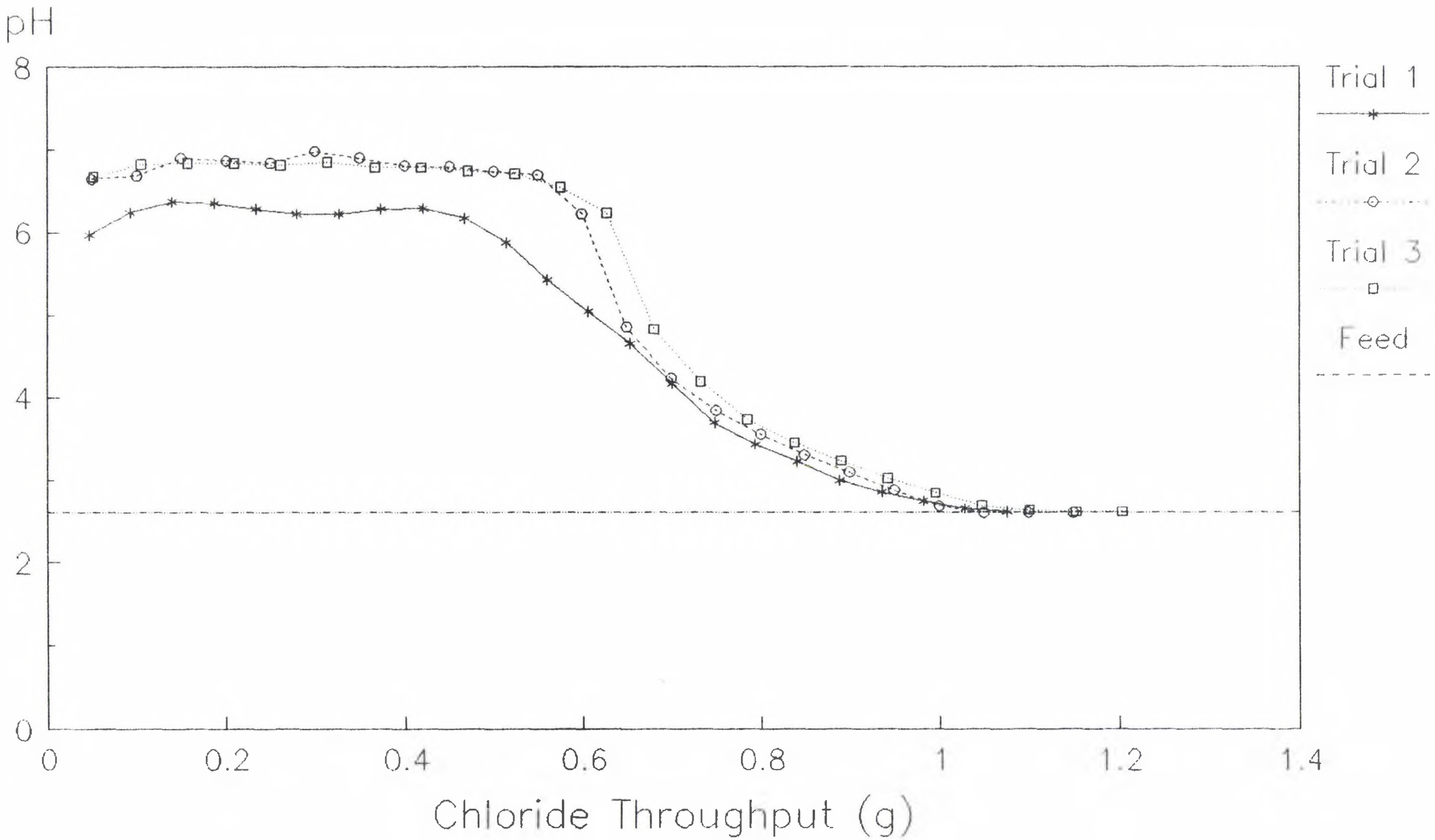

Figure 40. Aged Resin 2 Effluent pH as a Function of Chloride Throughput

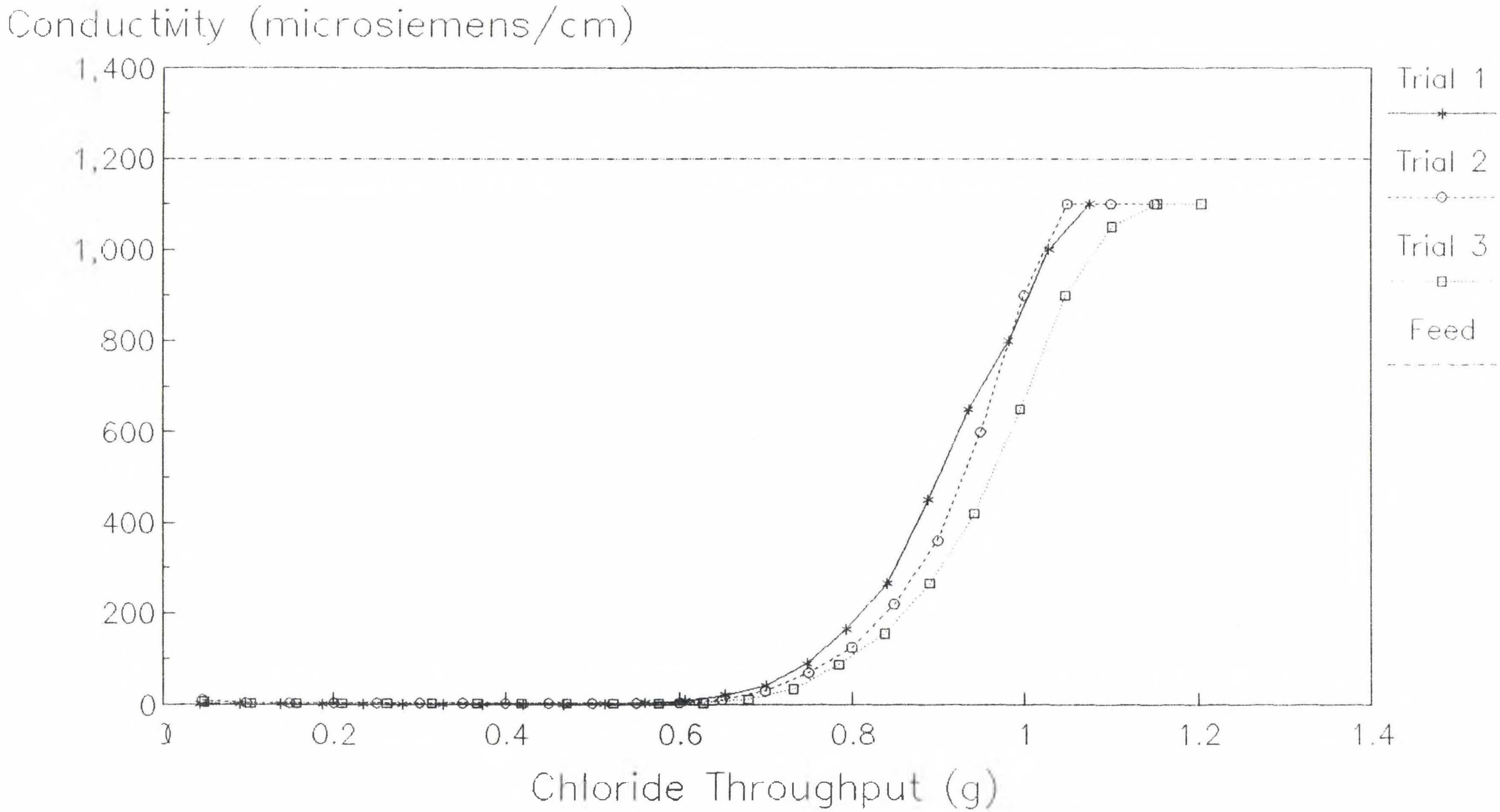

Figure 41. Aged Resin 2 Effluent Conductivity as a Function of Chloride Throughput

Experimental Data for Resin Three

Data was collected for aged and virgin resin 3 samples according to procedures developed in Appendix B. Tabulated data for virgin runs one to three are found in tables 22, 23 and 24. The plots of the effluent chloride concentration (figure 42), effluent pH (figure 43) and the effluent conductivity (figure 44) for all three runs follow. Tabulated data for aged runs one to three are found in table 25, 26 and 27. The plots of the effluent chloride concentration (figure 45), effluent pH (figure 46) and the effluent conductivity (figure 47) for all three runs follow.

Resin 3 Virgin Run 1

Bed Ht 10.5 cm Volume 51.54 cm3

Time	Flow	Total Cl-	Reading	ppm Cl-	pH	Cond.
Feed	73.5		66	44.0	2.59	1150.0
15		0.048	3	0.0	5.91	11.0
30		0.097	1	0.0	5.81	1.3
45	73.5	0.145	8	3.0	5.96	0.8
60		0.194	4	0.2	5.97	0.8
75		0.242	9	3.8	5.97	0.9
90		0.291	7	2.3	5.99	0.9
105		0.339	7	2.3	5.94	0.9
120		0.388	8	3.0	5.86	1.0
135		0.436	9	3.8	5.80	1.1
150	74.0	0.485	9	3.8	5.67	1.4
165		0.533	5	0.9	5.48	2.0
180		0.582	6	1.6	5.23	3.1
195		0.630	6	1.6	4.93	6.0
210		0.679	14	7.3	4.74	9.0
225		0.727	6	1.6	4.49	15.0
240		0.776	8	3.0	4.26	25.0
255		0.824	11	5.2	4.01	44.0
270	73.0	0.873	20	11.5	3.77	80.0
285		0.921	20	11.5	3.51	135.0
300		0.970	37	23.5	3.22	265.0
315		1.018	49	32.0	3.08	365.0
330		1.066	67	44.7	2.91	575.0
345		1.115	90	60.9	2.79	750.0

Table 22. Experimental Column Contact Data Collected for Virgin Resin 3, Run 1.

Resin 3 Virgin Run 2

Bed Ht 10.5 cm Volume 51.54 cm3

Time	Flow	Total Cl-	Reading	ppm Cl-	pH	Cond.
Feed	73.6		66	44.0	2.57	1150.0
15		0.049	6	1.6	6.00	1.0
30		0.097	7	2.3	5.98	0.9
45	73.0	0.146	10	4.5	6.01	0.9
60		0.194	11	5.2	6.05	0.9
75		0.243	8	3.0	6.01	0.9
90		0.291	8	3.0	5.99	0.9
105	73.5	0.340	10	4.5	5.92	1.0
120		0.388	11	5.2	5.91	1.0
135		0.437	9	3.8	5.96	1.1
150		0.486	10	4.5	5.83	1.3
165		0.534	8	3.0	5.60	1.7
180	74.0	0.583	10	4.5	5.36	2.6
195		0.631	10	4.5	5.12	4.0
210		0.680	13	6.6	4.83	8.0
225		0.728	14	7.3	4.53	14.0
240	74.0	0.777	13	6.6	4.24	27.0
255		0.826	16	8.7	3.95	50.0
270		0.874	41	26.3	3.65	310.0
285		0.923	51	33.4	3.43	320.0
300		0.971	60	39.7	3.04	400.0
315		1.020	82	55.3	2.85	650.0
330		1.068	102	69.4	2.77	750.0
345		1.117	116	79.2	2.69	900.0
360		1.165	152	104.7	2.58	1150.0
375		1.214	151	103.9	2.56	1200.0
390		1.263	149	102.5	2.56	1200.0

Table 23. Experimental Column Contact Data Collected for Virgin Resin 3, Run 2.

Resin 3 Virgin Run 3

Bed Ht 10.5 cm Volume 51.54 cm3

Time	Flow	Total Cl-	Reading	ppm Cl-	pH	Cond.
Feed	74.2		71	47.5	2.55	1200.0
15		0.053	12	5.9	5.92	1.4
30		0.106	2	0.0	5.96	0.9
45		0.159	6	1.6	5.91	0.9
60	74.0	0.211	7	2.3	5.88	0.9
75		0.264	10	4.5	5.78	0.9
90		0.317	10	4.5	5.85	0.9
105		0.370	3	0.0	5.84	1.0
120	75.0	0.423	6	1.6	5.79	1.1
135		0.476	10	4.5	5.71	1.3
150		0.529	9	3.8	5.55	1.7
165	74.5	0.582	11	5.2	5.30	5.5
180		0.634	7	2.3	5.00	7.0
195		0.687	7	2.3	4.71	9.5
210		0.740	7	2.3	4.28	19.0
225		0.793	14	7.3	4.06	38.0
240		0.846	19	10.8	3.74	80.0
255		0.899	30	18.6	3.43	160.0
270	73.5	0.952	44	28.4	3.16	300.0
285		1.004	64	42.6	2.96	470.0
300		1.057	91	61.6	2.82	700.0
315	74.0	1.110	110	75.0	2.72	850.0
330		1.163	134	92.0	2.64	1000.0
345		1.216	152	104.7	2.58	1150.0

Table 24. Experimental Column Contact Data Collected for Virgin Resin 3, Run 3.

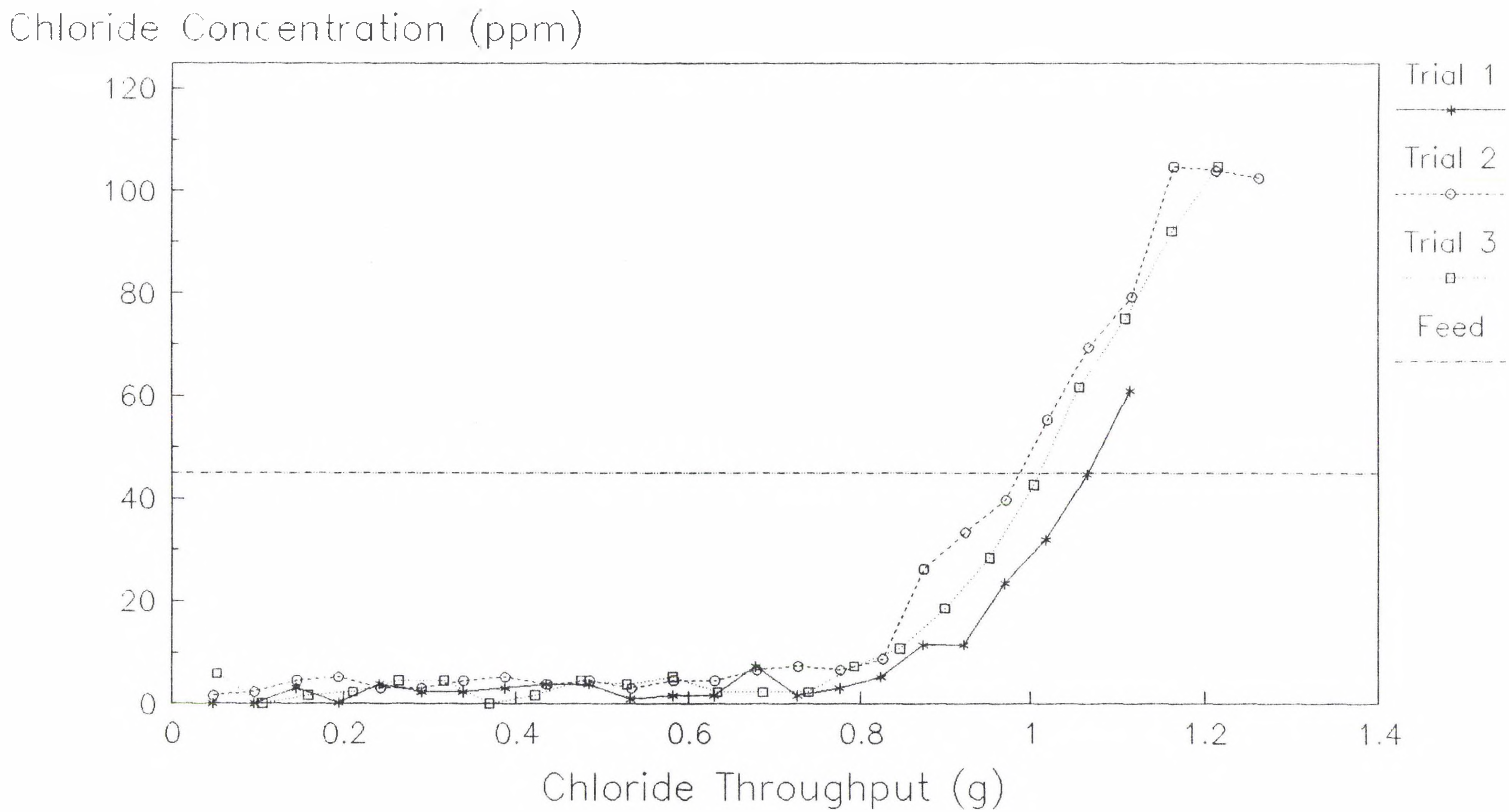

Figure 42. Virgin Resin 3 Effluent Chloride Concentration as a Function of Chloride Throughput

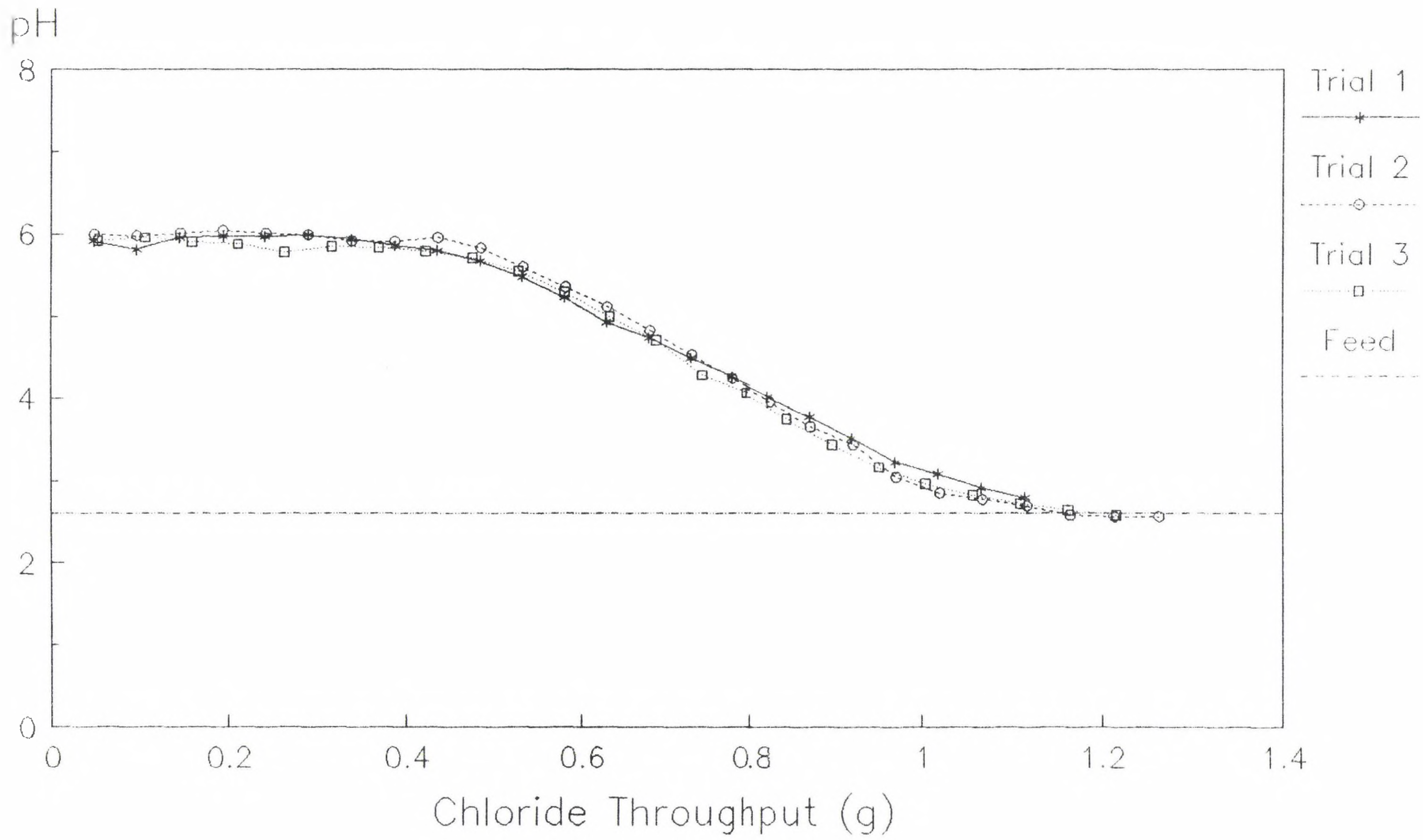

Figure 43. Virgin Resin 3 Effluent pH as a Function of Chloride Throughput

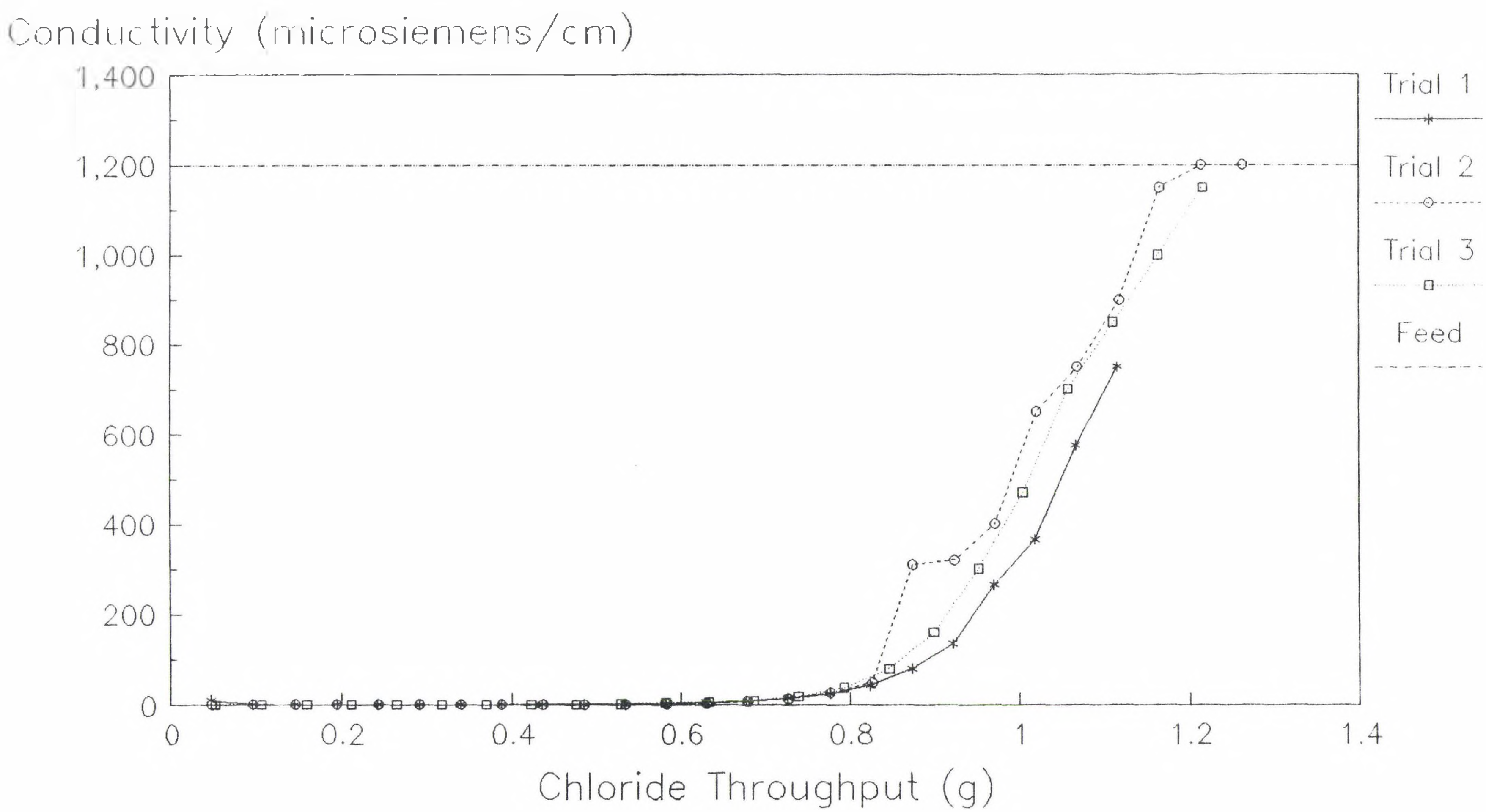

Figure 44. Virgin Resin 3 Effluent Conductivity as a Function of Chloride Throughput

Resin 3 Aged Run 1

Bed Ht 10.9 cm Volume 53.51 cm3

Time	Flow	Total Cl-	Reading	ppm Cl-	pH	Cond.
Feed	73.9		68	45.4	2.58	1150.0
15		0.050	8	3.0	4.67	2.3
30		0.101	8	3.0	5.70	1.3
45		0.151	11	5.2	5.66	1.3
60		0.201	8	3.0	5.60	1.5
75	74.0	0.251	14	7.3	5.52	1.7
90		0.302	10	4.5	5.40	2.2
105		0.352	15	8.0	5.24	3.1
120	73.5	0.402	13	6.6	5.03	5.0
135		0.453	13	6.6	4.84	7.5
150		0.503	14	7.3	4.64	11.5
165		0.553	16	8.7	4.46	16.5
180		0.603	17	9.4	4.30	23.0
195	74.0	0.654	21	12.2	4.10	35.0
210		0.704	22	12.9	3.93	55.0
225		0.754	17	9.4	3.75	80.0
240		0.805	26	15.7	3.55	125.0
255	74.0	0.855	29	17.9	3.35	195.0
270		0.905	40	25.6	3.15	310.0
285		0.955	61	40.4	2.98	460.0
300		1.006	80	53.8	2.85	625.0
315		1.056	92	62.3	2.76	800.0
330		1.106	105	71.5	2.70	900.0
345		1.157	117	80.0	2.66	1000.0

Table 25. **Experimental Column Contact Data Collected for Aged Resin 3, Run 1.**

Resin 3 Aged Run 2

Bed Ht 10.9 cm Volume 53.51 cm3

Time	Flow	Total Cl-	Reading	ppm Cl-	pH	Cond.
Feed	73.8		69	46.1	2.58	1150.0
15		0.051	3	0.0	4.63	11.0
30	73.5	0.102	9	3.8	5.66	1.3
45		0.153	13	6.6	5.68	1.2
60		0.204	15	8.0	5.51	1.7
75		0.255	12	5.9	5.50	1.8
90		0.306	12	5.9	5.41	2.2
105		0.357	12	5.9	5.24	3.1
120		0.408	12	5.9	4.95	7.5
135		0.459	12	5.9	4.57	12.0
150	74.0	0.510	10	4.5	4.44	16.0
165		0.561	8	3.0	4.29	22.5
180		0.612	8	3.0	4.14	32.0
195		0.663	12	5.9	3.98	46.0
210		0.714	13	6.6	3.80	70.0
225		0.765	20	11.5	3.63	105.0
240		0.816	23	13.6	3.45	155.0
255		0.867	33	20.7	3.26	240.0
270		0.918	49	32.0	3.09	360.0
285		0.969	66	44.0	2.90	600.0
300		1.020	79	53.1	2.79	720.0
315		1.071	108	73.6	2.68	950.0
330		1.122	126	86.3	2.62	1100.0
345		1.173	126	86.3	2.59	1150.0

Table 26. Experimental Column Contact Data Collected for Aged Resin 3, Run 2.

Resin 3 Aged Run 3

Bed Ht 10.9 cm Volume 53.51 cm3

Time	Flow	Total Cl-	Reading	ppm Cl-	pH	Cond.
Feed	73.6		67	44.7	2.59	1150.0
15		0.049	5	0.9	4.58	11.0
30		0.099	9	3.8	5.58	1.7
45		0.148	2	0.0	5.57	1.6
60		0.197	6	1.6	5.53	1.8
75	74.0	0.247	9	3.8	5.33	2.6
90		0.296	1	0.0	5.19	3.5
105		0.345	7	2.3	5.04	5.0
120		0.395	9	3.8	4.85	7.5
135		0.444	13	6.6	4.71	9.5
150	73.5	0.493	5	0.9	4.56	13.0
165		0.543	5	0.9	4.41	17.5
180		0.592	11	5.2	4.25	24.5
195	73.5	0.641	9	3.8	4.09	36.5
210		0.691	12	5.9	3.93	55.0
225		0.740	13	6.6	3.76	80.0
240	73.5	0.789	22	12.9	3.57	120.0
255		0.839	23	13.6	3.40	175.0
270		0.888	31	19.3	3.23	260.0
285		0.937	47	30.6	3.07	375.0
300		0.987	61	40.4	2.91	575.0
315		1.036	89	60.2	2.76	800.0
330		1.085	115	78.5	2.65	1000.0
345		1.135	128	87.7	2.60	1100.0

Table 27. **Experimental Column Contact Data Collected for** Aged Resin 3, Run 3.

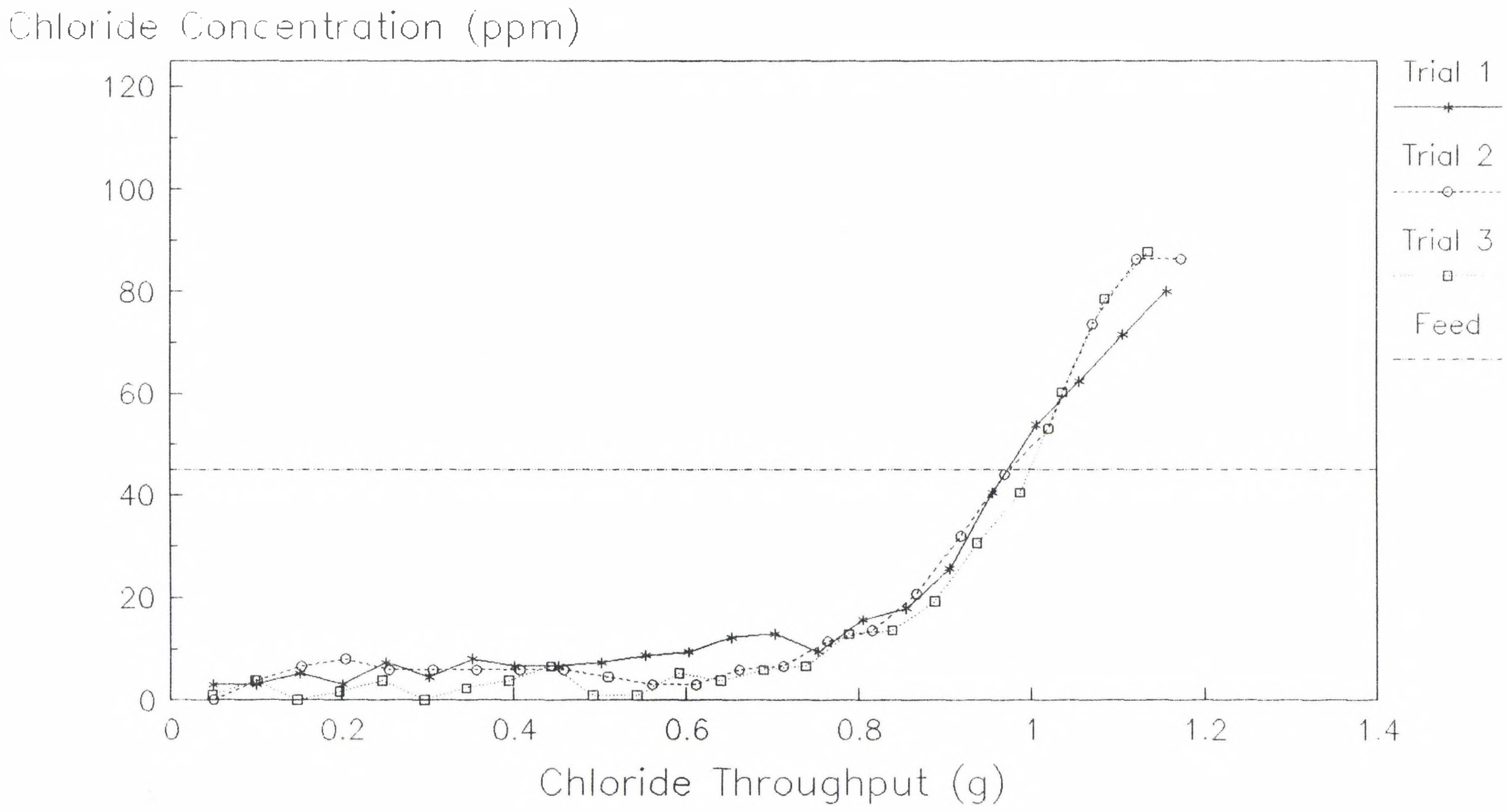

Figure 45. Aged Resin 3 Effluent Chloride Concentration as a Function of Chloride Throughput

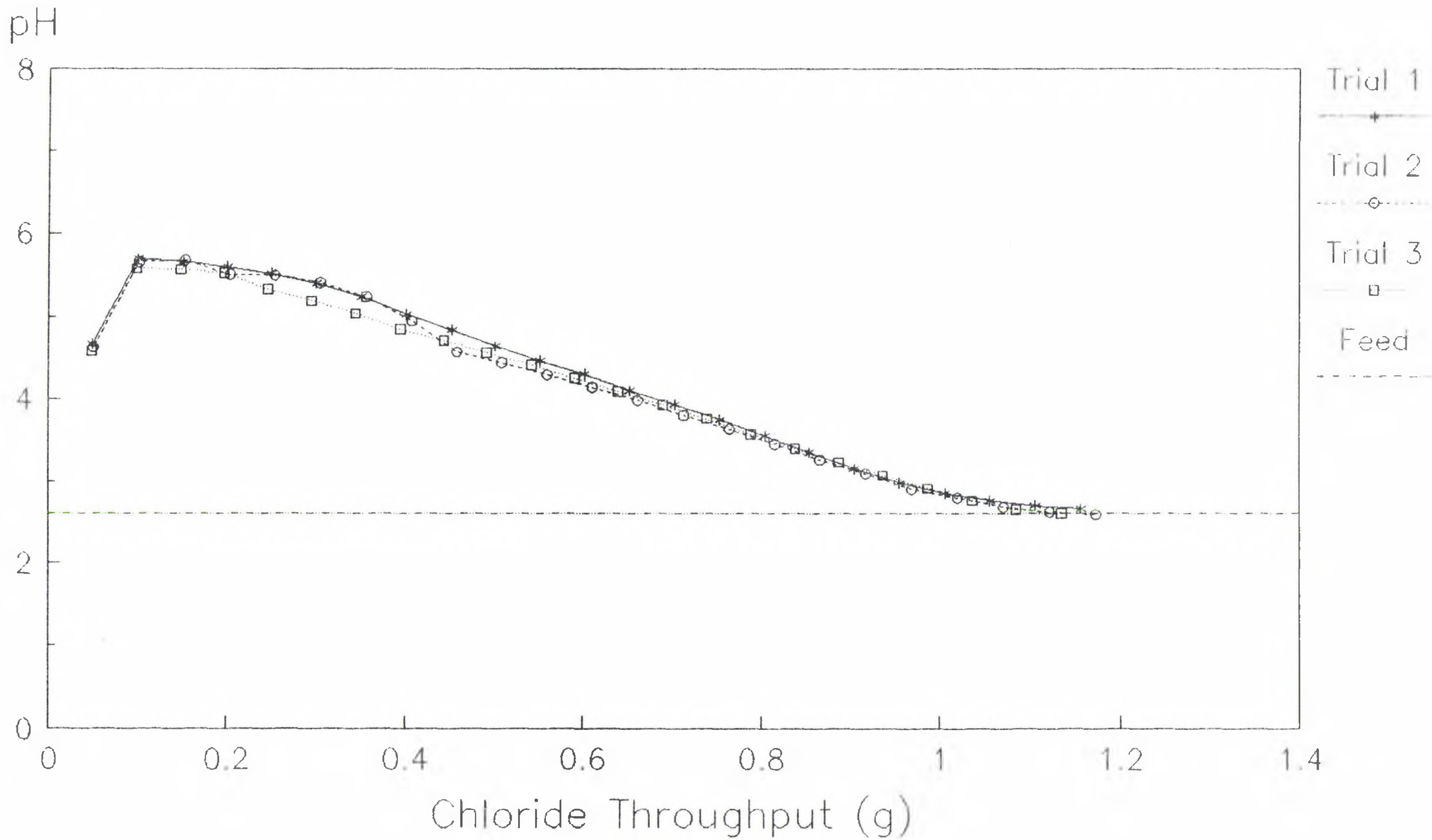

Figure 46. Aged Resin 3 Effluent pH as a Function of Chloride Throughput

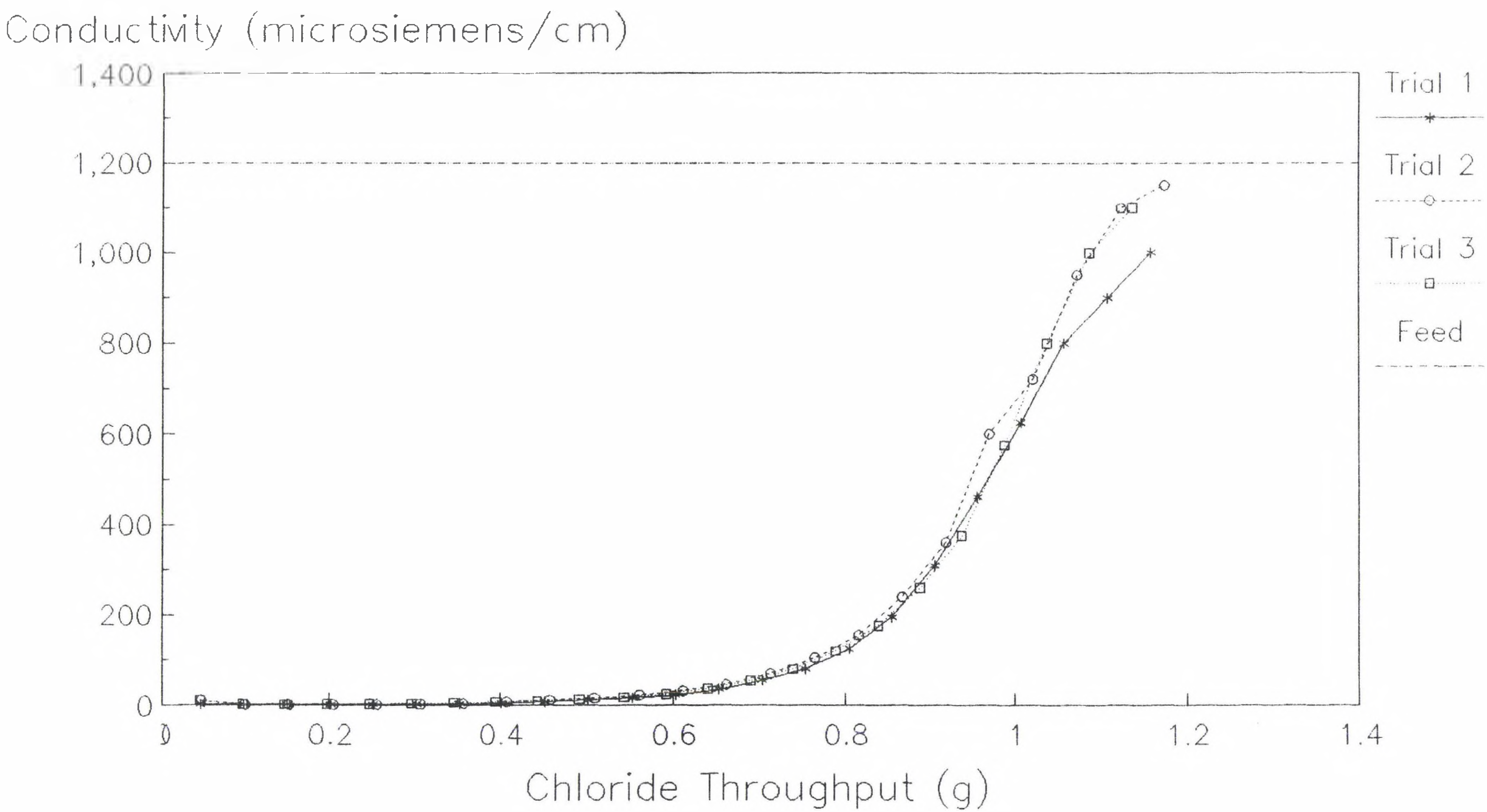

Figure 47. Aged Resin 3 Effluent Conductivity as a Function of Chloride Throughput

Experimental Data for Resin Four

Data was collected for aged and virgin resin 4 samples according to procedures developed in Appendix B. Tabulated data for virgin runs one to three are found in tables 28, 29 and 30. The plots of the effluent chloride concentration (figure 48), effluent pH (figure 49) and the effluent conductivity (figure 50) for all three runs follow. Tabulated data for aged runs one to three are found in table 31, 32 and 33. The plots of the effluent chloride concentration (figure 51), effluent pH (figure 52) and the effluent conductivity (figure 53) for all three runs follow.

Resin 4 Virgin Run 1

Bed Ht 10.7 cm Volume 52.52 cm3

Time	Flow	Total Cl-	Reading	ppm Cl-	pH	Cond.
Feed	73.8		67	44.7	2.55	1200.0
15		0.049	8	3.0	6.08	5.0
30	74.0	0.099	7	2.3	6.52	2.6
45		0.148	8	3.0	6.70	2.5
60		0.198	8	3.0	6.75	2.5
75		0.247	3	0.0	6.76	2.6
90		0.297	4	0.2	6.77	2.6
105		0.346	13	6.6	6.74	2.6
120		0.396	9	3.8	6.74	2.6
135		0.445	10	4.5	6.72	2.7
150	74.0	0.495	12	5.9	6.71	2.8
165		0.544	8	3.0	6.73	3.0
180		0.594	15	8.0	6.71	3.5
195		0.643	13	6.6	6.63	5.0
210	73.5	0.693	11	5.2	5.87	6.0
225		0.742	14	7.3	4.39	23.0
240		0.792	20	11.5	3.80	75.0
255		0.841	19	10.8	3.57	120.0
270		0.891	41	26.3	3.31	220.0
285		0.940	50	32.7	3.11	340.0
300		0.990	74	49.6	2.91	550.0
315		1.039	109	74.3	2.73	825.0
330		1.089	133	91.2	2.62	1025.0
345		1.138	155	106.8	2.57	1200.0

Table 28. Experimental Column Contact Data Collected for Virgin Resin 4, Run 1.

Resin 4 Virgin Run 2

Bed Ht 10.7 cm Volume 52.52 cm3

Time	Flow	Total Cl-	Reading	ppm Cl-	pH	Cond.
Feed	72.8		67	44.7	2.55	1200.0
15		0.049	6	1.6	5.82	1.0
30		0.098	6	1.6	5.78	0.9
45		0.146	3	0.0	5.78	0.9
60		0.195	9	3.8	5.86	0.9
75		0.244	10	4.5	5.88	0.9
90		0.293	9	3.8	5.87	0.9
105		0.341	7	2.3	5.88	0.9
120		0.390	8	3.0	5.79	0.9
135		0.439	11	5.2	5.84	1.0
150		0.488	10	4.5	5.74	1.2
165		0.536	6	1.6	5.60	1.4
180		0.585	8	3.0	5.32	2.4
195		0.634	8	3.0	5.07	4.0
210		0.683	7	2.3	4.75	8.5
225	73.0	0.731	12	5.9	4.34	18.0
240		0.780	12	5.9	4.04	38.0
255		0.829	21	12.2	3.78	75.0
270		0.878	22	12.9	3.56	115.0
285		0.926	28	17.2	3.37	180.0
300		0.975	39	24.9	3.22	260.0
315	72.5	1.024	51	33.4	3.03	395.0
330		1.073	83	56.0	2.86	600.0
345		1.121	121	82.8	2.67	950.0
360		1.170	148	101.8	2.58	1150.0

Table 29. Experimental Column Contact Data Collected for Virgin Resin 4, Run 2.

Resin 4 Virgin Run 3

Bed Ht 10.7 cm Volume 52.52 cm3

Time	Flow	Total Cl-	Reading	ppm Cl-	pH	Cond.
Feed	71.7		72	48.2	2.55	1200.0
15		0.052	4	0.2	6.22	7.0
30		0.104	14	7.3	6.12	0.9
45	71.5	0.155	13	6.6	5.97	0.8
60		0.207	6	1.6	6.02	0.8
75		0.259	12	5.9	6.02	0.8
90	71.5	0.311	10	4.5	5.90	0.8
105		0.363	10	4.5	5.87	0.9
120		0.415	11	5.2	5.38	1.0
135		0.466	14	7.3	5.64	1.2
150		0.518	12	5.9	5.48	2.0
165		0.570	7	2.3	5.16	3.6
180		0.622	12	5.9	4.83	8.0
195		0.674	12	5.9	4.38	18.0
210		0.725	8	3.0	4.11	33.0
225		0.777	15	8.0	3.79	75.0
240		0.829	22	12.9	3.54	125.0
255		0.881	34	21.4	3.38	180.0
270	72.0	0.933	44	28.4	3.22	255.0
285		0.985	56	36.9	3.08	360.0
300		1.036	71	47.5	2.91	550.0
315		1.088	107	72.9	2.73	800.0
330		1.140	145	99.7	2.59	1100.0
345		1.192	160	110.3	2.55	1200.0

Table 30. Experimental Column Contact Data Collected for Virgin Resin 4, Run 3.

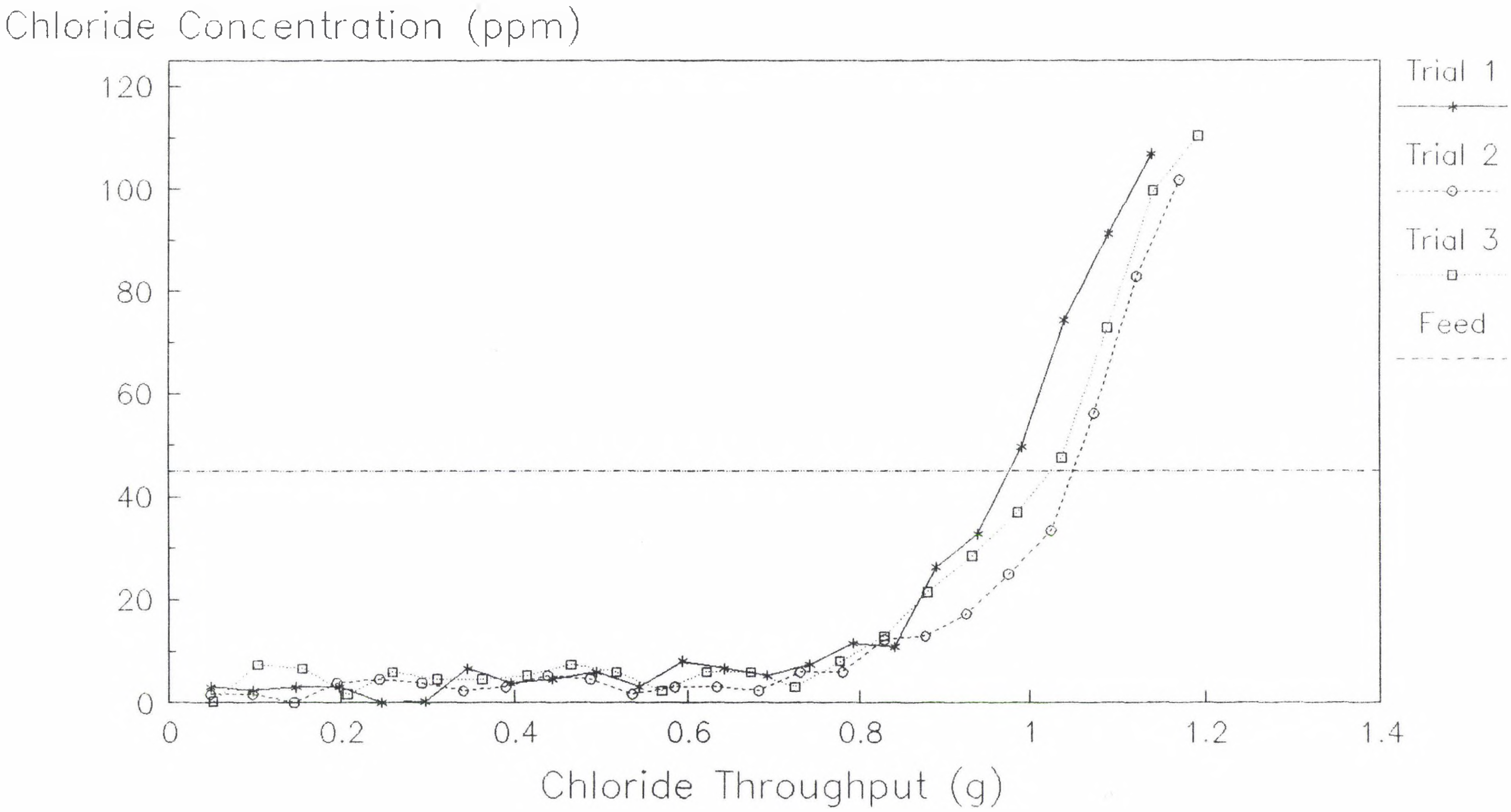

Figure 48. Virgin Resin 4 Effluent Chloride Concentration as a Function of Chloride Throughput

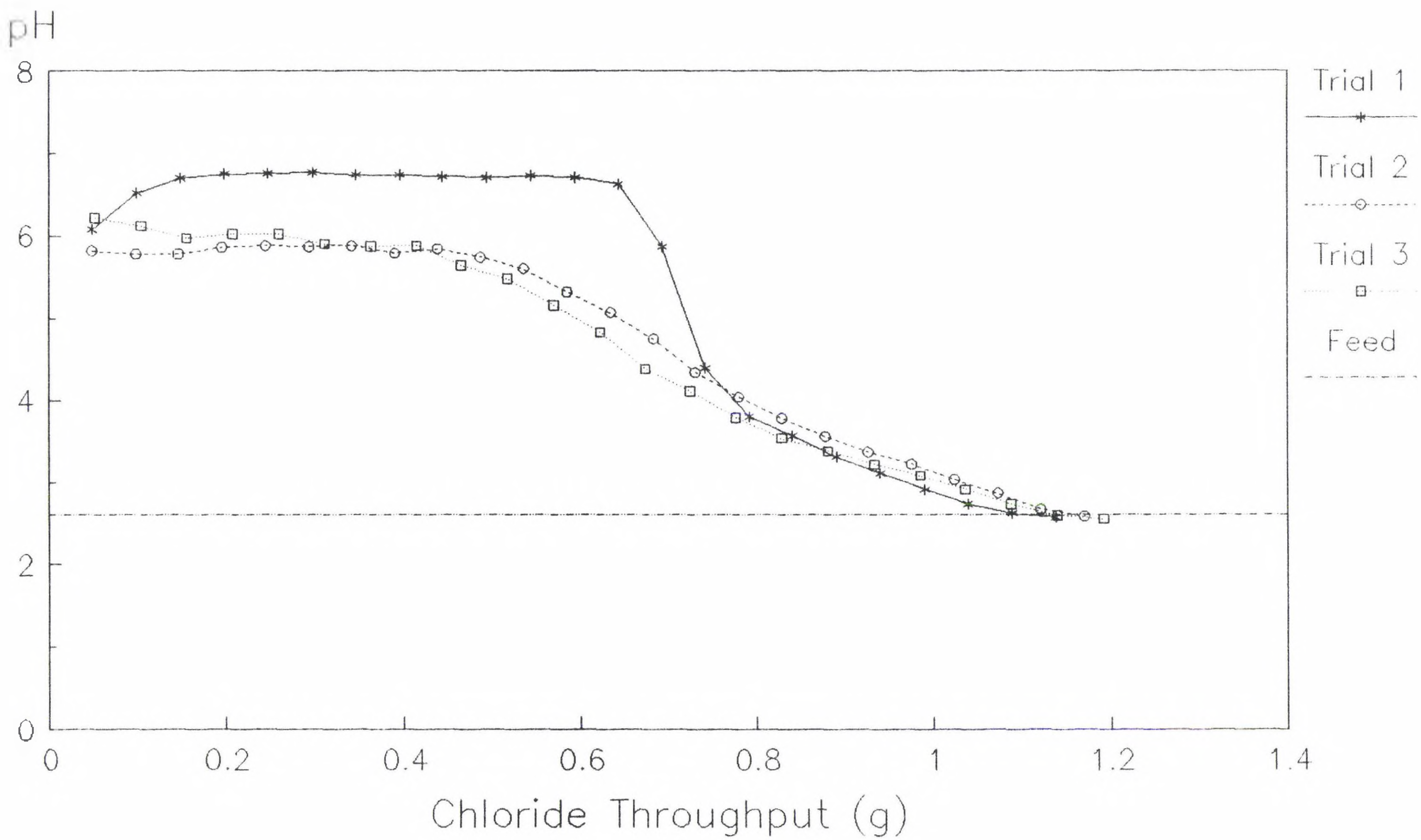

Figure 49. Virgin Resin 4 Effluent pH as a Function of Chloride Throughput

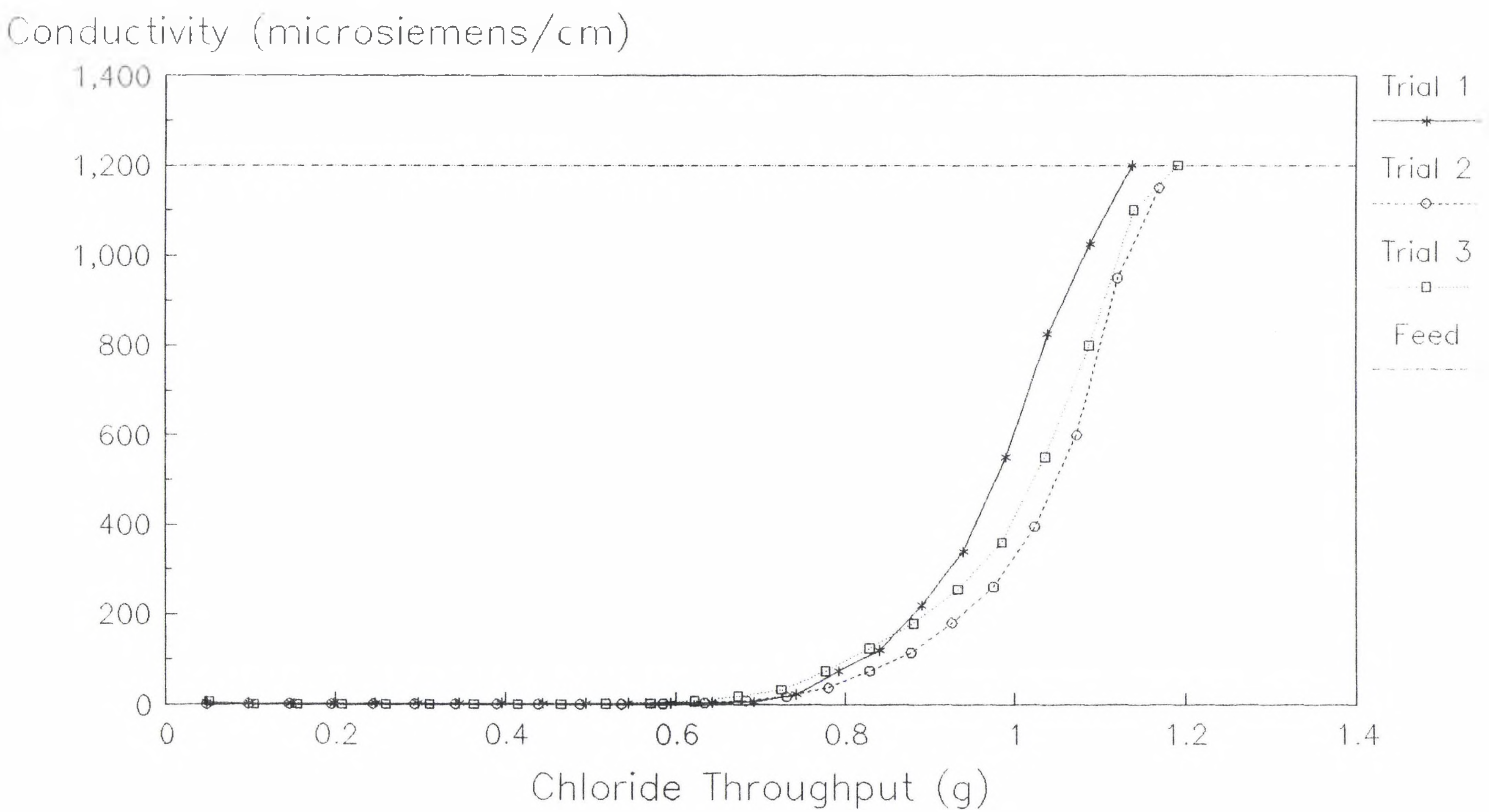

Figure 50. Virgin Resin 4 Effluent Conductivity as a Function of Chloride Throughput

Resin 4 Aged Run 1

Bed Ht 11.0 cm Volume 54.00 cm3

Time	Flow	Total Cl-	Reading	ppm Cl-	pH	Cond.
Feed	73.0		65	43.3	2.58	1150.0
15		0.047	6	1.6	6.21	13.0
30		0.095	11	5.2	6.05	1.2
45		0.142	14	7.3	5.97	1.0
60		0.189	13	6.6	5.86	1.0
75		0.237	7	2.3	5.83	1.1
90		0.284	13	6.6	5.74	1.2
105		0.332	5	0.9	5.58	1.6
120		0.379	11	5.2	5.33	2.5
135		0.426	7	2.3	5.00	5.0
150		0.474	10	4.5	4.72	9.0
165		0.521	14	7.3	4.44	16.0
180		0.568	11	5.2	4.20	27.0
195		0.616	17	9.4	3.97	50.0
210		0.663	20	11.5	3.66	95.0
225	73.0	0.711	23	13.6	3.47	140.0
240		0.758	37	23.5	3.22	255.0
255		0.805	57	37.6	3.03	400.0
270		0.853	78	52.4	2.87	600.0
285		0.900	100	68.0	2.73	800.0
300		0.947	125	85.6	2.62	1050.0
315		0.995	140	96.2	2.58	1150.0
330		1.042	145	99.7	2.56	1200.0
345		1.090	146	100.4	2.55	1200.0
360		1.137	137	94.1	2.55	1200.0
375		1.184	141	96.9	2.55	1200.0

Table 31. Experimental Column Contact Data Collected for Aged Resin 4, Run 1.

Resin 4 Aged Run 2

Bed Ht 11.0 cm Volume 54.00 cm3

Time	Flow	Total Cl-	Reading	ppm Cl-	pH	Cond.
Feed	71.7		65	43.3	2.55	1200.0
15		0.047	7	2.3	6.40	11.5
30	71.0	0.093	12	5.9	6.47	1.0
45		0.140	10	4.5	6.01	0.9
60		0.186	9	3.8	5.87	0.9
75		0.233	12	5.9	5.81	1.0
90		0.279	11	5.2	5.77	1.2
105		0.326	9	3.8	5.64	1.5
120	71.5	0.372	6	1.6	5.32	2.8
135		0.419	6	1.6	5.15	3.8
150		0.465	14	7.3	4.90	6.5
165		0.512	7	2.3	4.60	11.0
180		0.558	14	7.3	4.38	18.0
195		0.605	14	7.3	4.08	36.5
210		0.651	18	10.1	3.84	65.0
225		0.698	23	13.6	3.58	115.0
240	72.5	0.744	29	17.9	3.29	220.0
255		0.791	61	40.4	3.02	415.0
270		0.838	88	59.5	2.85	700.0
285	71.5	0.884	117	80.0	2.68	900.0
300		0.931	140	96.2	2.60	1100.0
315		0.977	142	97.6	2.57	1200.0
330		1.024	147	101.1	2.56	1200.0
345	72.0	1.070	143	98.3	2.56	1200.0
360		1.117	149	102.5	2.56	1200.0

Table 32. Experimental Column Contact Data Collected for Aged Resin 4, Run 2.

Resin 4 Aged Run 3

Bed Ht 11.0 cm Volume 54.00 cm3

Time	Flow	Total Cl-	Reading	ppm Cl-	pH	Cond.
Feed	71.8		68	45.4	2.55	1200.0
15		0.049	10	4.5	6.23	13.0
30		0.098	3	0.0	6.20	0.8
45		0.147	9	3.8	6.15	0.8
60	71.0	0.195	5	0.9	5.83	1.0
75		0.244	4	0.2	5.77	1.1
90		0.293	8	3.0	5.77	1.3
105		0.342	5	0.9	5.55	1.8
120		0.391	8	3.0	5.30	2.5
135		0.440	11	5.2	5.12	4.3
150	72.0	0.488	11	5.2	4.86	8.0
165		0.537	10	4.5	4.56	12.0
180		0.586	6	1.6	4.30	23.0
195		0.635	11	5.2	3.99	44.0
210		0.684	16	8.7	3.71	85.0
225		0.733	22	12.9	3.43	160.0
240	72.0	0.781	42	27.0	3.17	290.0
255		0.830	65	43.3	2.99	445.0
270		0.879	86	58.1	2.84	650.0
285		0.928	116	79.2	2.70	875.0
300		0.977	131	89.8	2.62	1050.0
315		1.026	142	97.6	2.58	1150.0
330		1.075	143	98.3	2.56	1200.0
345	72.0	1.123	146	100.4	2.56	1200.0
360		1.172	146	100.4	2.56	1200.0

Table 33. Experimental Column Contact Data Collected for Aged Resin 4, Run 3.

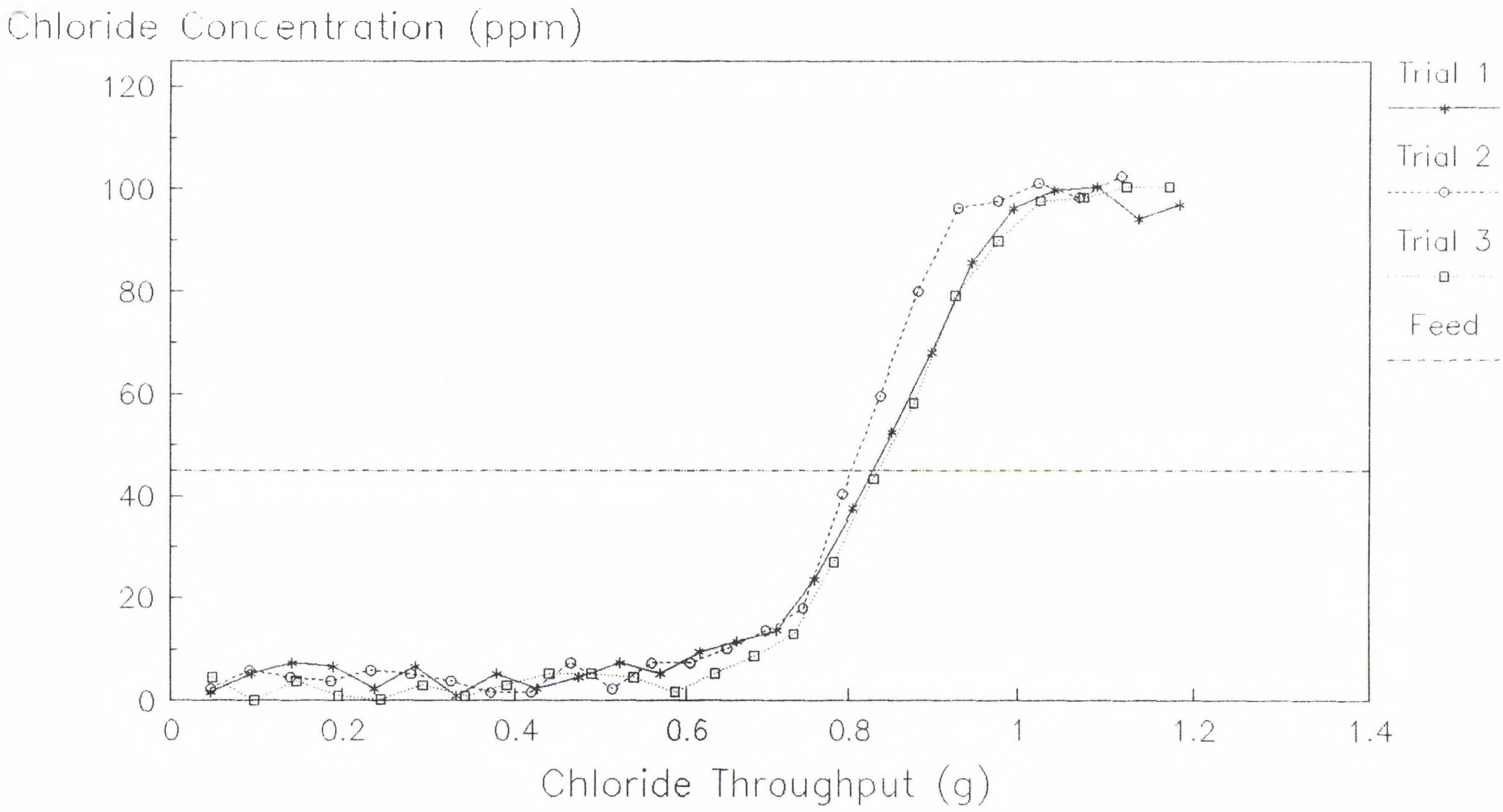

Figure 51. Aged Resin 4 Effluent Chloride Concentration as a Function of Chloride Throughput

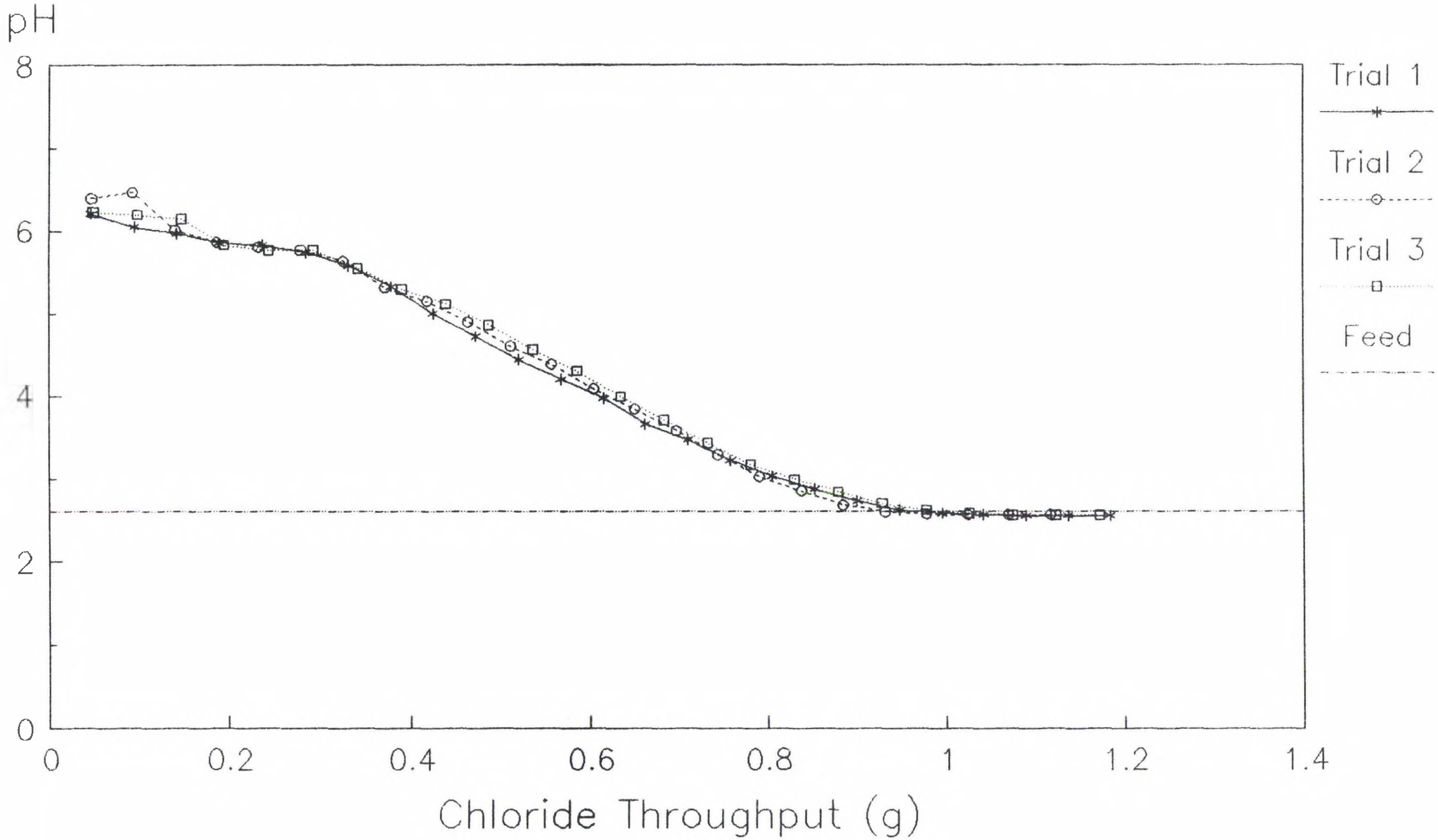

Figure 52. Aged Resin 4 Effluent pH as a Function of Chloride Throughput

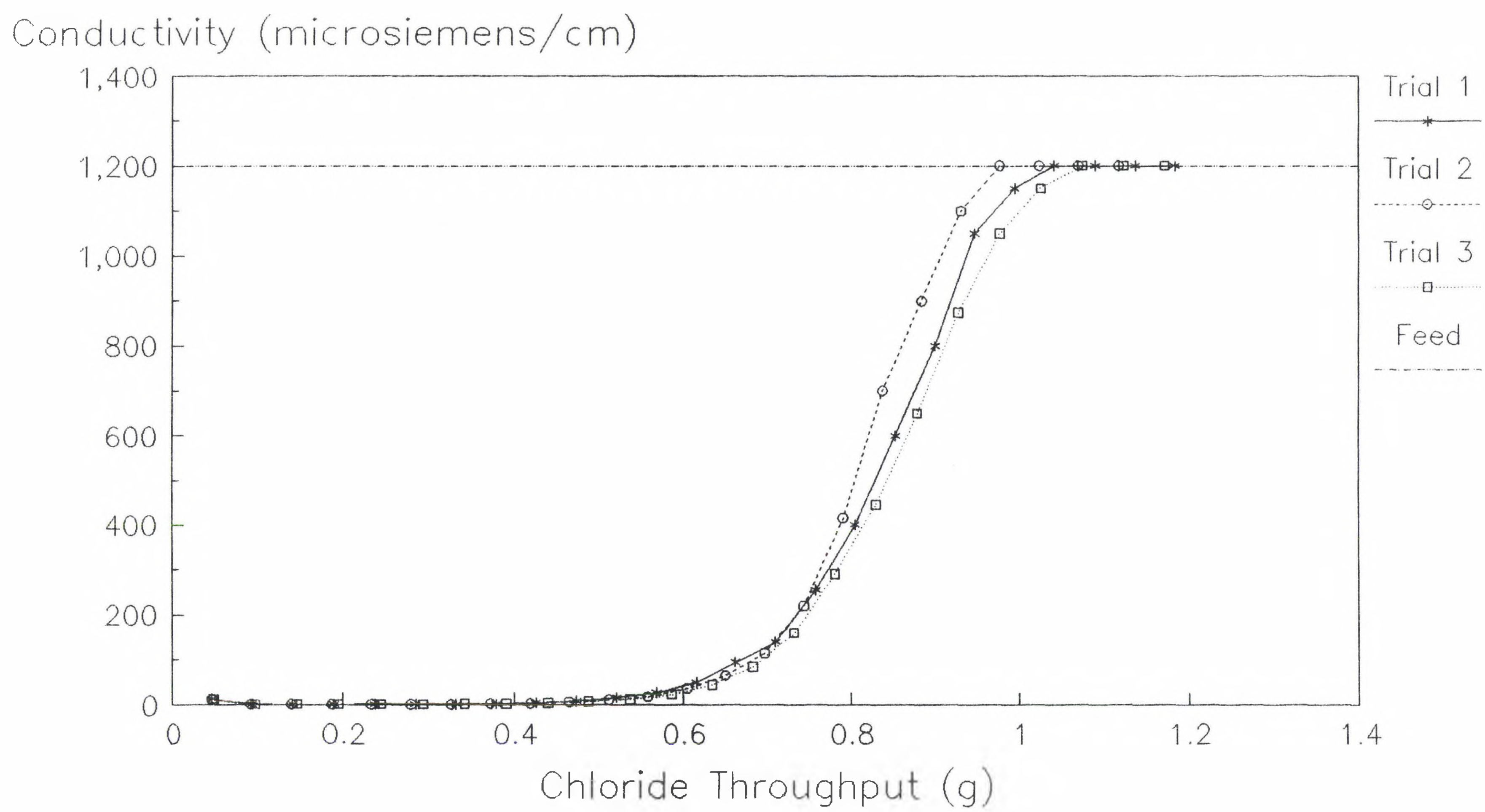

Figure 53. Aged Resin 4 Effluent Conductivity
as a Function of Chloride Throughput

Table of Capacities Using Chloride Determined Exhaustion

Table 34 is a summary of the areas determined from chloride limited exhaustion. The areas were determined using the Newton-Cotes method of numerically integrating area under curves. This area represents the amount of chloride ion that has passed through the column during the time period. This was then subtracted from the total amount of chloride ion fed to the column to calculate the amount of chloride ion retained on the resin bed. The area under the curve equates to 1 gram of chloride retained on the resin per unit area. Finally, dividing the amount of chloride ion retained for each resin sample by the volume of resin in the test column gives the resin capacity in grams of chloride retained per cm^3 of resin. This data is presented graphically in figure 54.

Resin	Run #	Volume	Area	Area/cm3	Average
Virgin Resin 1	1	51.54	37.6588	0.7307	0.72
	2	51.54	36.5864	0.7099	
Aged Resin 1	1	54.00	31.5678	0.5846	0.56
	2	54.00	29.8379	0.5526	
	3	54.00	29.9508	0.5546	
Virgin Resin 2	1	53.01	40.1895	0.7581	0.76
	2	53.01	41.2486	0.7781	
	3	53.01	38.8468	0.7328	
Aged Resin 2	1	53.51	33.8792	0.6331	0.65
	2	53.51	34.5736	0.6461	
	3	53.51	35.1618	0.6571	
Virgin Resin 3	1	51.54	40.7148	0.7900	0.74
	2	51.54	35.7893	0.6944	
	3	51.54	38.1099	0.7394	
Aged Resin 3	1	53.51	33.4594	0.6253	0.66
	2	53.51	34.6403	0.6474	
	3	53.51	37.1393	0.6941	
Virgin Resin 4	1	52.52	35.9188	0.6839	0.71
	2	52.52	39.2093	0.7466	
	3	52.52	36.1711	0.6887	
Aged Resin 4	1	54.00	29.6859	0.5497	0.56
	2	54.00	29.7162	0.5503	
	3	54.00	31.7814	0.5885	

Table 34. Resin Capacities Determined Using Column Contact Experiment With Chloride Limited Exhaustion.

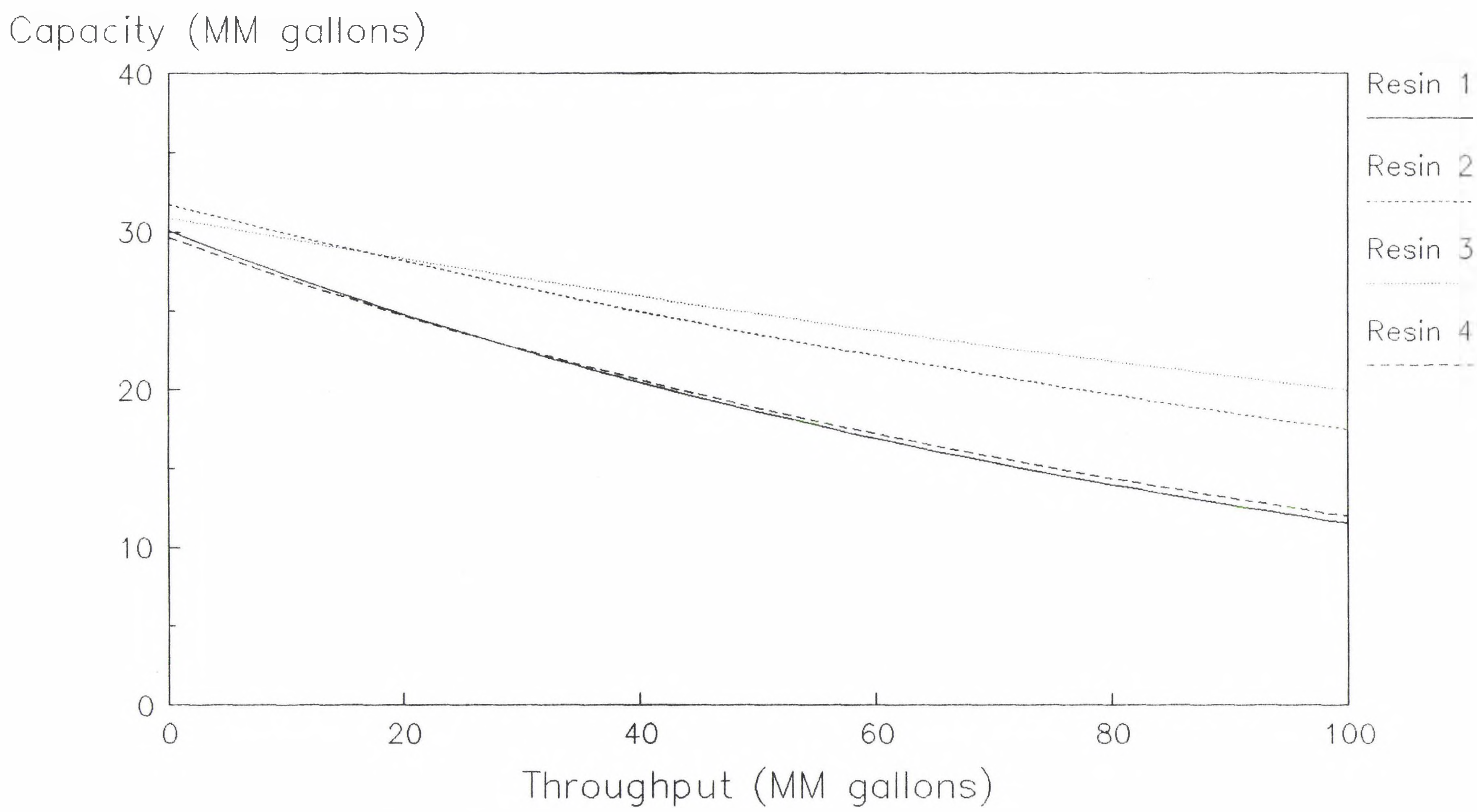

Figure 54. Capacity as a Function of Throughput for Four Test Resins Using Chloride Limited Exhaustion

Table of Capacities Using Conductivity Determined Exhaustion

Table 35 is a summary of the areas determined from conductivity limited exhaustion. The areas were determined using the Newton-Cotes method of numerically integrating area under curves. This area represents the amount of chloride ion that has passed through the column during the time period. This was then subtracted from the total amount of chloride ion fed to the column to calculate the amount of chloride ion retained on the resin bed. The area under the curve equates to 1 gram of chloride retained on the resin per unit area. Finally, dividing the amount of chloride ion retained for each resin sample by the volume of resin in the test column gives the resin capacity in grams of chloride retained per cm^3 of resin. This data is presented graphically in figure 55.

Conductivity = 10.0 mmhos/cm

Resin	Run #	Volume	X at Break	Capacity (l)	Cap/cm3	Cap (gal)	Cost per Regen	Water Cost	Average Cost
Virgin Resin 1	1	51.54	0.6235	13.95	0.2706	506123	$261.59	$1.93	$2.04
	2	51.54	0.6893	15.42	0.2992	559536	$261.59	$2.14	
Aged Resin 1	1	54.00	0.6432	14.39	0.2665	498329	$261.59	$1.91	$1.77
	2	54.00	0.5764	12.89	0.2388	446575	$261.59	$1.71	
	3	54.00	0.5687	12.72	0.2356	440609	$261.59	$1.68	
Virgin Resin 2	1	53.01	0.8165	18.27	0.3446	644411	$261.59	$2.46	$2.40
	2	53.01	0.7741	17.32	0.3267	610947	$261.59	$2.34	
	3	53.01	0.7998	17.89	0.3375	631230	$261.59	$2.41	
Aged Resin 2	1	53.51	0.6109	13.67	0.2554	477639	$261.59	$1.83	$1.92
	2	53.51	0.6500	14.54	0.2718	508209	$261.59	$1.94	
	3	53.51	0.6704	15.00	0.2803	524159	$261.59	$2.00	
Virgin Resin 3	1	51.54	0.6870	15.37	0.2982	557669	$261.59	$2.13	$2.14
	2	51.54	0.6960	15.57	0.3021	564975	$261.59	$2.16	
	3	51.54	0.6900	15.44	0.2995	560104	$261.59	$2.14	
Aged Resin 3	1	53.51	0.4843	10.83	0.2025	378655	$261.59	$1.45	$1.37
	2	53.51	0.4363	9.76	0.1824	341126	$261.59	$1.30	
	3	53.51	0.4510	10.09	0.1886	352619	$261.59	$1.35	
Virgin Resin 4	1	52.52	0.7045	15.76	0.3001	561204	$261.59	$2.15	$2.06
	2	52.52	0.6906	15.45	0.2942	550131	$261.59	$2.10	
	3	52.52	0.6324	14.15	0.2694	503769	$261.59	$1.93	
Aged Resin 4	1	54.00	0.4807	10.75	0.1991	372430	$261.59	$1.42	$1.48
	2	54.00	0.5016	11.22	0.2078	388623	$261.59	$1.49	
	3	54.00	0.5125	11.47	0.2123	397068	$261.59	$1.52	

Table 35. Resin Capacities Determined Using Column Contact Experiment With Conductivity Limited Exhaustion.

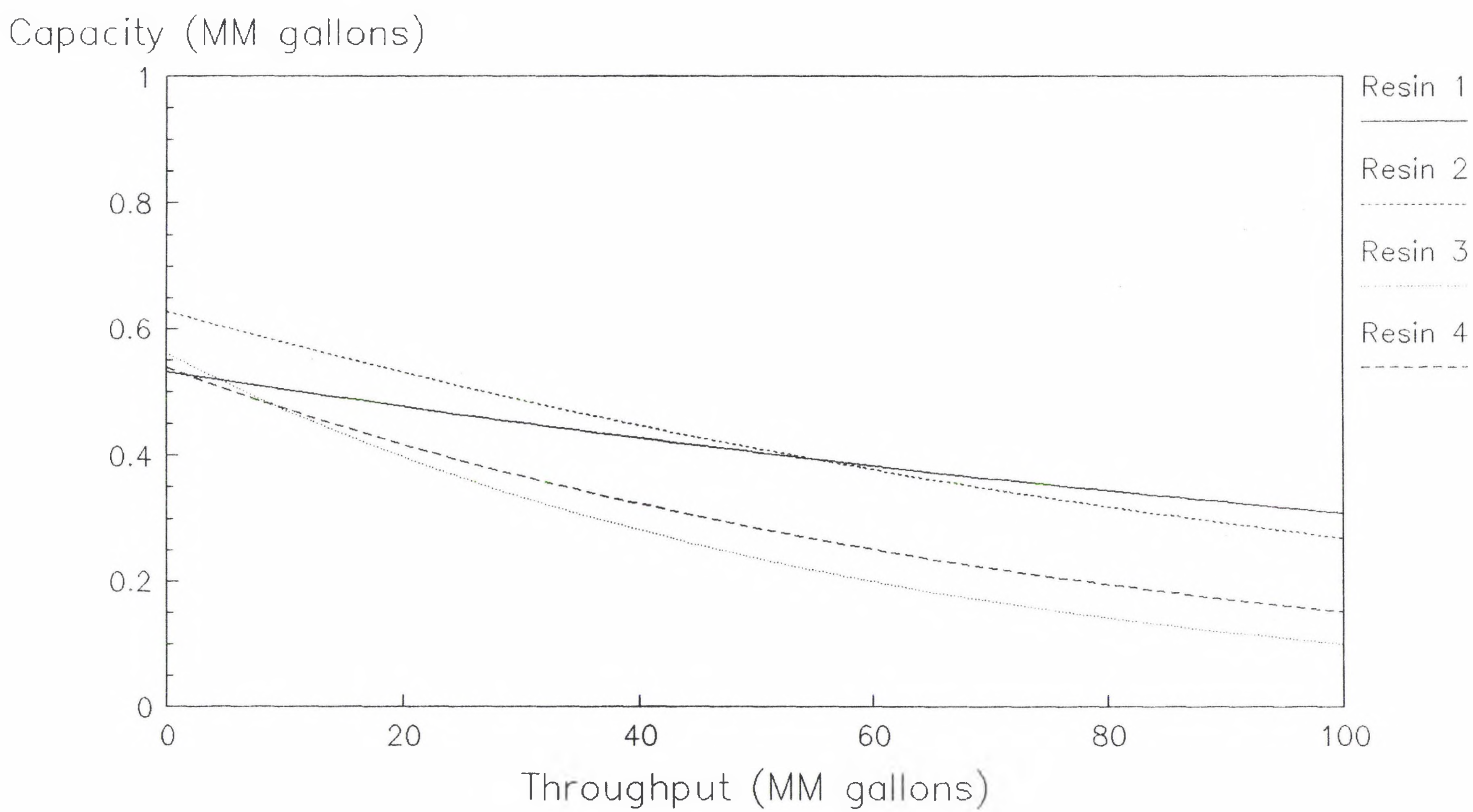

Figure 55. Capacity as a Function of Throughpu for Four Test Resins Using Conductivity Limited Exhaustion

APPENDIX E: FLOWRATE DETERMINATION DATA

This appendix contains the experimental data from the column contact runs for determining the test flow rate. The following items are included;

Pump Standardization Curve

Standardization of the Masterflex pump was performed to correlate the flow setting to a volumetric flow rate. This curve was then used to plan the experimental flow settings used for operation, regeneration and backwash. During critical flow measurement, occasional spot checks were performed to determine whether there was any drift from the standardization curve due to tubing wear. Flow rates were determined by collecting pump effluent in a graduated cylinder and recording time to pump 25 ml. Refer to Appendix B for detailed procedure.

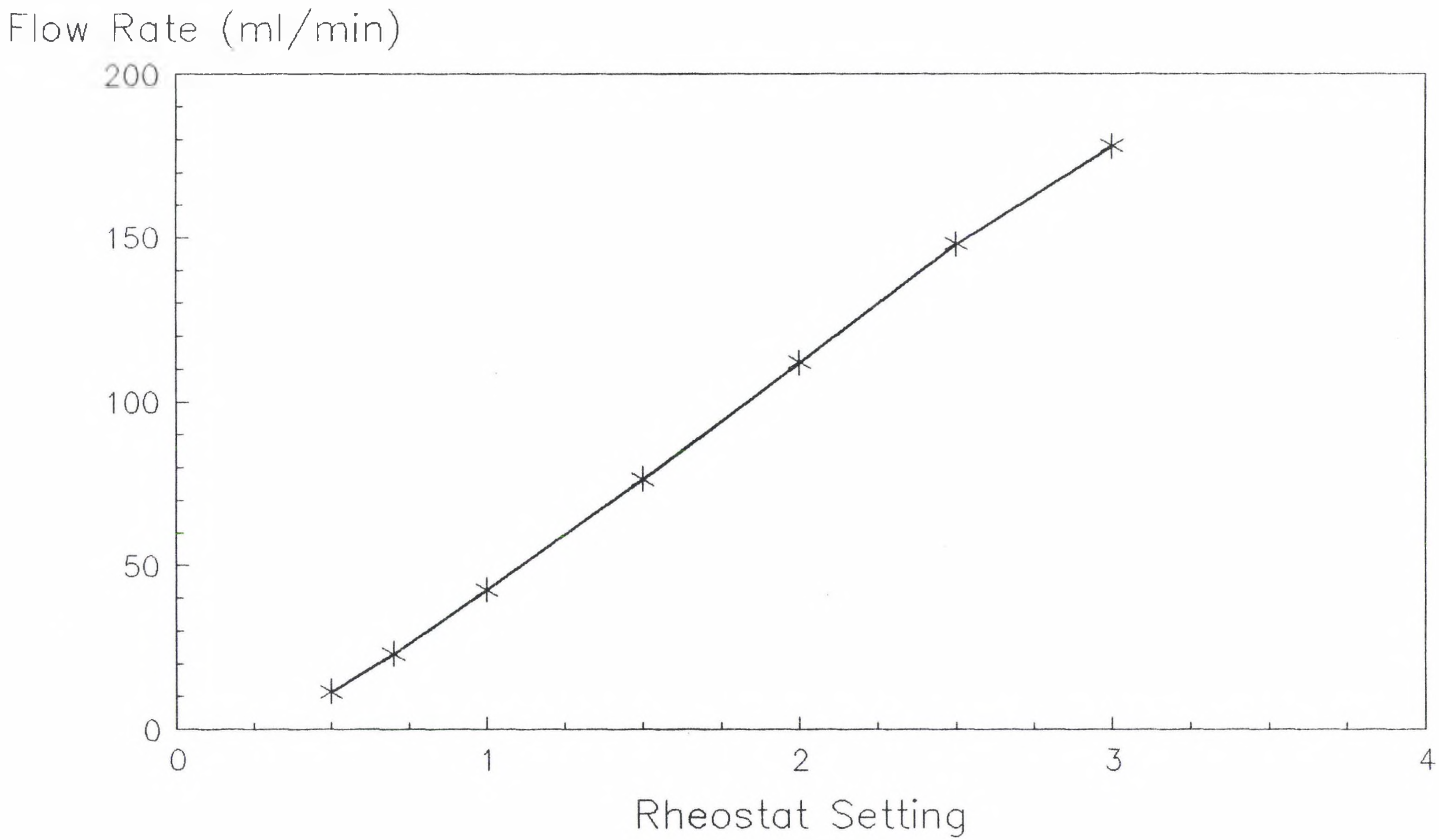

Figure 56. Flow Rate as a Function of Rheostat Setting for Masterflex Pump

Table of Experimental Data for Various Flow Settings

The following tables summarize the data collected at various flow settings to determine the point where ion slippage occurs. Samples were taken in accordance with the procedures developed in Appendix B. Table 36 data is for flow setting .75 (26.7 ml/min). Table 37 data is for flow setting 1.15 (51.4 ml/min). Table 38 data is for flow setting 1.50 (77.2 ml/min). Table 39 data is for flow setting of 1.75 (90 ml/min). Table 40 data is for flow setting 2.00 (107.4 ml/min). Finally, table 41 data is for flow setting 2.50 (141 ml/min).

Run Speed .75

Time	Flow	Total Cl-	Reading	ppm Cl-	pH	Cond.
Feed	26.7		69	46.1	2.71	1250
30		0.037	14	7.3	5.55	0.80
60		0.074	13	6.6	6.47	0.80
90		0.111	18	10.1	6.31	0.85
120	27	0.148	22	12.9	6.30	0.85
150		0.185	18	10.1	6.34	0.85
180		0.221	14	7.3	6.38	0.85
210		0.258	15	8.0	6.32	0.85
240		0.295	16	8.7	6.37	0.80
270		0.332	14	7.3	6.40	0.80
300	26.5	0.369	13	6.6	6.32	0.80
330		0.406	9	3.8	6.36	0.80
360		0.443	11	5.2	6.38	0.80
390		0.480	13	6.6	6.37	0.80
420	27	0.517	10	4.5	6.36	0.90
450		0.554	15	8.0	6.41	0.80
480		0.591	11	5.2	6.48	0.85
510		0.628	15	8.0	6.30	0.95
540		0.664	13	6.6	6.28	1.00
570	26.5	0.701	14	7.3	6.04	1.30
600		0.738	10	4.5	5.46	2.80
630		0.775	13	6.6	4.97	7.50
660		0.812	15	8.0	4.57	18.50
690		0.849	14	7.3	4.21	39.50
720		0.886	24	14.3	3.96	70.00
750	26.5	0.923	21	12.2	3.74	115.00
780		0.960	26	15.7	3.54	180.00
810		0.997	43	27.7	3.35	275.00
825		1.015	49	32.0	3.28	325.00
840		1.034	60	39.7	3.21	390.00
855		1.052	65	43.3	3.14	455.00
870		1.071	68	45.4	3.09	500.00
885		1.089	78	52.4	3.04	600.00
900		1.107	82	55.3	2.99	700.00
915		1.126	88	59.5	2.93	770.00

Table 36. Resin Capacity Determined Using Column Contact Experiment With Conductivity Limited Exhaustion at Flow Setting of .75.

Run 1.15

Time	Flow	Total	Cl-Reading	ppm Cl-	pH	Cond.
Feed	51.4		69	46.1	2.56	1250.0
30	51.0	0.071	16	8.7	6.12	1.2
60		0.142	13	6.6	5.66	1.0
90		0.213	18	10.1	6.15	1.1
120		0.284	15	8.0	6.13	1.0
150	52.0	0.355	9	3.8	6.15	1.0
180		0.426	13	6.6	6.11	1.0
210		0.497	9	3.8	6.02	1.2
240		0.568	10	4.5	5.78	1.5
270	51.0	0.639	18	10.1	5.21	3.5
300		0.710	13	6.6	4.36	16.5
330		0.781	17	9.4	4.10	38.0
360		0.852	18	10.1	3.75	90.0
390		0.923	27	16.5	3.40	185.0
420		0.994	47	30.6	3.16	330.0
450	51.5	1.065	85	57.4	2.93	550.0
480		1.136	112	76.4	2.68	950.0
510		1.208	148	101.8	2.57	1250.0

Table 37. Resin Capacity Determined Using Column Contact Experiment With Conductivity Limited Exhaustion at Flow Setting of 1.15.

Run Speed 1.5

Time	Flow	Total Cl-	Reading	ppm Cl-	pH	Cond.
Feed	77.2		63	41.9	2.70	1250
15		0.048	14	7.3	6.42	7.50
30		0.097	12	5.9	6.52	1.90
45		0.145	10	4.5	6.57	1.60
60	78.0	0.194	11	5.2	6.56	1.70
75		0.242	12	5.9	6.53	1.60
90		0.291	10	4.5	6.53	1.65
105		0.339	11	5.2	6.52	1.70
120	77.0	0.388	9	3.8	6.53	1.65
135		0.436	13	6.6	6.47	1.80
150		0.485	12	5.9	6.42	2.05
165		0.533	11	5.2	6.30	2.40
180	77.0	0.582	10	4.5	5.92	3.20
195		0.630	15	8.0	5.28	7.50
210		0.679	14	7.3	4.72	12.50
225		0.727	16	8.7	4.32	29.50
240	77.0	0.775	22	12.9	4.00	65.00
255		0.824	28	17.2	3.74	115.00
270		0.872	32	20.0	3.52	190.00
285	77.0	0.921	40	25.6	3.34	290.00
300		0.969	55	36.2	3.17	440.00
315		1.018	71	47.5	3.03	600.00
330		1.066	95	64.4	2.90	800.00

Table 38. Resin Capacity Determined Using Column Contact Experiment With Conductivity Limited Exhaustion at Flow Setting of 1.50.

Run Speed 1.75

Time	Flow	Total Cl-Reading	ppm Cl-	pH	Cond.
Feed	90.0		66	44.0	2.47	1250.0
15	89.0	0.059	18	10.1	6.49	0.9
30		0.119	25	15.0	6.23	0.9
45		0.178	25	15.0	6.30	0.9
60		0.237	20	11.5	6.22	0.9
75		0.297	24	14.3	6.30	0.9
90	90.0	0.356	27	16.5	6.16	1.0
105		0.416	21	12.2	6.01	1.1
120		0.475	17	9.4	5.64	2.0
135	90.0	0.534	24	14.3	5.12	4.3
150		0.594	20	11.5	4.72	10.0
165		0.653	18	10.1	4.28	25.0
180	90.0	0.712	18	10.1	3.92	60.0
195		0.772	34	21.4	3.60	115.0
210		0.831	40	25.6	3.36	205.0
225		0.890	52	34.1	3.16	330.0
240	91.0	0.950	61	40.4	3.00	465.0
255		1.009	76	51.0	2.88	625.0
270		1.068	103	70.1	2.68	850.0

Table 39. Resin Capacity Determined Using Column Contact Experiment With Conductivity Limited Exhaustion at Flow Setting of 1.75.

Run 2.00

Time	Flow	Total Cl-	Reading	ppm Cl-	pH	Cond.
Feed	107.4		65	43.3	2.58	1250.0
10	107.0	0.046	24	14.3	5.87	21.5
20		0.093	18	10.1	5.86	0.9
30		0.139	20	11.5	6.26	0.65
40		0.186	14	7.3	6.26	0.65
50		0.232	14	7.3	6.10	0.75
60		0.279	16	8.7	6.35	0.7
70		0.325	18	10.1	6.36	0.7
80	108	0.372	16	8.7	5.91	1
90		0.418	20	11.5	5.75	1.45
100		0.465	21	12.2	5.35	2.95
110		0.511	18	10.1	4.95	6
120		0.558	18	10.1	4.66	11
130		0.604	17	9.4	4.39	20
140		0.651	20	11.5	4.12	37
150	108	0.697	18	10.1	3.86	65
160		0.743	19	10.8	3.63	110
170		0.790	31	19.3	3.45	165
180	107	0.836	41	26.3	3.28	245
190		0.883	54	35.5	3.13	355
200		0.929	57	37.6	3.01	460
210	107	0.976	78	52.4	2.88	600
220		1.022	95	64.4	2.78	800
230		1.069	113	77.1	2.68	1100

Table 40. Resin Capacity Determined Using Column Contact Experiment With Conductivity Limited Exhaustion at Flow Setting of 2.00.

Run 2.50

Time	Flow	Total	Cl-Reading	ppm Cl-	pH	Cond.
Feed	141.0		63	41.9	2.57	1250.0
5	141.0	0.030	15	8.0	4.42	2.7
20		0.118	23	13.6	6.12	0.7
30		0.177	14	7.3	6.13	0.7
40		0.236	10	4.5	6.06	0.8
45		0.266	21	12.2	5.99	0.9
50	141.0	0.295	13	6.6	5.78	1.2
55		0.325	18	10.1	5.60	1.6
60		0.354	17	9.4	5.46	2.2
65		0.384	13	6.6	5.39	3.0
70		0.413	14	7.3	5.14	3.9
75		0.443	17	9.4	5.01	5.0
80		0.472	11	5.2	4.86	7.5
85		0.502	23	13.6	4.72	10.0
90	141.0	0.531	10	4.5	4.63	13.0
95		0.561	10	4.5	4.45	18.0
100		0.590	15	8.0	4.30	25.0
105		0.620	8	3.0	4.15	35.0
110		0.649	9	3.8	3.99	50.0
115		0.679	14	7.3	3.87	65.0
120		0.708	9	3.8	3.74	85.0
125	141.0	0.738	14	7.3	3.62	110.0
130		0.767	24	14.3	3.51	145.0
135		0.797	25	15.0	3.40	185.0
140		0.826	31	19.3	3.30	230.0
145		0.856	37	23.5	3.22	280.0
150	141.0	0.885	48	31.3	3.11	360.0
155		0.915	51	33.4	3.04	440.0
160		0.944	58	38.3	2.95	520.0
170		1.003	79	53.1	2.80	750.0
180		1.062	111	75.7	2.67	1000.0
190		1.121	130	89.1	2.58	1250.0

Table 41. Resin Capacity Determined Using Column Contact Experiment With Conductivity Limited Exhaustion at Flow Setting of 2.50.

Plot of Chloride Concentration as a
Function of Time for Varying Flow Rates

Figure 57 reflects the chloride concentration data of the previous section. At the point of exhaustion as determined by conductivity, the area under the curve was calculated and subtracted from the amount of chloride ion fed to the column. This capacity was then plotted as a function of flow rate to determine the optimum flow rate for the experiment.

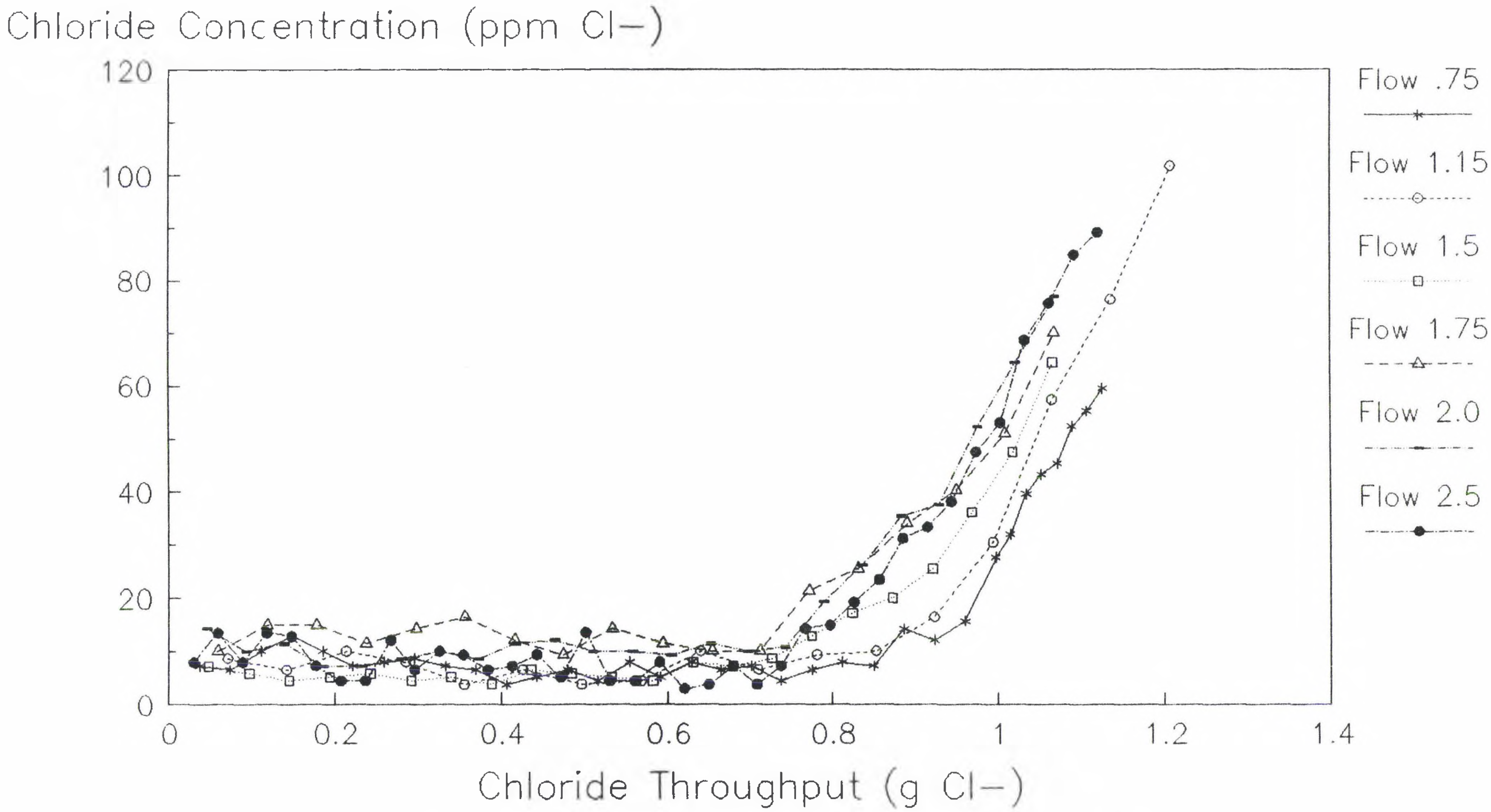

Figure 57. Effluent Chloride Concentration as a Function of Chloride Throughput at Varying Flow Setting

Plot of Conductivity as a Function of Time for Varying Flow Rates

Figure 58 reflects the conductivity data of the previous section. At the point of exhaustion, defined to be 10 microsiemens/cm, the time (expressed as grams of chloride fed to the column) was recorded. This end point was then used with the effluent chloride concentration plot to determine the capacity of the resin at that particular flow setting.

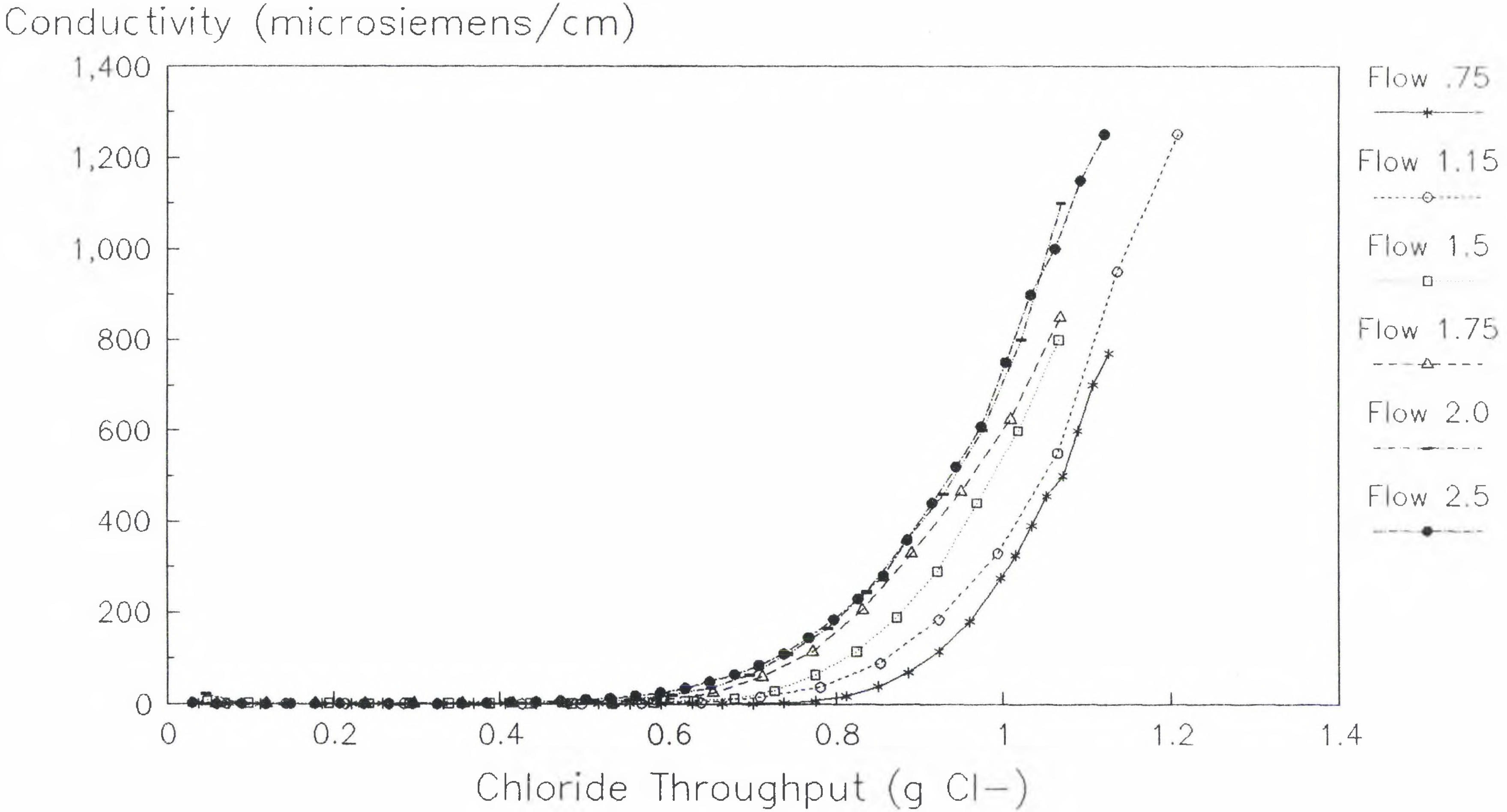

Figure 58. Effluent Conductivity as a Function of Chloride Throughput with Varying Flow Setting

Plot of pH as a Function of Time for Varying Flow Rates

Figure 59 reflects the pH data of the previous section. Though not used as a determinant of exhaustion, the data serves to verify the decay behavior of increased flow rate on capacity. The initial low pH can be attributed to sodium ions that were not completely rinsed from the column during the regeneration cycle.

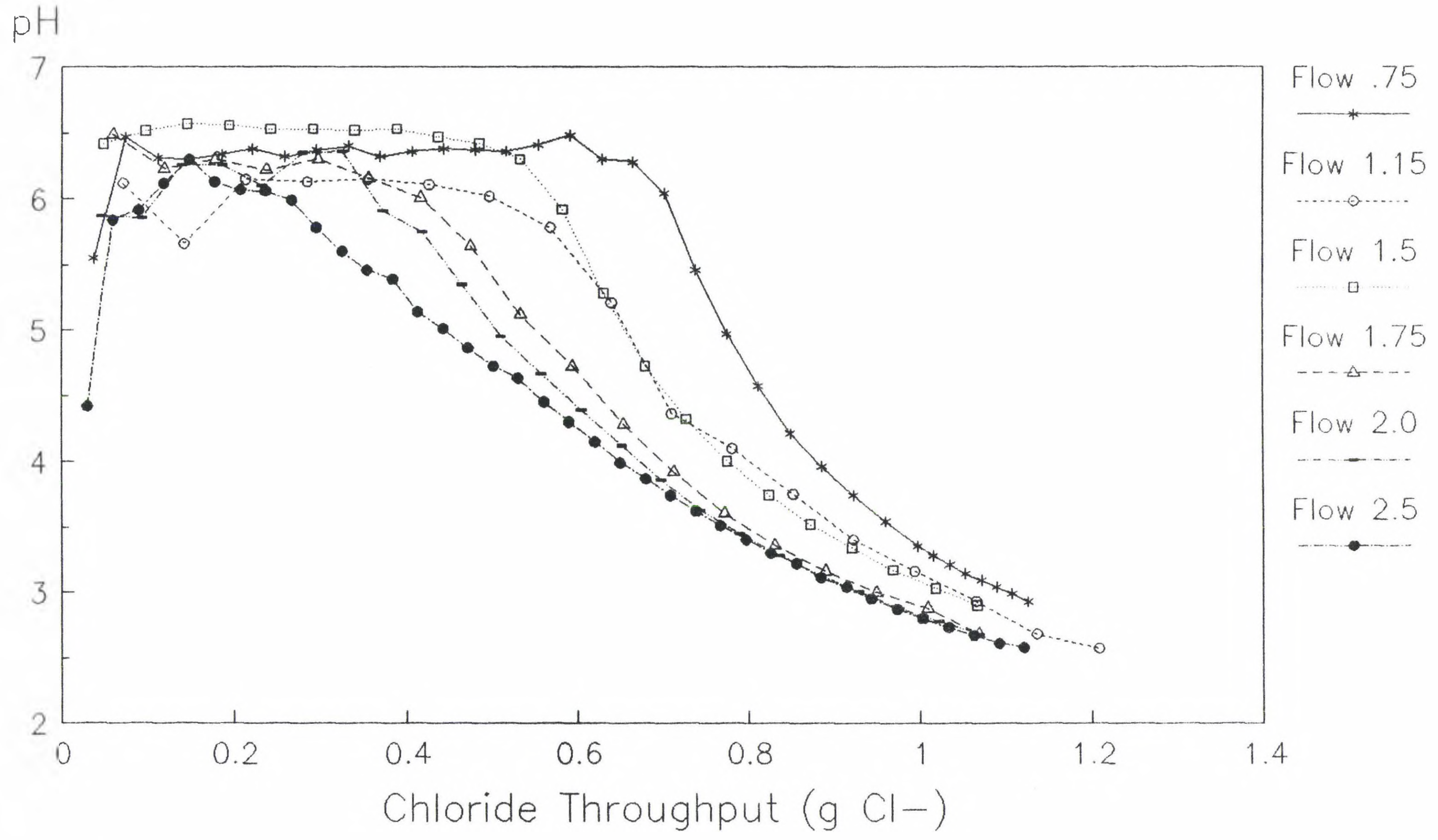

Figure 59. Effluent pH as a Function of
Chloride Throughput with Varying Flow Setting

Plot of Capacity as a Function of Time for Varying Flow Rates

Figure 60 represents the capacity data as a function of flow rate determined in the previous section. The point of inflection was determined to be between 50 and 90 ml/min. Choosing 75 ml/min as the experimental flow rate served as a compromise between loss of accuracy due to too high of a flow and the attempt to have an experimental run time of less than 8 hours.

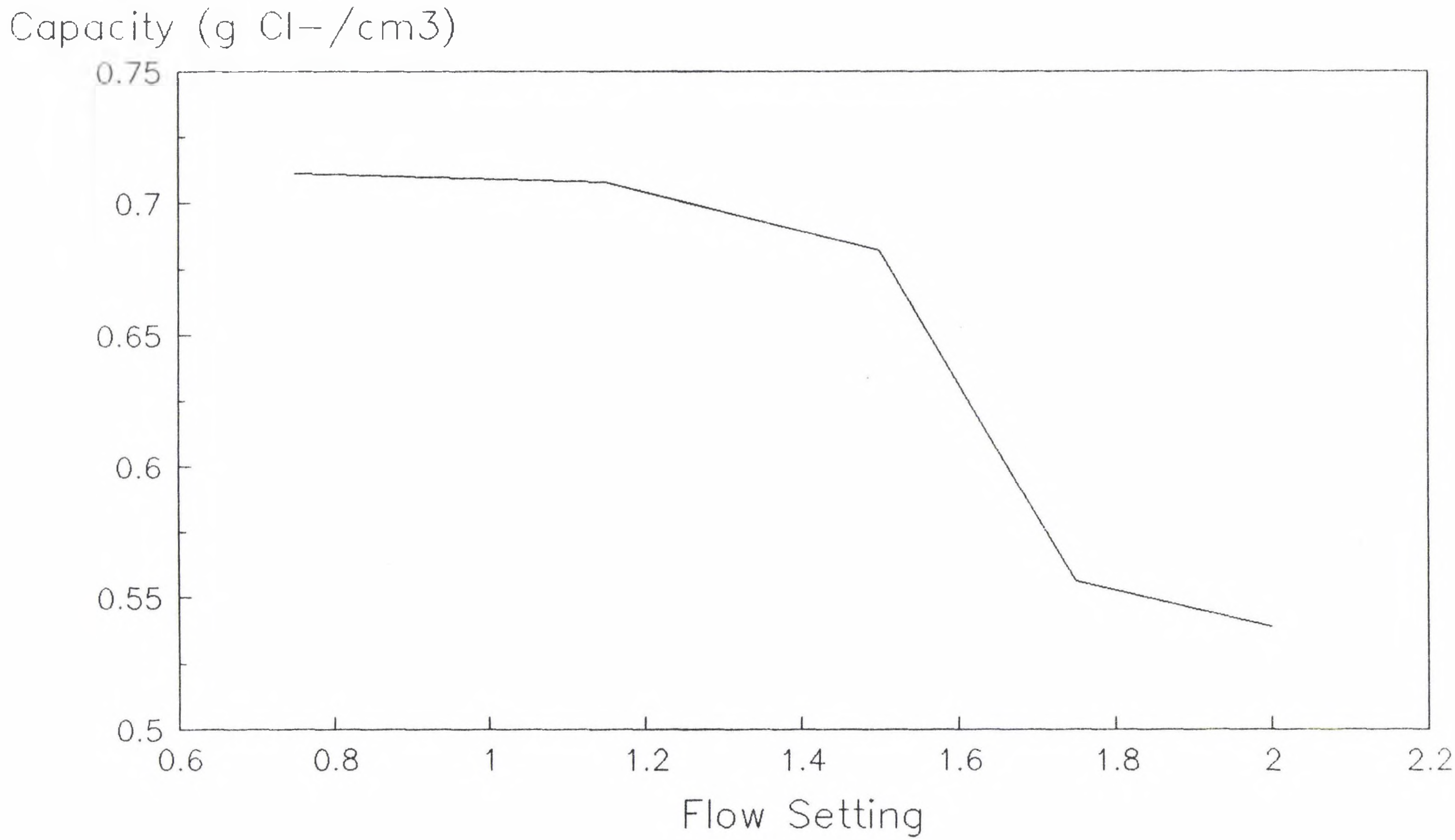

Figure 60. Capacity as a Function of Flow Rate Using Chloride Limited Exhaustion

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